HEALTH

Cell – The Fundamental Unit of Life

Introduction

Cells are the basic **structural and functional units** of life. They form the foundation of all living organisms and contain specialized structures called **organelles**, such as the nucleus, mitochondria, and endoplasmic reticulum.

- **Discovery**: Cells were first discovered by **Robert Hooke** in 1665.
- **Nucleus Discovery**: The nucleus was later discovered by **Robert Brown**.
- **Classification**: Based on structural complexity, cells are categorized into:
  - **Prokaryotic Cells**
  - **Eukaryotic Cells**

Types of Cells

1. Prokaryotic Cells

- **Structure**: Unicellular organisms lacking membrane-bound organelles, including a true nucleus.
- **Genetic Material**: DNA is located in a region called the **nucleoid**.
- **Size**: Typically small (0.1–5 µm in diameter).
- **Examples**: **Bacteria** and **Archaea**.

2. Eukaryotic Cells

- **Structure**: Contain a **nucleus** and other **membrane-bound organelles**.
- **Functionality**: Organelles perform specialized functions such as energy production, protein synthesis, and waste disposal.
- **Examples**: **Animals**, **plants**, **fungi**, **protozoans**, and **algae**.

3. Prokaryotes vs Eukaryotes

Feature	Prokaryotic Cells	Eukaryotic Cells
Nucleus	Absent	Present
Size	Small (0.1–5 µm)	Larger (10–100 µm)
Organelles	Non-membrane-bound	Membrane-bound organelles present
Cell Type	Mostly unicellular	Unicellular or multicellular
Examples	Bacteria, Archaea	Plants, Animals, Fungi, Protozoans

Cell Organelles and Their Functions

1. Nucleus

- **Structure**: Double-membraned organelle found in eukaryotes.
- **Functions**:
  - Stores **DNA** (genetic material).
  - Regulates **cell growth**, **reproduction**, and **protein synthesis**.
  - Controls all cellular activities.

a. Nucleolus

- **Non-membrane-bound** structure within the nucleus.
- Synthesizes **ribosomal RNA (rRNA)** and assembles **ribosomes**.
- Covers ~25% of the nucleus volume.

b. Chromatin

- Complex of **DNA, RNA, and proteins**.
- Condenses to form chromosomes.
- Facilitates **DNA packaging** in the nucleus.

2. Mitochondria

- Known as the **"Powerhouse of the Cell"**.
- **Function**: Produces **ATP** through **cellular respiration**.
- **Contains its own DNA** (inherited maternally).

a. Mitochondrial Diseases

- Result from **mutations in mitochondrial DNA (mtDNA)**.
- Affects energy production, leading to symptoms like **muscle weakness**, **organ failure**, and **neurological damage**.

b. Maternal DNA

- Mitochondrial DNA is inherited **only from the mother**.
- Used in **ancestry tracing** and identifying **genetic disorders**.

c. Mitochondrial DNA Profiling

- Applied in forensic science when **nuclear DNA is scarce**.
- Useful for degraded samples like **hair, bones, and teeth**.
- Less unique than nuclear DNA, hence **limited for individual identification**.

3. Endoplasmic Reticulum (ER)

- A **network of membranes** involved in synthesis and transport.

Type	Features & Functions
Rough ER	Has ribosomes; synthesizes proteins.
Smooth ER	Synthesizes lipids; detoxifies chemicals; metabolizes carbohydrates.

4. Golgi Apparatus

- Acts as the **post office of the cell**.
- Modifies, sorts, and packages **proteins and lipids**.
- Works in close coordination with the ER.

5. Ribosomes

- Small, **non-membrane-bound** organelles.
- Site of **protein synthesis** (translation of mRNA into proteins).
- Found freely in the **cytoplasm** or on **rough ER**.

6. Lysosomes

- Membrane-bound organelles containing **digestive enzymes**.
- Degrade **waste materials**, **cellular debris**, and **pathogens**.
- Prominent in animal cells.
- Also called the **"Suicide Bags"** of cells.

7. Vacuoles

- Membrane-bound sacs used for **storage**.
- **Plant cells**: Large central vacuole maintains **turgor pressure**.
- **Animal cells**: Smaller vacuoles for **waste and nutrient storage**.

8. Cytoplasm

- Gel-like substance between **nucleus** and **cell membrane**.
- Suspends organelles and facilitates **biochemical processes**.

