Toppersnotes
Unleash the topper in you

UPSC Prelims

Union Public Service Commission

Volume – 8

Science & Technology

SIERRA INNOVATIONS

INDEX

1 CHAPTER

Basics of Biology

Biology is the scientific study of living organisms, encompassing various specialized fields that explore their morphology, physiology, anatomy, behavior, origin and distribution.

A. Cell Biology

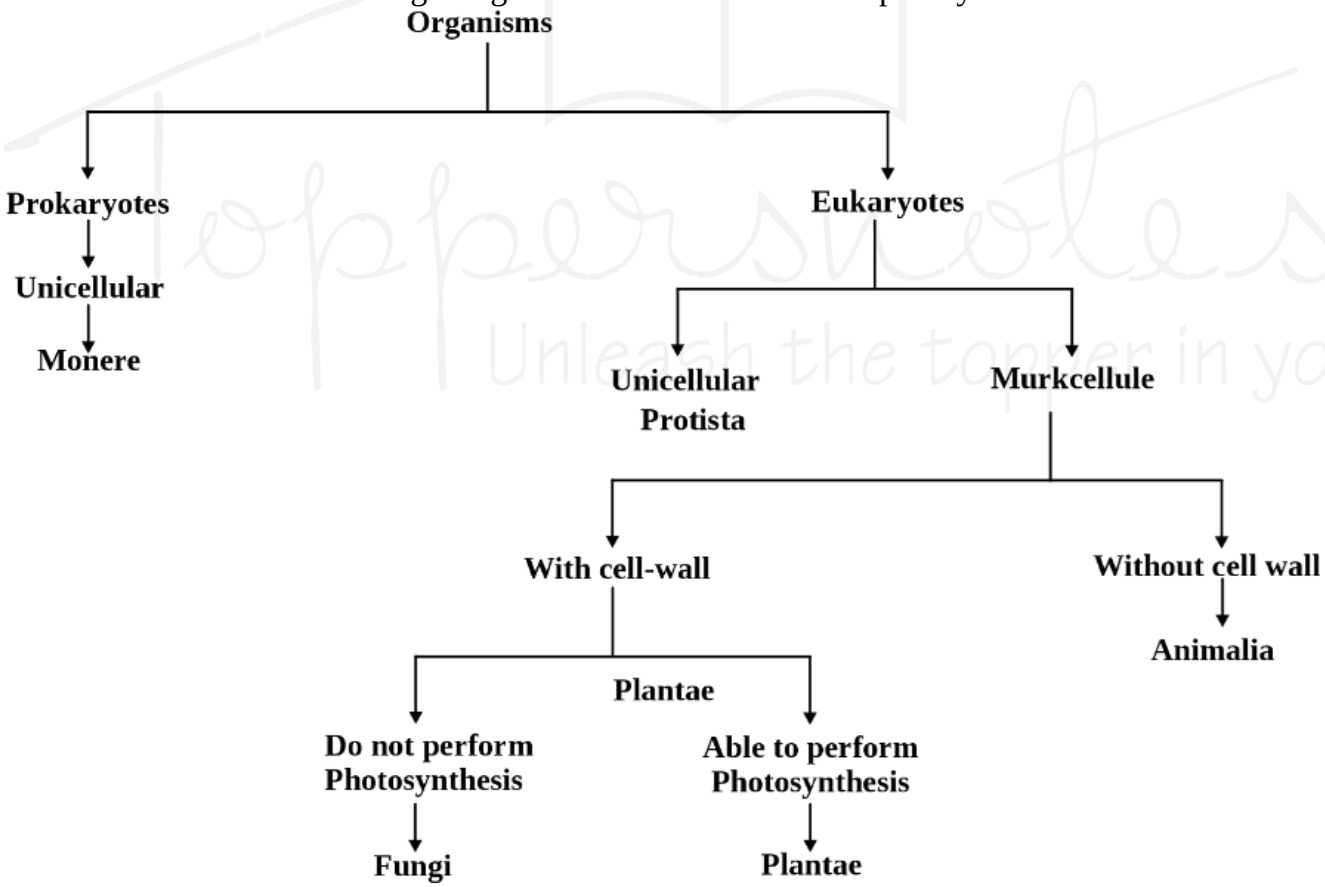
- A cell is the fundamental, structural and functional unit of all living organisms.
- It houses the biochemical machinery such as enzymes, genetic material, membranes, necessary for metabolism, growth, reproduction and response to stimuli.
- Cells can exist independently (as in many unicellular organisms) or as part of multicellular assemblies and are bounded by a plasma membrane that regulates exchange with the environment.

DID YOU KNOW?

Robert Hooke first saw and described a live cell. Robert Brown later discovered the nucleus.

B. Classification of Cells

- Cells fall into two overarching categories based on internal complexity:



- **Prokaryotic Cells**: Do not have well-defined membrane-bound organelles and nuclei.
- **Eukaryotic Cells** It contains well defined membrane and nuclei. They are further divided into Animal cells and Plant cells.

DID YOU KNOW?

- Carbon, Hydrogen, Nitrogen are sets of elements that are responsible for the origin of life on the Earth.
- **Endosymbiotic theory** says complex cells arose when one prokaryote settled inside another; the host supplied shelter, the guest supplied new skills, and the partnership evolved into organelles like mitochondria and chloroplasts
  - ✓ The first-ever nitrogen-fixing eukaryote is a marine algae that carries a cyanobacterial partner able to make fertiliser from N_2 which gives a modern glimpse of this "one-cell-inside-another" teamwork in action.

C. Difference Between Prokaryotic & Eukaryotic Cells

Characteristic	Prokaryotic Cell	Eukaryotic Cell
Size of cell	Typically 0.2–2.0 μm in diameter	Typically 10–100 μm in diameter
Example	Bacteria and Archaea	Animals and Plants
Nucleus	Absent	Present
Membrane-enclosed organelles	Absent	Present: Examples include lysosomes, Golgi complex, endoplasmic reticulum, mitochondria, and chloroplasts.
Flagella (hair-like appendages that help cells move)	Consist of two protein building blocks	Complex: consist of multiple microtubules
Cell wall	Usually present: Chemically complex	Only in plant cells and fungi (chemically simpler)
Plasma membrane	Yes	Yes
Cytoplasm	Yes	Yes
Ribosomes	Smaller	Larger
Cell division	Binary Fission	Mitosis and Meiosis
Number of chromosomes	One, but not true chromosome	More than one

D. Plant Cell V/S Animal Cell

Feature	Plant Cell	Animal Cell
Cell Wall	Rigid layer of cellulose providing structural support	It is absent in the animal cell.
Plastids	Chloroplasts (photosynthesis), leucoplasts (storage), chromoplasts (pigment)	None
Vacuole	Single large central vacuole for turgor pressure and storage	Small or absent
Centrioles	Generally absent in higher plant cells	Present and function in cell division
Shape	Usually fixed, rectangular due to rigid cell wall	Variable, often round or irregular

E. Cell Organelles

Cell organelles are specialized structures within the cell that carry out specific functions essential for the cell's survival and efficiency. They include:

- **Nucleus**:
  - ✓ The nucleus is the cell's control center, housing genetic material (DNA).
  - ✓ It is encased by a nuclear membrane with pores that facilitate material exchange with the cytoplasm.

- ✓ It regulates gene expression and coordinates activities like growth and reproduction.
- ✓ Both animal and plant cells have a nucleus, though plant cells may have multiple nuclei under certain conditions.