9. Cell Membrane (Plasma Membrane)

- Semi-permeable **phospholipid bilayer**.
- Regulates **movement of substances** in and out of the cell.
- **Animal cells**: Outermost boundary.
- **Plant cells**: Lies beneath the **cell wall**.

10. Centrioles (Animal Cells Only)

- Involved in **cell division**.
- Produce **spindle fibers** during mitosis and meiosis.
- Located near the **nucleus** in the **cytoplasm**.

11. Chloroplasts (Plant Cells Only)

- Site of **photosynthesis**.
- Contains **chlorophyll**, which absorbs solar energy.
- Converts light energy into **chemical energy** (glucose).

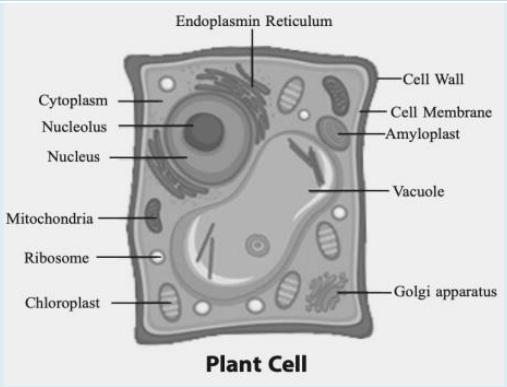
12. Cell Wall (Plant Cells Only)

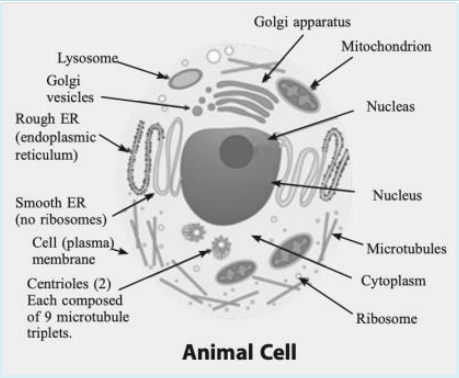
- Thick layer outside the **cell membrane**.
- Provides **mechanical support**, **protection**, and **structural strength**.
- Composed mainly of **cellulose**.
- **Absent in animal cells**.

[PYQ-2020]: The plant cell wall is primarily made of **cellulose**.

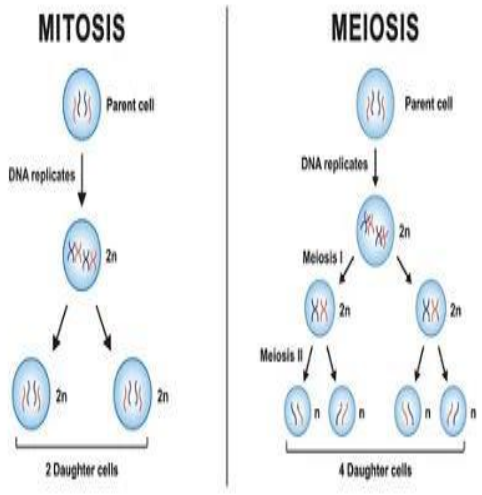
Plant Cell vs Animal Cell

Aspect	Plant Cell	Animal Cell
Cell Wall	Present (cellulose-based)	Absent
Centrioles	Absent (except in some lower plants)	Present
Plastids	Present (e.g., chloroplasts)	Absent
Vacuole	Large central vacuole	Small or absent
Lysosomes	Rare	Common
Energy Storage	Starch	Glycogen
Cytokinesis	Cell plate formation	Cleavage furrow formation





CELL DIVISION & MULTIPLICATION: REPRODUCTION



1. Cell Division

Cell division is the biological process by which a parent cell divides into two or more daughter cells. It is a fundamental mechanism for:

- **Growth**
- **Tissue repair**
- **Reproduction**

Uncontrolled cell division can lead to diseases such as **cancer**.

Types of Cell Division

- **Mitosis**: Produces new **body (somatic) cells**. One mother cell divides into two identical daughter cells. It is responsible for **growth and tissue renewal**.
- **Meiosis**: Produces **gametes** (egg and sperm cells). It ensures genetic diversity and maintains a constant chromosome number across generations.

2. Somatic Cells

- Somatic cells are **diploid (2n)**, meaning they contain two sets of chromosomes, one from each parent.
- These cells make up **all body tissues and organs**, except gametes.
- **Somatic mutations** are changes in the DNA of somatic cells after fertilization. They are:
- **Non-heritable**

- Caused by environmental factors or replication errors
- Associated with conditions like **skin cancer, lung cancer**, and **Sturge-Weber syndrome**

3. Germ Cells

- Germ cells give rise to **gametes** (sperm in males, ova in females).
- They are **diploid (2n)**, but undergo **meiosis** to produce **haploid (1n)** gametes.
- Germ cells are essential for **sexual reproduction**.

4. Sexual Reproduction

Sexual reproduction begins with the **fusion of gametes** to form a **zygote**, which develops into a new individual.

Male Reproductive System:

- Includes **testes, sperm ducts**, and **penis**
- Testes produce **sperm cells**

Female Reproductive System:

- Includes **ovaries, oviducts (fallopian tubes)**, and **uterus**
- Ovaries produce **ova (eggs)**
- Fertilization occurs when a **sperm fuses with an egg** to form a **zygote**

5. Stages of Sexual Reproduction

1. **Pre-Fertilization**:
   - Involves **gamete formation (gametogenesis)** and **gamete transfer**
   - Transfer may involve external agents (e.g., wind, water, pollinators)
2. **Fertilization**:
   - **Fusion of male and female gametes (syngamy)** to form a zygote
   - May occur **externally** (e.g., in amphibians) or **internally** (e.g., in humans)
3. **Post-Fertilization**:
   - Zygote undergoes **mitotic divisions** (embryogenesis)
   - In animals: Embryo develops in the **uterus (viviparous)** or inside an egg (**oviparous**)
   - In plants: Zygote forms a **seed**, leading to germination

6. Three-Parent Baby

- A reproductive technique involving **genetic material from one man and two women**
- Helps prevent **mitochondrial diseases**
- Utilizes techniques like **Maternal Spindle Transfer (MST)**
- Developed as an advancement in **assisted reproduction**

7. Mutation

- A **mutation** is a change in the DNA sequence
- Can be **harmless**, **beneficial**, or **harmful**
- Causes include:
  - **Replication errors**
  - **Radiation** (e.g., UV)
  - **Chemical exposure**

Examples of mutation outcomes:

- **Genetic disorders** (e.g., cystic fibrosis)
- **Cancer**
- **Evolutionary changes**

8. Artificial Insemination (AI)

- A fertility treatment that involves directly inserting sperm into the female reproductive tract
- Methods include:
  - **Intrauterine (IUI)**
  - **Intracervical (ICI)**
  - **Intratubal (ITI)**
- Used in human medicine and **animal breeding**

9. Sex-Sorted Semen Technology

- Technique used in **artificial insemination for livestock**
- Produces over **90% female calves**, compared to 50% with conventional semen

❖ Developed indigenously by **NDDB** under **'Make in India'** and **'Atmanirbhar Bharat'**

10. Assisted Reproductive Technologies (ART)

ART refers to all medical procedures that handle gametes (sperm or egg) outside the human body to facilitate pregnancy.

Types of ART:

❖ **In Vitro Fertilization (IVF)**:

- Most common ART method
- Involves fertilization outside the body
- Embryo is implanted into the uterus
- Used in cases of:
    - Blocked fallopian tubes
    - Male infertility
    - Genetic disorders
    - Unexplained infertility
- In **2024**, Goa became the **first Indian state** to provide **free IVF** in government hospitals

❖ **Gamete Intrafallopian Transfer (GIFT)**:

- Eggs and sperm are mixed and placed in the **fallopian tube**
- Fertilization occurs **inside the body**
- Suitable for **unexplained or mild male infertility**

❖ **Intracytoplasmic Sperm Injection (ICSI)**:

- A **single sperm** is directly injected into an egg
- Used in severe cases of **male infertility**

❖ **Artificial Womb**:

- Technology simulating the **uterus** to grow embryos externally
- Also known as **ectogenesis**
- Helps in the care of **premature infants**

11. Assisted Reproductive Technology (Regulation) Act, 2021

❖ Regulates ART services in India

❖ Enforced alongside the **Surrogacy (Regulation) Act, 2021**

Key Provisions:

❖ ART clinics and banks require **registration and licensing**

❖ **National and State Boards** oversee regulation

❖ **National Registry** maintains ART-related records

❖ **Eligibility**:

- Services available to **single women** and **married couples**
- Women: **21–50 years**, Men: **21–55 years**
- **Infertility** must be medically certified
- **Foreigners** are allowed ART services

❖ **Donor Regulations**:

- **Semen donors**: 21–55 years
- **Egg donors**: 23–35 years, only one donation allowed
- A single donor's gametes cannot be used for more than one couple

❖ **Other Guidelines**:

- Written **consent** required from donors and commissioning parties
- **Screening for genetic diseases** is mandatory
- **Sex-selective ART** is **prohibited**
- **Insurance coverage** must be provided for egg donors
- The child born through ART is **legally equivalent** to a natural child
- Donors have **no parental rights**

Surrogacy

Surrogacy is a medical process in which a woman (known as the **surrogate mother**) carries and delivers a child on behalf of another individual or couple, referred to as the **intended parents**. Upon birth, the surrogate relinquishes all parental rights and hands over the child to the intended parents.