- **Endoplasmic Reticulum:** The ER is a membrane network responsible for synthesizing and transporting proteins and lipids. It has two types:
  - ✓ **Rough ER:** it has ribosomes stuck on its surface. It builds and modifies proteins, then packs them into vesicles to be sent outside the cell or delivered to other organelles
  - ✓ **Smooth ER:** Lacking ribosomes, it synthesizes lipids, handles metabolism, and detoxifies harmful substances.
  - ✓ Both plant and animal cells have both types of ER.
- **Golgi Apparatus**: It plays a crucial role in processing and packaging proteins and lipids and is involved in the formation of lysosomes and other vesicles. It collaborates with the ER and is found in both plant and animal cells.
- **Mitochondria**:
  - ✓ It is known as the cell's "powerhouse," mitochondria generate energy (ATP) through cellular respiration.
  - ✓ They have a double membrane structure, with the inner membrane folded into cristae to increase surface area for energy production.
  - ✓ **Mitogenome:** is a small circular chromosome found inside the mitochondria, built of double-stranded DNA.

DID YOU KNOW?

Recently, researchers have found that inhibiting **Dynamin-related protein (Drp1)** activity could restore mitochondrial function and serve as potential treatment to treat Parkinson's Disease(**neurodegenerative disease**).

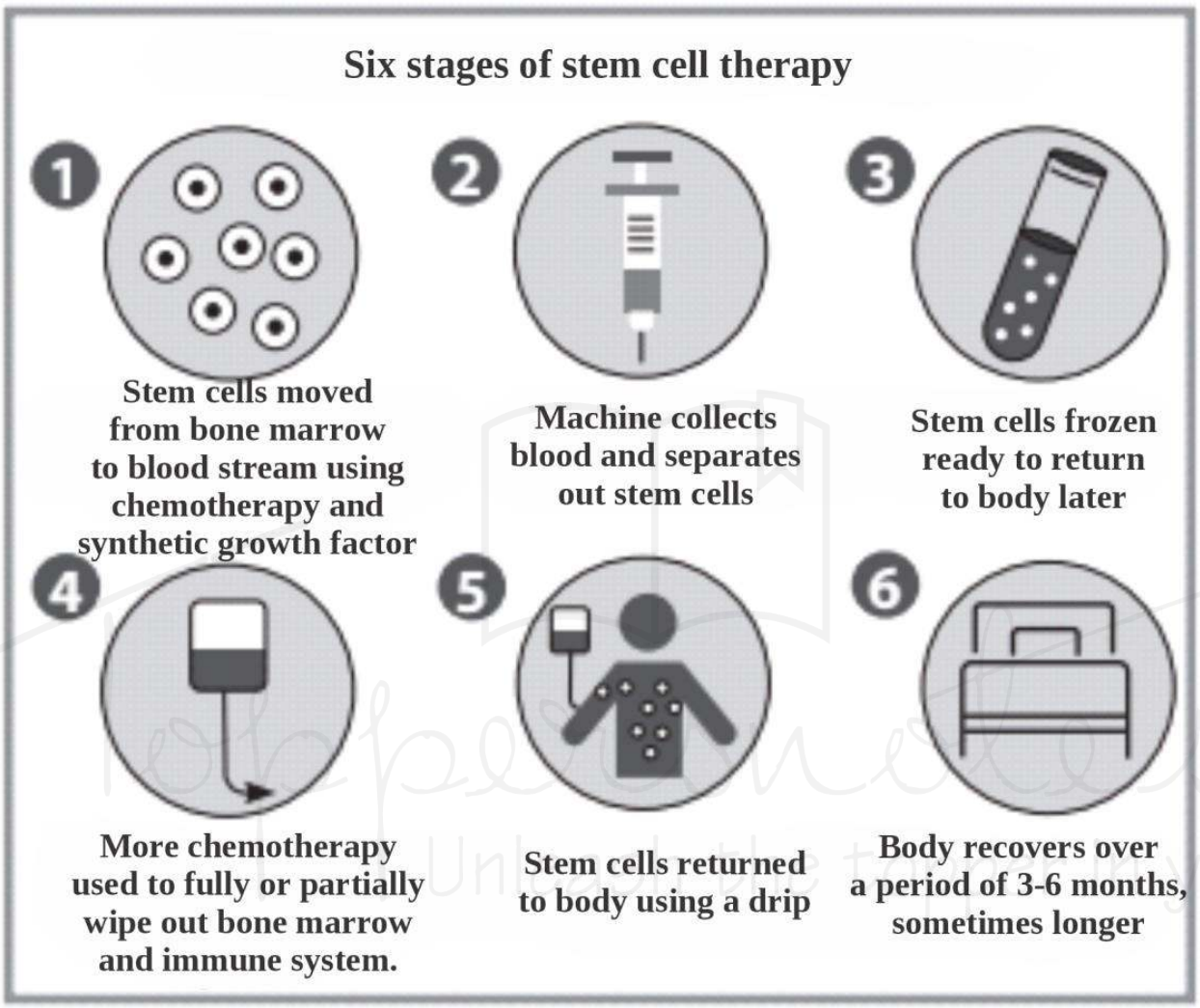
- **Chloroplasts** (in plants): It is the site of photosynthesis, where plants convert sunlight into chemical energy and stored in the form of glucose.
  - ✓ They contain the green pigment chlorophyll, which absorbs light energy.
- **Lysosomes**:They are the membrane-bound organelles that contain digestive enzymes.
  - ✓ They break down waste materials, cellular debris, and foreign substances.
- **Ribosomes**: Ribosomes are small, non-membrane-bound structures responsible for protein synthesis.
  - ✓ They can either be attached to the rough ER or float freely in the cytoplasm, translating mRNA into proteins in both plant and animal cells.
- **Centrosome/Centrioles**:Centrosomes are small, non-membrane-bound organelles that play a key role in cell division.
  - ✓ They are present only in animal cells.
- **Vacuoles**: Vacuoles are membrane-bound organelles that store nutrients, waste and maintain turgor pressure.
  - ✓ Plant cells typically have a large central vacuole, while animal cells have smaller vacuoles for storing water, nutrients, and waste.

F. Stem Cells

- Stem cells are unspecialized cells that can develop into various types of cells, such as muscle or brain cells.
- They can divide and differentiate into specialized cells with distinct functions.
- Cell potency is the ability of a stem cell to transform into different cell types.

Therapeutic Cloning

- Therapeutic cloning uses somatic-cell nuclear transfer to create patient-specific embryonic stem cells, which can be coaxed into any tissue type.
- The aim is to grow immune-matched, healthy organs or tissues for transplantation, sidestepping rejection and donor shortages.
- Stem cells are undifferentiated cells with two defining properties:
  - ✓ **Self-renewal:** the ability to undergo numerous cycles of cell division while maintaining the undifferentiated state.
  - ✓ **Potency:** It relates to the ability of a cell to differentiate into specialized cell types.



Types of Stem Cells

Depending on differentiation potential, stem cells classify as:

- **Totipotent**: can form all embryonic and extra-embryonic cell types (e.g., zygote).
- **Pluripotent Stem Cells** can develop into any cell type in the body, except those needed for fetal development. E.g: Embryonic stem cells.
- **Multipotent Stem Cells** can form a limited range of cell types. E.g: Adult stem cells and cord blood stem cells.
- **Unipotent**: can generate one specific cell type (e.g., muscle stem cells → muscle fibers).
- **Induced Pluripotent Stem Cells** are reprogrammed skin or blood cells that revert to an embryonic-like pluripotent state.

DID YOU KNOW?

- **Viroids:** are infectious agents that consist only of naked RNA without any protective layer.
- **Virions:** Virus is the nucleoprotein particle, whereas a virion is the active, infectious form of the virus.

G. Blood Composition

- **Plasma**
  - ✓ Makes up about 55 % of blood volume; mostly water.
  - ✓ Carries important proteins: fibrinogen (clotting), globulins (immunity), albumin (maintains blood volume).
  - ✓ Contains dissolved minerals such as sodium, calcium, and magnesium.
- **Formed Elements**

Type	Key Facts	Main Function
Erythrocytes (Red Blood Cells)	Most numerous; made in red bone marrow; biconcave shape; lifespan of about 120 days.	Carry oxygen and carbon dioxide with the help of haemoglobin.
Leucocytes (White Blood Cells)	Only about 1 % of blood; colourless, have nuclei; irregular shape. **Granulocytes** – neutrophils, eosinophils, basophils. **Agranulocytes** – lymphocytes, monocytes.	Defend the body against infections and foreign material.
Platelets (Thrombocytes)	Tiny cell fragments.	Start the clotting process; deficiency causes bleeding problems.

1. **Types of leucocytes**
   - ✓ **B cells:** produces an army of proteins in response to pathogens in blood.
   - ✓ **T cells:** help B-cells produce antibodies.
2. **Macrophage-** are a type of white blood cell that acts as the body's first line of defence against infection. They are large, specialized cells that recognize, engulf and destroy target cells.

- Lymph **(Tissue Fluid)**
  - ✓ Formed when some plasma leaks out of capillaries and becomes interstitial fluid.
  - ✓ A clear fluid rich in lymphocytes (crucial for immune responses).
  - ✓ Transports fats from intestinal villi (lacteals) and carries certain hormones and nutrients.

H. Classification of Organisms

DID YOU KNOW?

Nitric oxide is a molecule synthesised in the human body that dilate blood vessels and increases blood flow.

- Classification arranges the immense diversity of life into nested groups based on shared features and evolutionary history. This framework extends from broad domains down to individual species and enables biologists to name, compare and study organisms in a systematic way.

R.H. Whittaker's 5 Kingdom Classification					
Property	**Monera**	**Protista**	**Fungi**	**Plantae**	**Animalia**
Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cell organization	Mostly unicellular	Mostly unicellular	Multicellular and unicellular	Mostly multicellular	Mostly multicellular

Cell wall	Present in most	Present in some; absent in others	Present	Present	Absent
Nutritional class	Phototrophic, heterotrophic, or chemoautotrophic	Heterotrophic and phototrophic	Heterotrophic	Phototrophic	Heterotrophic
Mode of nutrition	Absorptive	Absorptive or ingestive	Absorptive	Mostly absorptive	Mostly ingestive
Motility	Motile or non-motile	Motile or non-motile	Nonmotile	Mostly nonmotile	Mostly motile

1. Kingdom Monera

- ✓ Monera comprises the bacteria and cyanobacteria—single-celled prokaryotes without a true nucleus.
- ✓ Cell walls built of peptidoglycan (except Mycoplasma, which lack walls).
- ✓ Their nutrition ranges from photosynthesis (cyanobacteria) and chemosynthesis to heterotrophy.
- ✓ Reproduce asexually by binary fission; exchange genes via transformation, conjugation or transduction.
- ✓ Mycoplasmas are the smallest free-living cells, tolerate anaerobic conditions and include important pathogens.
- ✓ Sub-classification:

Category of Monera	**Representative Examples**
Archaebacteria(primitive bacteria)	Methanobacterium, Halobacterium, etc.
Eubacteria(true bacteria)	E. coli,salmonella,staphylococcus aureus,mycoplasma
Cyanobacteria(blue green algae)**.**	Nostoc ,Anabaena,spirulina

DID YOU KNOW?

1. **Hibernation:** It is a prolonged period of dormancy in animals, usually during the winter months, where metabolic rates drop significantly. (e.g. bats, bears, ground squirrels)
2. **Aestivation:** It is a state of dormancy or inactivity that some animals enter during hot and dry conditions, typically in the summer. (e.g. snail, frog, desert tortoise, etc.)

2. Kingdom Protista

- ✓ All single-celled eukaryotes are classified under **Protista**.
- ✓ Protists are primarily aquatic and serve as a link between plants, animals, and fungi.
- ✓ As eukaryotes, protists have a well-defined nucleus and membrane-bound organelles, they reproduce both asexually and sexually, involving cell fusion and zygote formation.
- ✓ Sub-classification:

Category of Protista	**Representative Examples**
Chrysophytes (Diatoms & Golden Algae)	Navicula spp., Coscinodiscus spp., Dinobryon spp.
Dinoflagellates	Gonyaulax spp., Noctiluca scintillans, Ceratium spp.
Euglenoids	Euglena gracilis, Phacus spp.
Slime Molds (Myxomycetes)	Physarum polycephalum, Fuligo septica
Amoeboid Protozoans (Rhizopoda)	Amoeba proteus, Entamoeba histolytica
Flagellated Protozoans (Zooflagellates)	Trypanosoma gambiense, Giardia lamblia
Ciliated Protozoans (Ciliophora)	Paramecium caudatum, Vorticella campanula
Sporozoans	Plasmodium vivax, Toxoplasma gondii

DID YOU KNOW?

Archaea are organisms consisting of a single cell without a nucleus. They inhabit a wide range of habitats including extreme environments.

3. Kingdom Fungi

- ✓ Fungi are primarily multicellular eukaryotes (except yeasts which are unicellular) that secrete enzymes to digest organic matter externally.
- ✓ Cell walls are made of chitin; lack chloroplasts and any mechanism for active movement.
- ✓ They get nutrition by saprophytism (decomposers), parasitism (rusts, smuts) or mutualism (mycorrhizae).
- ✓ Reproduce via spores—both asexual (conidia) and sexual (ascospores, basidiospores).
- ✓ Sub-classification:

Category of Fungi	Representative Examples
Phycomycetes (Oomycetes & Zygomycetes)	Mucor spp., Rhizopus stolonifer, Albugo candida
Ascomycetes (Sac Fungi)	Aspergillus niger, Penicillium chrysogenum, Neurospora crassa, Saccharomyces cerevisiae
Basidiomycetes (Club Fungi)	Agaricus bisporus, Puccinia graminis, Ustilago maydis, Polyporus spp.
Deuteromycetes (Imperfect Fungi)	Alternaria alternata, Colletotrichum spp., Trichoderma harzianum, Helminthosporium spp.

4. Kingdom Plantae

- ✓ Kingdom Plantae includes all eukaryotic, chlorophyll-containing organisms, commonly known as plants.
- ✓ Some members are partially heterotrophic, such as insectivorous plants (e.g., Bladderwort and Venus flytrap) and parasites like Cuscuta (an epiphyte).
- ✓ Plant cells are eukaryotic, with prominent chloroplasts and cell walls made primarily of cellulose.
- ✓ They are autotrophs, using chlorophyll for photosynthesis.
- ✓ Sub-classification:

Category of Plantae	Representative Examples
Algae	Chlamydomonas reinhardtii, Volvox globator, Sargassum natans, Porphyra tenera
Bryophytes	Marchantia polymorpha, Funaria hygrometrica, Polytrichum commune
Pteridophytes	Selaginella kraussiana, Pteris vittata, Dryopteris filix-mas
Gymnosperms	Cycas revoluta, Pinus roxburghii, Ginkgo biloba
Angiosperms	Oryza sativa, Zea mays, Mangifera indica, Rosa indica

5. Kingdom Animalia

- ✓ It is characterized by heterotrophic, multicellular eukaryotic organisms whose cells lack cell walls.
- ✓ These organisms directly or indirectly depend on plants for food. They are heterotrophs and lack the rigid cell walls found in plants.
- ✓ The sexual reproduction is by copulation of male and female followed by embryological development.
- ✓ Sub-classification:

Category of Animalia	Representative Examples
Porifera	Sycon (Scypha), Spongilla spp., Euspongia spp.
Cnidaria (Coelenterata)	Hydra spp., Aurelia aurita (jellyfish), Adamsia palliata (sea anemone)
Ctenophora	Pleurobrachia spp., Ctenoplana spp.