Purpose

Surrogacy is primarily used by individuals or couples who are unable to conceive or carry a pregnancy due to medical reasons such as infertility, absence of a uterus, repeated miscarriages, or life-threatening conditions during pregnancy.

Types of Surrogacy

1. **Commercial Surrogacy**

- Involves **monetary compensation** or rewards beyond the reimbursement of medical expenses and insurance.
- It is **prohibited or strictly regulated** in many countries due to ethical, moral, and legal concerns regarding exploitation and commodification of women's bodies.

2. **Altruistic Surrogacy**

- Involves **no financial compensation** to the surrogate except for medical expenses and insurance coverage.
- Legally permitted in **India** under the **Surrogacy (Regulation) Act, 2021**.

Surrogacy (Regulation) Act, 2021

The **Surrogacy (Regulation) Act, 2021** is a central law passed to regulate surrogacy practices in India.

Key Provisions:

- **Definition**: Surrogacy is defined as a practice wherein a woman bears and gives birth to a child for an intending couple with the intention of handing over the child after birth.
- **Commercial Surrogacy**: Prohibited in all forms.
- **Altruistic Surrogacy**: Permitted with strict conditions and regulation.
- **Limit on Attempts**: A surrogate mother cannot undergo more than **three surrogacy attempts**.
- **Abortion Provisions**: Permissible only in accordance with the **Medical Termination of Pregnancy Act, 1971**, and under medical advice.
- **Consent and Agreement**: The surrogate mother must give her **informed written consent** and sign a formal agreement surrendering all rights over the child.
- **Insurance**: The intending couple must provide **general health insurance coverage** for the surrogate mother for a minimum of **36 months**.

Institutional Framework Created:

1. **National Assisted Reproductive Technology and Surrogacy Board** (Central level)
    - Chaired by the **Minister of Health and Family Welfare**.
2. **State/UT Assisted Reproductive Technology and Surrogacy Boards** (State level)
    - Established by respective State/UT governments with legislatures.
3. **National Assisted Reproductive Technology and Surrogacy Registry**
    - Maintains a **centralised database** for the registration and monitoring of all surrogacy clinics and ART services.

Mitochondrial Replacement Therapy (MRT)

(UPSC Prelims PYQ – 2021)

MRT, also known as **Mitochondrial Donation Treatment**, is an advanced in-vitro fertilization (IVF) technique aimed at preventing **mitochondrial diseases**—a group of disorders caused by mutations in the mitochondrial DNA (mtDNA). These mutations impact the energy-producing function of cells, particularly in energy-intensive organs like the **brain, heart, muscles, kidneys, and liver**.

How MRT Works:

- MRT involves replacing **defective mitochondria** in a mother's egg with **healthy mitochondria** from a donor.
- The resulting embryo has **nuclear DNA** from both parents and a small fraction of **mitochondrial DNA (about 37 genes)** from a third person — the donor.
- Hence, the process leads to so-called **"three-parent babies"**, though **over 99.8% of the genetic material** still comes from the mother and father.

Recent Development:

- In **2023**, the **first baby** conceived through MRT was born in the **United Kingdom**, marking a milestone in reproductive medicine.

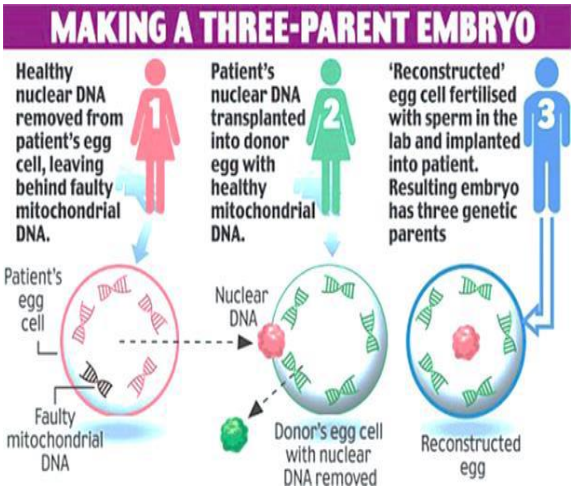
Techniques of MRT:

1. **Pronuclear Transfer (PNT):**

- Both the **mother's egg and the donor egg** are fertilized with sperm.
- The **pronuclei** (containing genetic material) are removed from both zygotes.
- The **mother's pronucleus** is transferred into the **enucleated donor zygote** (which has healthy mitochondria).
- The resulting embryo contains **parents' nuclear DNA** and **donor's mitochondrial DNA**.

2. **Maternal Spindle Transfer (MST):**

- The **spindle apparatus** (containing the mother's nuclear DNA) is removed from her egg **before fertilization**.
- It is then inserted into a **donor egg** (with healthy mitochondria) that has had its nucleus removed.
- The reconstructed egg is then **fertilized with the father's sperm**, resulting in an embryo with healthy mitochondria.



FOOD & FUEL FOR CELL

Nutrition Overview

Nutrition refers to the intake and utilization of nutrients—chemical substances essential for the growth, maintenance, and repair of cells, tissues, and organs in all living organisms. Nutrients are broadly categorized into:

- **Macronutrients** – Required in larger quantities
- **Micronutrients** – Required in trace amounts

1. Macronutrients

These are the major elements required in substantial quantities and are crucial for metabolic functions. The main macronutrients are:

A. Proteins

- Composed of long chains of **amino acids** (organic molecules made of carbon, hydrogen, nitrogen, oxygen, and sometimes sulfur).
- Functions:

- Structural support for cells and tissues
- Regulation of bodily processes (enzymes, hormones, antibodies)
- Signaling and immune responses
- **20 different amino acids** combine in specific sequences to form proteins with unique 3D structures.

- **Enzymes** are a type of protein that catalyze biochemical reactions.

Key Concepts:

AlphaFold (DeepMind AI)

- ❖ AlphaFold 2 and AlphaFold 3 are deep-learning models developed by *DeepMind* to predict 3D protein structures with high accuracy, aiding in drug development.
- ❖ **2024 Nobel Prize in Chemistry** awarded to David Baker, Demis Hassabis, and John Jumper for their contribution via AlphaFold in protein structure prediction.

HSP70 (Heat Shock Protein 70)

- ❖ A **molecular chaperone** that assists in correct protein folding and prevents misfolding during stress (heat, oxidative stress, tumors).
- ❖ Misfolded proteins are linked to diseases like **Alzheimer's, Parkinson's**, and congenital cataracts.

Recombinant Proteins (RPs)

- ❖ Proteins produced via **recombinant DNA (rDNA)** technology by inserting specific genes into organisms like *E. coli* or *Pichia pastoris (Komagataella phaffii)*.
- ❖ Applications: **Insulin, monoclonal antibodies, vaccines**

Gluten

- ❖ A protein formed from **gliadins and glutenins** when mixed with water.
- ❖ Found in **wheat, barley, rye** – gives elasticity to dough.
- ❖ Problematic in **coeliac disease** due to poor digestion by protease enzymes.

Protein-Folding Problem

- ❖ A major challenge in biology—predicting how a linear amino acid chain folds into its functional 3D shape.

B. Carbohydrates

- ❖ **Primary energy source** for the body; broken into glucose and stored as glycogen.
- ❖ Produced mainly by **plants**; composed of carbon, hydrogen, and oxygen (H:O ratio = 2:1).
- ❖ **Types:**

- **Monosaccharides** (e.g., Glucose, Fructose, Ribose)
- **Oligosaccharides** (e.g., Sucrose = Glucose + Fructose; Maltose = Glucose + Glucose; Lactose = Glucose + Galactose)
- **Polysaccharides** (e.g., Starch, Cellulose, Glycogen)
    - Long sugar chains, typically not sweet (called Non-sugars)
    - **Insulin** is a polymer of fructose

C. Fats

Fats are essential for long-term energy storage, insulation, and hormone production. They are categorized as:

Saturated Fats

- ❖ All fatty acid chains have **single bonds**, fully saturated with hydrogen.
- ❖ Found in **animal fats**, butter, red meat, palm oil.
- ❖ Solid at room temperature, associated with **high cholesterol** and **cardiovascular diseases**.

Unsaturated Fats

- ❖ Contain **one or more double bonds**, resulting in fewer hydrogen atoms.
- ❖ Found in **olive oil, nuts, seeds, fatty fish**.
- ❖ Generally considered healthier.