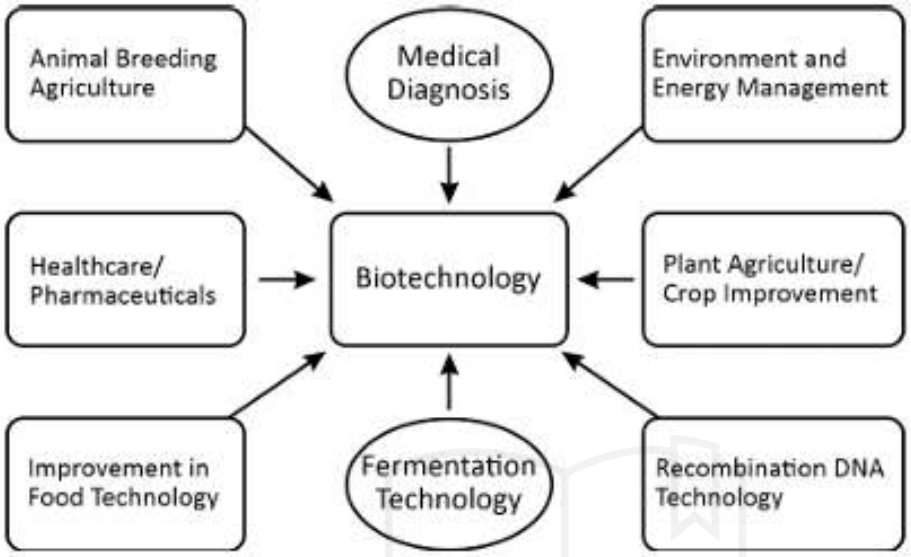
Platyhelminthes	Planaria spp., Taenia solium (pork tapeworm), Fasciola hepatica (liver fluke)
Nematoda (Aschelminthes)	Ascaris lumbricoides (roundworm), Wuchereria bancrofti (filarial worm) **C. elegans,** commonly known as "the worm," is widely used to study brain and cell functions.
Annelida	Nereis spp., Pheretima posthuma (earthworm), Hirudinaria granulosa (leech)
Arthropoda	Apis indica (honeybee), Bombyx mori (silkworm moth), Anopheles spp. (mosquito)
Mollusca	Pila globosa (apple snail), Sepia officinalis (cuttlefish), Octopus vulgaris
Echinodermata	Asterias rubens (starfish), Echinus spp. (sea urchin), Holothuria spp. (sea cucumber)
Hemichordata	Balanoglossus spp., Saccoglossus spp.
Chordata	Urochordata — Herdmania momus; Cephalochordata — Branchiostoma lanceolatum; Vertebrata — Fish (Labeo rohita), Amphibian (Rana tigrina), Reptile (Python molurus), Bird (Columba livia), Mammal (Homo sapiens)

Biology explains how life is organized from cells up to kingdoms and how structural design underlies function. Cells, which are either prokaryotic or eukaryotic, contain organelles that carry out essential tasks for survival, growth, immunity and internal balance. The system of biological classification together with the endosymbiotic origin of certain organelles illustrates the unity and diversity of life as shaped by evolution.

2 CHAPTER

Biotechnology

Biotechnology is the application of scientific principles from both engineering and biological sciences to develop useful products using living organisms or biological systems.



Modern biotechnology primarily evolved from the development of two core scientific fields: genetic engineering and bioprocess engineering.

- **Genetic engineering** involves techniques that modify the chemical structure of genetic material—DNA or RNA.
- ✓ These altered genes can then be introduced into another organism, allowing scientists to change its traits or characteristics.
- **Bioprocess engineering:** to ensure a sterile environment in chemical processes to promote the growth of specific microbes or eukaryotic cells for producing biotechnological products like antibiotics, vaccines and enzymes.

Types of Biotechnology -

Red Biotechnology	Health branch: development of vaccines and medicines (e.g. antibiotics), regenerative therapies and artificial organs
Green Biotechnology	Agricultural branch: used by over 13 million farmers to enhance pest resistance, improve crop nutrition and resilience to stress (drought, frost)
White Biotechnology	Industrial branch: optimization of manufacturing processes, production of biofuels, and development of sustainable industrial technologies
Yellow Biotechnology	Food-production branch: research to reduce saturated fat content in cooking oils
Blue Biotechnology	Marine branch: exploitation of aquatic resources for aquaculture, cosmetics, healthcare products, and biofuels from microalgae
Grey Biotechnology	Environmental branch: conservation and restoration of contaminated ecosystems via bioremediation processes
Gold Biotechnology	Bioinformatics branch: acquisition, storage, analysis and organization of biological data, especially DNA and amino acid sequences

Basics of Genetics

1. DNA (Deoxyribonucleic Acid)

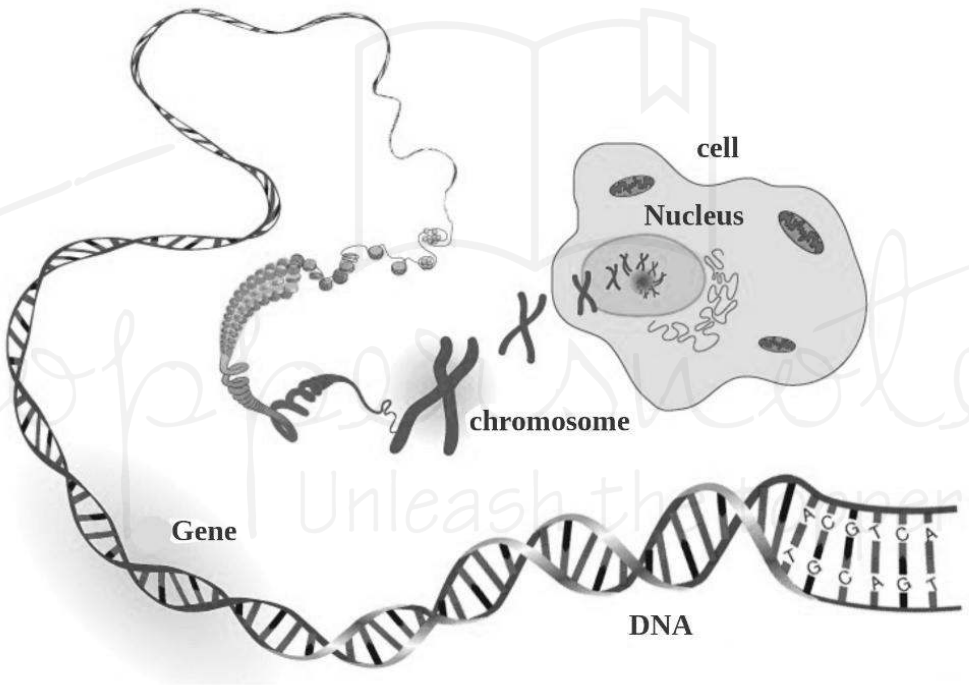
$$\text{DNA} \xrightarrow[\text{histones}]{\text{condensation}} \text{Chromatin} \xrightarrow[\text{condenses}]{\text{further}} \text{Chromosomes}$$

- ✓ DNA is a molecule that carries the genetic blueprint for the development, functioning and reproduction of all living organisms and many viruses.
- ✓ It consists of two long strands twisted into a double helix. Each strand is made up of nucleotide bases: Adenine (A), Thymine (T), Cytosine (C), and Guanine (G).
- ✓ The sequence of these bases encodes genetic instructions.
- ✓ The base pairing follows a specific rule: Adenine pairs with Thymine, and Cytosine pairs with Guanine.
- ✓ This pairing enables accurate replication of DNA during cell division.