Trans Fats

- ❖ Artificial fats with **trans double bonds**, produced by **hydrogenation**.
- ❖ Found in **processed foods**, margarine, fried snacks.

- Increase **LDL (bad cholesterol)** and decrease **HDL (good cholesterol)**.
- Linked to **heart disease**, many countries regulate or ban them.

2. Cholesterol

Cholesterol is a **fat-like waxy substance**, vital for:

- **Cell membrane formation**
- **Hormone synthesis**
- **Vitamin D** and **bile acid** production

It is transported via **lipoproteins**:

- **HDL (High-Density Lipoprotein) – Good Cholesterol**
  - Absorbs excess cholesterol and transports it to the liver for excretion.
  - High HDL levels reduce heart disease and stroke risk.
- **LDL (Low-Density Lipoprotein) – Bad Cholesterol**
  - Deposits cholesterol in artery walls, forming plaques (**atherosclerosis**).
  - Increases risk of **heart attacks** and **strokes**.

Nutrient Disorders and Health Impacts

Nutrient	Deficiency Disorders	Overconsumption Disorders
Proteins	Kwashiorkor, Marasmus, Malnutrition	Obesity, Cardiovascular diseases, Diabetes
Carbohydrates	Fatigue, Ketosis, Weight loss	Obesity, Insulin resistance, Type 2 Diabetes
Fats	Dry skin, Hormonal imbalance	Heart disease, Stroke, Atherosclerosis
Cholesterol	Hormonal disorders	Atherosclerosis, Heart attacks, Stroke

Major Sources of Macronutrients

- **Proteins**: Legumes, fish, meat, eggs, dairy, soy, nuts, seeds
- **Carbohydrates**: Rice, wheat, potatoes, sugarcane, fruits
- **Fats**: Oilseeds, ghee, butter, nuts, oily fish, avocados
- **Cholesterol**: Animal-based foods like meat, dairy, eggs

Micronutrients

Micronutrients, also known as **trace elements**, are nutrients required by the human body in **small quantities**, typically **less than 1 mg or 1000 micrograms** per day. Despite their small required amounts, they play a crucial role in maintaining overall health, supporting **enzyme functions**, strengthening the **immune system**, and ensuring proper **growth and development**.

Key Features of Micronutrients

- Include **vitamins** and **minerals**.
- Essential for **metabolic functions**, **tissue repair**, and **disease prevention**.
- Deficiency can lead to serious health conditions such as **anemia**, **rickets**, **scurvy**, and **goiter**.
- Overconsumption may cause **toxicity** and **organ damage**.
- Found in foods like **fruits**, **vegetables**, **dairy products**, **nuts**, **seeds**, and **whole grains**.

Five Important Micronutrients

1. **Vitamin A**
2. **Folate (Vitamin B9)**
3. **Iodine**
4. **Iron**
5. **Zinc**

Types of Micronutrients

1. Vitamins

Vitamins are **organic compounds** required in small amounts for various physiological

processes. Since most vitamins are **not synthesized in sufficient amounts** by the body, they must be obtained from dietary sources. They are categorized as:

a. Fat-Soluble Vitamins

These are stored in the body's **fat tissues and liver**:

❖ **Vitamin A (Retinol)**

- *Function*: Supports **vision**, **skin health**, and **immunity**
- *Sources*: Liver, fish oils, eggs, dairy, orange/yellow fruits and vegetables (e.g., carrots, mangoes)
- *Deficiency*: **Night blindness**

❖ **Vitamin D (Calciferol)**

- *Function*: Promotes **calcium absorption** and **bone health**
- *Sources*: Sunlight, fatty fish (salmon, mackerel), egg yolks, fortified foods
- *Deficiency*: **Rickets**, **Osteomalacia**

❖ **Vitamin E (Tocopherol)**

- *Function*: Acts as an **antioxidant**, protects cells from oxidative damage
- *Sources*: Nuts, seeds, vegetable oils, spinach, avocados
- *Deficiency*: **Infertility** or reproductive issues

❖ **Vitamin K (Phytonadione)**

- *Function*: Aids in **blood clotting** and **bone metabolism**
- *Sources*: Leafy greens (spinach, kale), broccoli, soybeans
- *Deficiency*: **Impaired blood clotting**

b. Water-Soluble Vitamins

These are **not stored** in the body and must be consumed regularly:

❖ **Vitamin B-Complex:** Includes B1 (Thiamine), B2 (Riboflavin), B3 (Niacin), B5 (Pantothenic acid), B6 (Pyridoxine), B7 (Biotin), B9 (Folate), B12 (Cobalamin)

Vitamin	Functions	Sources	Deficiency
B1 (Thiamine)	Energy metabolism	Whole grains, pork, legumes	**Beriberi**
B2 (Riboflavin)	Growth & metabolism	Dairy, eggs, leafy vegetables	**Ariboflavinosis**
B3 (Niacin)	Cellular repair & metabolism	Meat, fish, whole grains, peanuts	**Pellagra**
B5 (Pantothenic acid)	Fatty acid metabolism	Whole grains, avocados, meat	**Paresthesia**
B6 (Pyridoxine)	Protein metabolism, RBC formation	Bananas, potatoes, poultry	**Anemia**
B7 (Biotin)	Enzyme functions, skin health	Eggs, nuts, seeds	**Dermatitis & Enteritis**
B9 (Folate)	DNA synthesis, cell growth	Leafy greens, citrus fruits, cereals	**Megaloblastic anemia**
B12 (Cobalamin)	Nerve function, RBC formation	Animal products, fortified foods	**Megaloblastic anemia**

❖ **Vitamin C (Ascorbic Acid)**

- *Function*: Strengthens **immunity**, acts as an **antioxidant**, helps in **tissue repair** and **collagen synthesis**
- *Sources*: Citrus fruits, strawberries, bell peppers, broccoli
- *Deficiency*: **Scurvy** (bleeding gums, poor wound healing)

2. Minerals

Minerals are **inorganic elements** essential for maintaining **health and metabolic functions**. They are broadly classified as:

a. Macrominerals

Required in larger amounts:

- **Calcium** – Bone and teeth health
- **Magnesium** – Nerve and muscle function
- **Potassium** – Fluid balance and muscle contraction
- **Sodium** – Nerve impulse transmission and fluid regulation

b. Trace (Microminerals)

Required in smaller quantities:

- **Iron** – Hemoglobin formation
- **Zinc** – Immunity, enzyme function
- **Iodine** – Thyroid hormone production
- **Copper** – Iron metabolism
- **Selenium** – Antioxidant defense
- **Manganese** – Bone formation, metabolism

Micronutrients, though needed in minute quantities, are **vital for human health and survival**. A balanced diet including diverse food sources ensures sufficient intake of both **vitamins** and **minerals**, preventing both **deficiencies** and **toxicities**.

SELF DEFENCE SYSTEM: CELL – Immune System

1. Overview of the Immune System

❖ **Definition**: Immunity refers to the body's defense mechanism against infections caused by foreign antigens such as bacteria, viruses, fungi, toxins, and other substances.

❖ **Components**: The immune system comprises lymphoid organs, tissues, immune cells (white blood cells), and soluble molecules like **antibodies** and **cytokines**.

2. Immune Cells

❖ **White Blood Cells (WBCs)**: Core components of immune responses.

- **Lymphocytes** (20–40% of WBCs): B cells and T cells.
- **Myeloid Cells**: Granulocytes and monocytes.

❖ **Production Site**: All immune cells originate in the **bone marrow**.

❖ Both **innate** and **adaptive** immunity involve granulocytes and monocytes.

3. Types of Immunity

A. Innate Immunity (Non-Specific & Inborn)

❖ Present at birth; provides immediate but general defense.

❖ **Barriers** contributing to innate immunity:

- **Physical Barriers**: Skin, mucus linings of respiratory, gastrointestinal, and urogenital tracts.
- **Physiological Barriers**: Secretions like saliva, tears, milk, and stomach acid.
- **Cellular Barriers**: Leukocytes including monocytes, neutrophils (PMNL), macrophages, and **Natural Killer (NK) cells**.
- **Cytokine Barriers**: **Interferons** secreted by virus-infected cells to protect nearby cells.

B. Acquired (Adaptive) Immunity

❖ Develops after exposure to a pathogen or antigen.

❖ **Characteristics**: Antigen-specific and has immunological memory.

❖ **Responses**:

- **Primary Response**: Initial exposure; low-intensity immune response.
- **Secondary Response**: Stronger and faster response during re-exposure due to memory cells.

Subtypes of Acquired Immunity:

❖ **Humoral Immune Response**:

- Mediated by **B-lymphocytes**.
- Involves production of **antibodies** that neutralize pathogens.