DID YOU KNOW?

- ➢ ***Extrachromosomal DNA*** (ecDNA) are the small circular DNA fragments that float freely in the nucleus, separated from chromosomes. It is formed due to DNA damages or errors during DNA replication.
- ➢ **Transgenic animals**: animals that have their DNA manipulated to possess and express an extra gene.

2. Gene



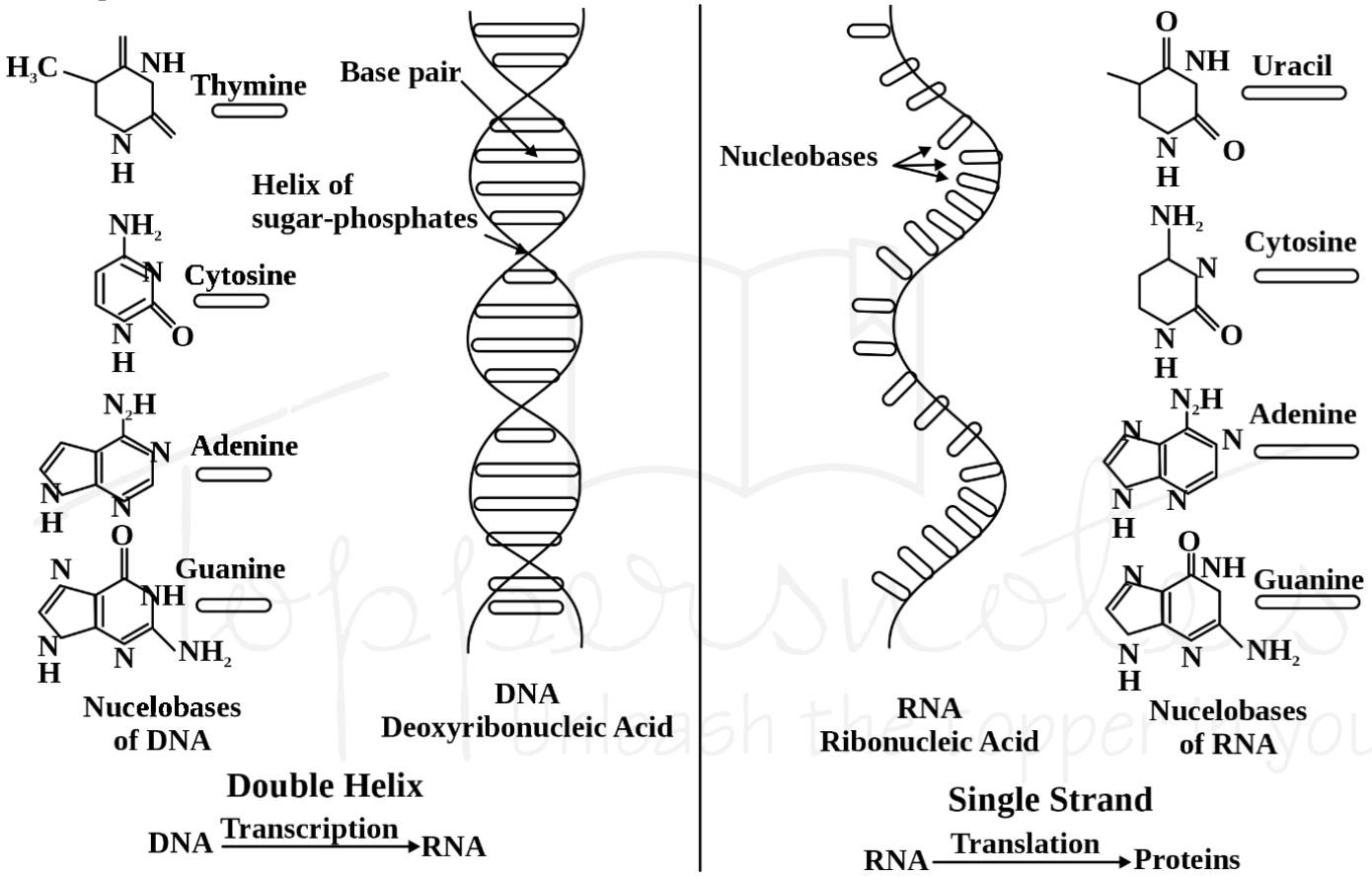
- ✓ A gene is a specific segment of DNA that contains instructions to produce a functional product, usually a protein.
- ✓ Genome is the entire set of DNA instructions found in a cell.
- ✓ These genes vary in size and function, and the human genome is estimated to contain between 20,000 to 25,000 genes.
- ✓ Based on function, genes can be classified into the following types:
  - **Structural Genes**: These genes code for proteins that are involved in cellular structure or function.
  - **Regulatory Genes**: These genes control the expression of other genes, determining when and how much of a protein is produced.
  - **Non-coding Genes**: These do not code for proteins but are involved in gene regulation and other essential functions.

3. Chromosome

- ✓ Chromosomes are thread-like structures located in the nucleus of cells.
- ✓ They are made of DNA and proteins and serve as carriers of genetic material.
- ✓ Each chromosome contains many genes that determine hereditary traits.
- ✓ Humans have 46 chromosomes, arranged in 23 pairs.

4. RNA (Ribonucleic Acid)

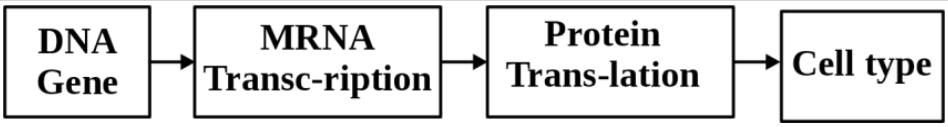
- ✓ RNA is a single-stranded molecule that plays a critical role in protein synthesis and gene expression. While similar to DNA, it differs in the following ways:
  - RNA contains ribose sugar instead of deoxyribose.
  - It has the nitrogenous base Uracil (U) instead of Thymine (T).
  - RNA bases include Adenine (A), Uracil (U), Cytosine (C), and Guanine (G).
- ✓ It acts as a messenger (mRNA), carrying genetic instructions from DNA to the ribosome, where proteins are made.



Comparison Between DNA and RNA		
Parameters	**DNA**	**RNA**
Structure	Double-stranded helix	Single-stranded
Nitrogenous Bases	Adenine (A), Thymine (T), Cytosine (C), Guanine (G)	Has Uracil in the place of Thymine (T)
Function	**Stores genetic information** for inheritance	Regulates gene expression and plays key role in **protein synthesis**

5. Protein Synthesis (Central Dogma of Molecular Biology)

- ✓ It explains the flow of genetic information within a biological system. It occurs in three main steps:



- **Replication**: This is the process of copying DNA so that each new cell receives an identical set of genetic material. It occurs in the nucleus before cell division.
- **Transcription**: In this process, a specific segment of DNA is used as a template to make RNA, particularly messenger RNA (mRNA). This RNA copy exits the nucleus and carries the genetic instructions to the ribosomes.
- **Translation**: The ribosome reads the mRNA sequence and assembles amino acids into a specific protein with the help of transfer RNA (tRNA).

Terms -

- **Microsatellites** are short, repeating sequences of DNA (1–6 base pairs) found in non-coding regions of the genome.
- **TDP1 enzyme** in the human body plays a role in DNA repair.
- **ISDra2-TnpB** is a compact, RNA-guided nuclease (an ancestor of CRISPR-Cas) that ICAR scientists have repurposed for precise plant genome editing.
- **Biosimilars-**biological product that is similar to approved biologic drugs.
- **Gene doping** illicitly inserts or edits genes,often via viral vectors or CRISPR to amplify EPO levels, muscle growth, or endurance, giving athletes a biological edge.
- **Gene Desert:** is a large region of DNA that lacks protein-coding genes.

6. Dark DNA

- ✓ It refers to regions of the genome that are difficult to analyze using standard sequencing techniques.
- ✓ These regions may have a high mutation rate or contain repetitive sequences, which makes them harder to interpret.
- ✓ Earlier considered non-functional "junk DNA", current research indicates that dark DNA may be involved in regulating gene activity and driving evolutionary changes.

DID YOU KNOW?

The Nobel Prize in Medicine 2024 was given for the discovery of microRNA. miRNA is small non-coding RNA that helps cells regulate gene expression by binding with mRNA.

7. Adenovirus vs Retrovirus

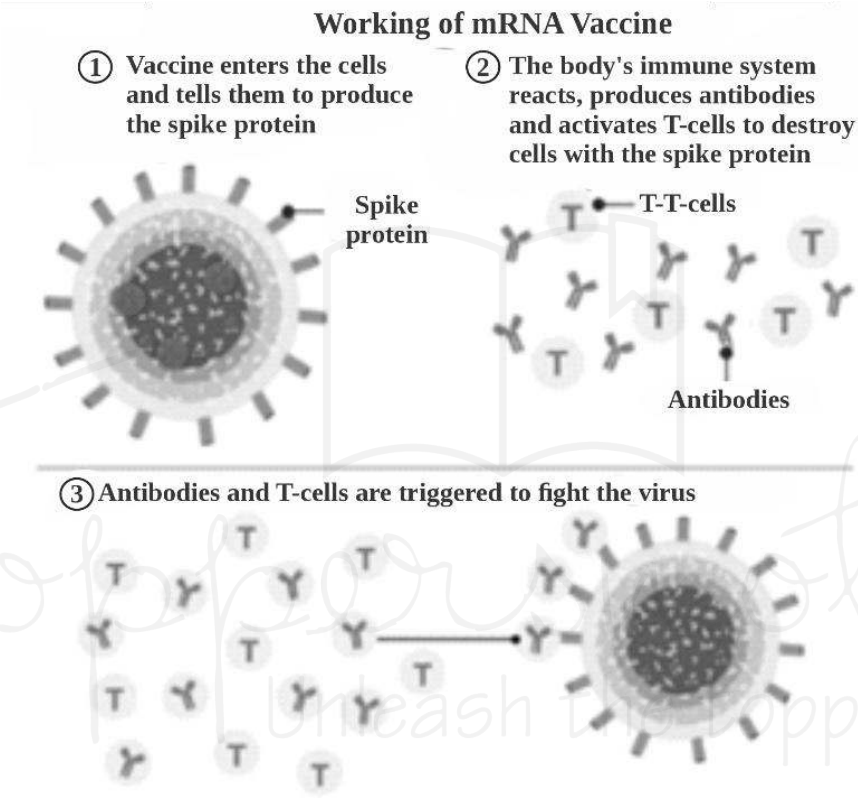
Feature	Adenovirus	Retrovirus
Genetic Material	DNA	RNA
Envelope	Non-enveloped	Enveloped
Mechanism of Infection	DNA enters host nucleus but does not integrate into host genome	RNA is converted to DNA using reverse transcriptase and integrates into host genome
Examples	Human Adenovirus, used in viral vectors for gene therapy	HIV, HTLV, SARS-CoV-2 (Coronavirus)

8. Transcriptome

- ✓ The transcriptome refers to the collection of all RNA molecules produced in a cell or organism, including:
  - Messenger RNA (mRNA) – carries genetic code for proteins.
  - Transfer RNA (tRNA) – brings amino acids for protein synthesis.
  - Ribosomal RNA (rRNA) – forms the core of the ribosome's structure.
  - Other non-coding RNAs – involved in gene regulation.

- ✓ It represents the protein-coding potential of the genome and varies across cell types and conditions.

9. **Reverse Transcriptase (RTs):** They are RNA-dependent DNA polymerases, a group of enzymes that play a unique role in the flow of genetic information.
10. **Aerial Metagenomics**
    - ✓ Aerial metagenomics is the study of genetic material such as DNA or RNA collected from the air in the form of aerosols or airborne particles.
    - ✓ It can be used to detect pathogens, study environmental biodiversity, and track microbial pollution.
11. **RNA INTERFERENCE (RNAi)**
    - ✓ RNA interference is a natural process that silences specific genes by blocking protein production, helping cells defend against viruses and aiding research and biotechnology.
12. **mRNA vaccines-**



13. **Monoclonal Antibodies**
    - ✓ These are **lab-engineered antibodies** designed to target specific cells or proteins in the body.
    - ✓ **Used in**: Cancer treatment, Autoimmune diseases like rheumatoid arthritis, etc.
14. **DNA Editing *v/s* RNA Editing**

DNA Editing	RNA Editing
It makes permanent changes	It makes temporary changes
It may result in irreversible errors	It is safer and flexible compared to DNA editing

Genome Sequencing and Related Concepts

1. **Genome Sequencing**
    - ✓ Genome sequencing is the process of determining the exact sequence of nucleotide bases—adenine (A), thymine (T), cytosine (C), and guanine (G)—across the entire genome of an organism.

- ✓ This helps scientists understand the complete set of DNA instructions that make up an organism's traits, behavior, and susceptibility to diseases.
- ✓ It also allows researchers to identify genes, study mutations, understand hereditary conditions, and develop tools for personalized medicine and biotechnology.

2. Human Genome Project

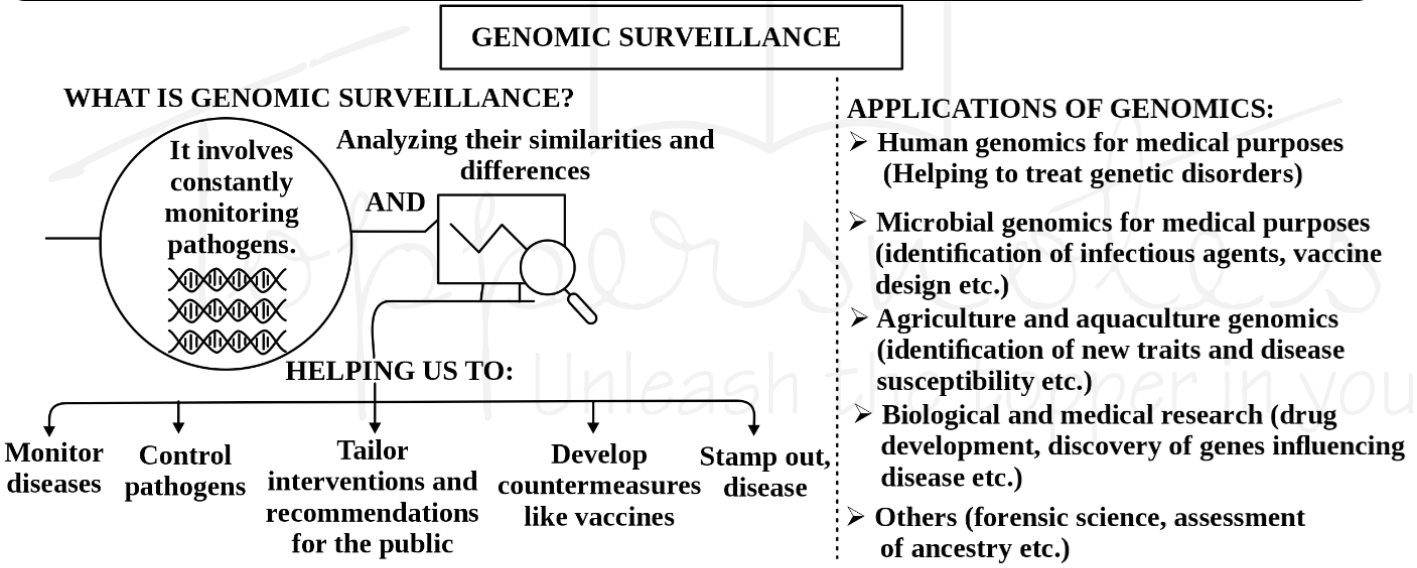
- ✓ The Human Genome Project (HGP) began in 1990 as an international scientific effort to sequence all 3.2 billion nucleotide pairs in the human genome.
- ✓ **Objectives:**
  - To identify and map all human genes.
  - To construct a detailed physical and genetic map of the genome.
  - To determine the DNA sequence of all 24 human chromosomes (22 autosomes and X & Y chromosomes).
- ✓ The project was completed ahead of schedule in 2003 and revolutionized medical and biological research.

DID YOU KNOW?

The Department of Biotechnology (DBT) and Biotechnology Research and Innovation Council (BRIC) launched the 'One Day One Genome' initiative on the 1st foundation day of BRIC.

One Day One Genome

- ➢ Aim: An annotated microbial genome will be publicly released every day to make microbial genomics data more accessible to researchers.
- ➢ It will highlight the unique bacterial species found in our country.



GENOMIC SURVEILLANCE IN INDIA

Regional Genome Sequencing Laboratories (RGSL) serve as the regional hub for genome sequencing.	**Indian SARS-CoV-2 Genomics Consortium (INSACOG) was established to expand Whole Genome Sequencing of SARS-CoV-2 across the nation*.**	**Indian Tuberculosis Genomic Surveillance Consortium (InTGS) is proposed on the lines of INSACOG.**

"INSACOG, jointly initiated by Ministry of Health & Family Welfare, and Department of Biotechnology (DBT) with Council for Scientific & Industrial Research (CSIR) and Indian Council of Medical Research (ICMR), is a consortium of over 50 laboratories.

3. Genome India Project

- ✓ Launched in 2020 by the Department of Biotechnology, the Genome India Project aims to sequence the genomes of at least 10,000 Indian citizens from diverse backgrounds.

- ✓ The goal is to understand the genetic variations across India's population and link them to disease susceptibility, drug response, and health patterns.
- ✓ This data will help promote predictive diagnostics, personalized medicine, and precision healthcare.
- ✓ The initiative is led by the Centre for Brain Research at IISc, Bengaluru, and involves over 20 national institutions.

DID YOU KNOW?

- **Unified Genomic Chip** (a Single Nucleotide Polymorphism (SNPs) chip) was launched by PM for genomic profiling and evaluation of Indian cattle breeds.
- **SNP** refers to a variation in a DNA sequence where a single nucleotide is different from the reference sequence. They can act as biological markers.
- **Tmesipteris oblanceolata**, a fork fern native to the South Pacific, has the largest known genome on Earth (about 160 gigabases) ,which is over fifty times the size of the human genome.

4. Earth Bio-Genome Project

- ✓ The Earth Bio-Genome Project (EBP) is a global initiative aiming to sequence and catalogue the genomes of all eukaryotic species on Earth over a span of 10 years.
- ✓ The goal is to build a "Digital Library of Life" for 1.5 million known species.
- ✓ It will help preserve biodiversity and support efforts in conservation, agriculture, and sustainability.
- ✓ The project will also uncover evolutionary relationships among various life forms.

5. The INDIgen Project

- ✓ This project was launched by CSIR (Council of Scientific and Industrial Research) to sequence the whole genomes of thousands of Indian individuals.
- ✓ It aims to create a comprehensive database representing the genetic diversity of India's population.
- ✓ The project supports personalized medicine, helps understand disease susceptibility, and aids in improving healthcare outcomes for the Indian population.

DID YOU KNOW?

Next-generation sequencing is a method of analyzing genetic material that can rapidly sequence large amounts of DNA or RNA. It can sequence an entire genome within days, compared to months with earlier techniques.

6. Heritable Human Genome Editing

- ✓ **South Africa** became the first country to permit **Heritable Human Genome Editing (HHGE)**.
- ✓ Unlike somatic cell editing, which only affects the individual, **HHGE** introduces changes in **germline cells** (sperm, eggs, or embryos), allowing these modifications to be passed down to future generations.

7. BIOE3 Policy (Biotechnology for Economy, Environment and Employment)

- ✓ It aims to establish a framework to adopt advanced technologies and align research to revolutionize bio-manufacturing processes.
- ✓ It will be implemented by the Department of Biotechnology.
- ✓ The policy aims to achieve a $300 billion bioeconomy by 2030.

Genome Editing

- Genome editing, also known as genome engineering or gene editing, refers to a group of techniques that enable scientists to modify the DNA of living organisms.

- This includes inserting, deleting, altering, or replacing specific genetic material at precise locations in the genome.
- By altering gene sequences, scientists can study gene functions, correct genetic disorders, and develop better treatments for various diseases.

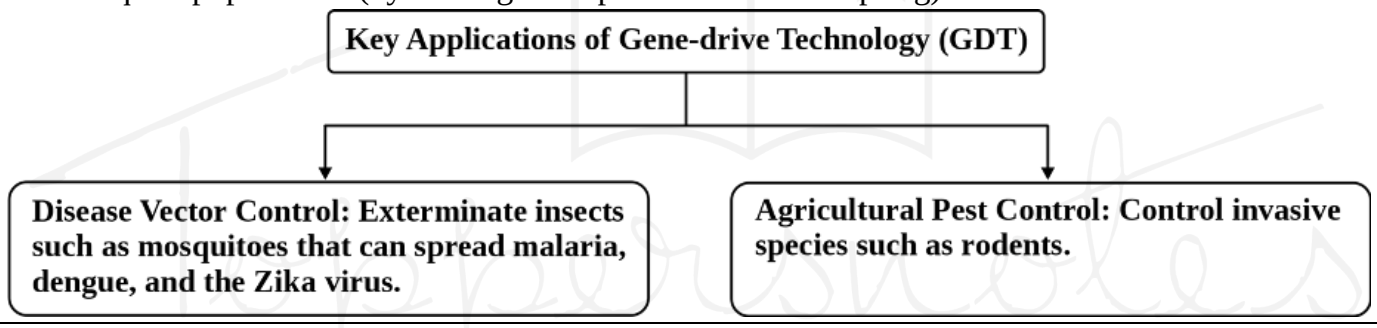
Genome Editing Techniques

- Several advanced tools have been developed for precise genome manipulation. The most important among them are:

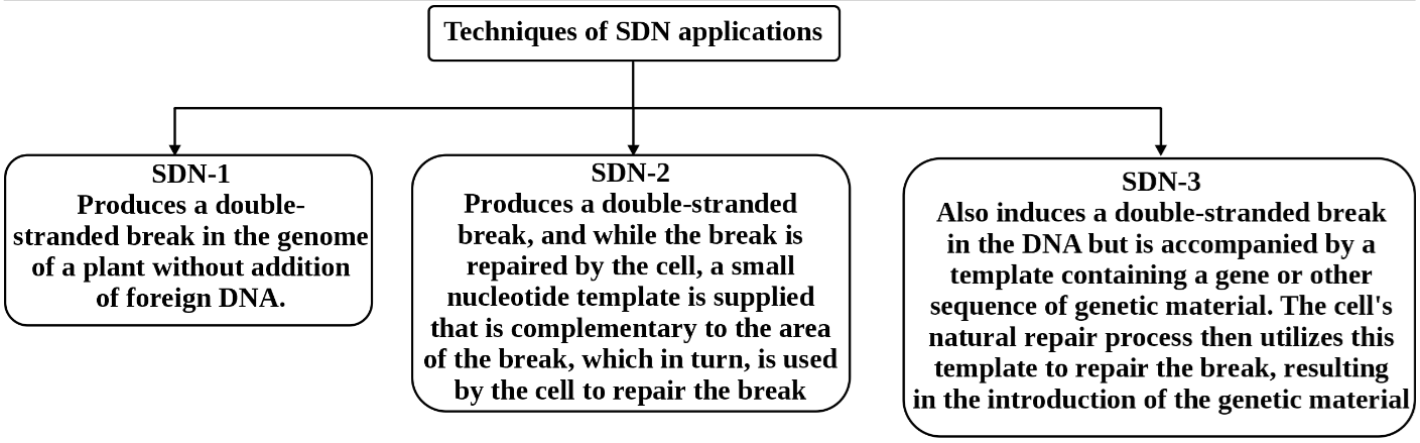
1. **CRISPR-Cas9 (Clustered Regularly Interspaced Short Palindromic Repeats and Cas9 Protein):** is currently the most widely used and revolutionary genome editing tool.
   - ✓ **CRISPR** is a short RNA sequence that guides the system to a specific DNA site by base-pair complementarity.
   - ✓ **Cas9** is a protein that acts as molecular scissors, cutting the DNA at the targeted location.
   - ✓ After the DNA is cut, scientists can delete, insert, or modify genetic material at the break site.
   - ✓ This method is efficient, cost-effective, and easy to use, making it suitable for a wide range of applications—from gene therapy to agriculture.

Gene-Drive Technology (GDT) -

- A type of genetic engineering technique that modifies genes to alter Mendelian inheritance (Normal).
- Mendelian inheritance refers to certain patterns of how traits are passed from parents to offspring.
- Applications based on Gene-drive Technology (GDT) have shown promising reductions in mosquito populations (by making them produce sterile offspring).



2. **TALENs (Transcription Activator-Like Effector Nucleases):** are another powerful genome editing tool.
   - ✓ They use **TALE proteins** that can recognize and bind to specific DNA sequences.
   - ✓ These proteins are attached to a nuclease (typically FokI), which cuts the DNA at the desired site.
   - ✓ The targeted cut enables gene modification or correction.
   - ✓ TALENs offer high specificity and are used in gene therapy and functional genomics.
3. **Zinc Finger Nucleases (ZFNs):** ZFNs are engineered proteins that combine:
   - ✓ A **zinc-finger protein domain**, designed to bind specific DNA sequences, and
   - ✓ A **FokI nuclease domain**, which performs the actual cutting.
   - ✓ Each zinc-finger recognizes a short DNA sequence, and when multiple fingers are combined, they allow targeting of long and unique genomic regions.
   - ✓ The FokI nuclease cuts the DNA between two binding sites, enabling precise gene editing.
4. **Site Directed Nuclease**
   - ✓ It is cleaving DNA strands to affect subsequent genome editing, taking advantage of natural repair mechanisms to introduce small changes.

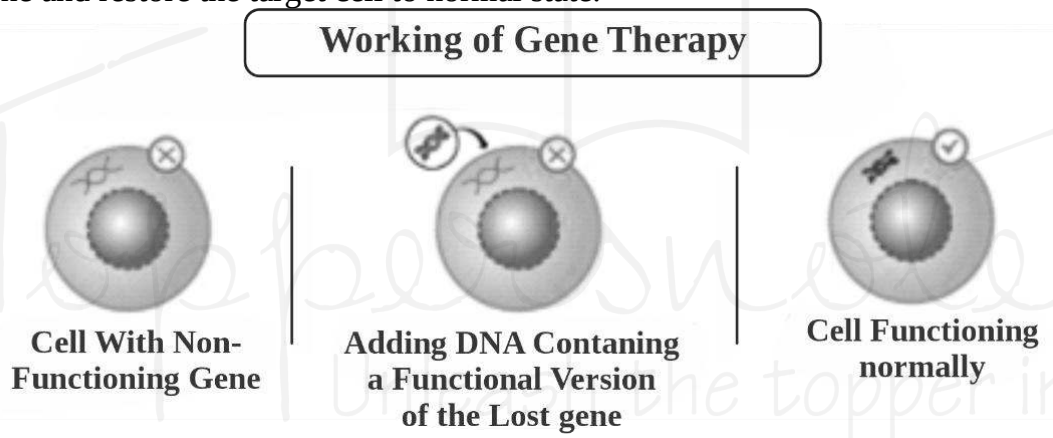


5. Homing Endonucleases (Mega-nucleases)

- ✓ Also known as **mega-nucleases**, these are naturally occurring enzymes that recognize long DNA sequences (14–40 base pairs).
- ✓ They bind very specifically to DNA and make cuts, triggering repair or modification at the targeted site.
- ✓ Unlike ZFNs and TALENs, in mega-nucleases, the DNA-binding and cleavage domains are not separate but integrated.
- ✓ They are highly specific but harder to design for new targets compared to CRISPR or TALENs.

Gene Therapy

- ➢ It is a technique that uses a gene to treat, prevent, or cure a disease or medical disorder.
- ➢ In most gene therapy, a normal gene is inserted into the genome to supplement an abnormal disease-causing gene and restore the target cell to normal state.



- ➢ **Types of Gene Therapy**
  - ✓ **Germline gene therapy:** In this, the Germline cells (egg or sperm) are modified by the introduction of functional genes.
  - ✓ **Somatic cell gene therapy:** In this, therapeutic genes are transferred to a patient's somatic cells (cells other than germline cells).

Haemophilia: is an inherited (through X chromosome), life-long, sex linked bleeding disorders occurring predominantly in males.

1. Somatic Cell Nuclear Transfer (SCNT)

- ✓ SCNT is a laboratory technique used to create a viable embryo by transferring the nucleus of a somatic (body) cell into an egg cell from which the nucleus has been removed.
- ✓ **Process of SCNT:**
  - **Extraction of Somatic Cell**: A body cell is collected, containing the full DNA of the donor organism.
  - **Enucleation**: The nucleus is removed from a donor egg cell.
  - **Nuclear Transfer**: The somatic cell nucleus is inserted into the enucleated egg.

- **Activation**: The egg is stimulated to begin dividing and developing like a natural embryo.
- **Embryo Implantation**: The developing embryo is implanted into a surrogate uterus to grow into a complete organism.

✓ **Applications:**

- **Cloning**: First used to clone Dolly the sheep in 1996.
- **Therapeutic Cloning**: Produces stem cells for research and treatment.
- **Conservation**: Explored for preserving endangered species.
- **Ethical and Scientific Concerns:** The technique faces criticism due to its low success rate, ethical concerns about cloning animals or humans, and potential health risks.

DID YOU KNOW?

Exosomes: are naturally occurring vesicles that have the potential to be manipulated to become promising drug delivery vehicles.

2. CAR-T Cell Therapy

✓ This therapy modifies T-cells, a type of white blood cell, to enhance their cancer-fighting abilities.

✓ The T-cells are extracted from the patient's blood and engineered in the lab by adding a gene for a synthetic receptor (CAR), which makes them potent cancer killers.

✓ These modified CAR-T cells are then reintroduced into the patient's body to target and destroy cancer cells.

✓ CARs are the proteins that assist the T-cells to recognize and attach to a specific protein present in cancer cells.