❖ **Cell-Mediated Immune Response (CMI)**:

- Mediated by **T-lymphocytes**.
- Involves recognition of antigens presented by **Antigen Presenting Cells (APCs)** using the **MHC complex**.
- **Helper T-cells (T-H)** activate **cytotoxic T-cells**, **macrophages**, and B-cells.

4. Types of Acquired Immunity

A. Active Immunity

❖ Body produces antibodies in response to antigens.

❖ **Slower onset** but long-lasting protection.

Types:

1. **Natural Active Immunity**: Gained through infection (e.g., chickenpox recovery).
2. **Artificial Active Immunity**: Gained through vaccination (e.g., COVID vaccine).

B. Passive Immunity

❖ Ready-made antibodies are introduced into the body.

❖ **Immediate** but **short-term** protection.

❖ Examples:

- ❖ Maternal antibodies (IgG) through placenta.
- ❖ Colostrum and breast milk (IgA).

5. Herd Immunity

❖ Occurs when a large portion of a population is immunized, reducing disease transmission.

❖ **Benefit**: Protects individuals who are not immune.

❖ Achieved through high **vaccination coverage** or sometimes **natural infection**.

6. Special Types of Immunity

A. Cellular Immunity (PYQ-2022)

❖ A type of **adaptive immunity** involving **T-cells**.

❖ T-cells directly destroy infected cells or activate other immune cells.

❖ Crucial against **intracellular pathogens** (viruses, some bacteria, fungi) and **cancer cells**.

B. Humoral Immunity (PYQ-2022)

❖ Mediated by **antibodies** secreted by **B-cells**.

❖ Effective against **extracellular pathogens** and toxins.

❖ Antibodies circulate in bodily fluids (humors).

7. Autoimmunity

❖ Immune system mistakenly attacks the body's own cells.

❖ Caused by failure to distinguish self from non-self.

❖ **Example**: **Rheumatoid arthritis** – immune system attacks joint tissues.

8. Hybrid Immunity

❖ Combines immunity from **natural infection** and **vaccination**.

❖ Offers stronger and broader protection.

❖ Example: Post-COVID infection followed by vaccination.

9. Antigens and Antibodies

A. Antigens

❖ Substances that trigger an immune response by stimulating antibody production.

❖ **Types**:

- **Heteroantigens**: Foreign (bacteria, viruses, venom, allergens).
- **Autoantigens**: Self-antigens; can cause **autoimmune diseases**.

B. Antibodies (Immunoglobulins - Ig)

❖ Y-shaped proteins produced by **B-cells**.

❖ Bind to specific antigens to neutralize them.

❖ Five major types:

1. IgG

❖ **Most abundant** antibody in serum.

❖ Monomer (2 antigen-binding sites).

❖ Functions:

- Secondary immune response.
- Activates complement system.
- Crosses placenta (passive immunity in newborns).
- Present in mother's milk.

2. IgM

- **First antibody** produced in primary response.
- Pentamer (binds to 5 antigens).
- Strong **complement activator**.
- Monomeric IgM also acts as a **B cell receptor (BCR)**.

3. IgA

- Exists as monomer (in blood) and dimer (secretory form).
- Found in **mucosal secretions** (saliva, tears, milk).
- Main defense at mucosal surfaces.
- Present in mother's milk – offers mucosal immunity to infants.

4. IgE

- Involved in **allergic responses**.
- Protects against **parasitic infections**.

5. IgD

- Present in small amounts in serum.
- Function not well-defined.
- Plays a role in **B-cell activation** and antigen-triggered differentiation.

Antigens vs Antibodies: A Comparative Overview

Aspect	Antigen	Antibody
Basic Definition	Also known as *immunogens*, antigens are foreign substances that trigger an immune response.	Also known as *immunoglobulins*, antibodies are proteins produced by the immune system to recognize, neutralize, or destroy antigens.
Origin	Originate outside the body (exogenous) or sometimes within (endogenous).	Produced within the body by activated B cells (plasma cells).
Production	Not produced by the body; introduced externally or arise internally due to infection, mutation, or abnormal processes.	Synthesized by plasma B cells in response to specific antigens.
Types	Exogenous, Endogenous, Autoantigens, Tumor Antigens	Five major classes: IgG, IgM, IgA, IgD, and IgE
Binding Site	Epitopes (specific regions on the antigen recognized by antibodies)	Paratopes (specific binding sites on the antibody that attach to epitopes)
Specificity	Antigens may be specific or nonspecific.	Each antibody is specific to a particular antigen or epitope.
Function	Triggers immune response; may cause disease or allergic reactions.	Neutralizes toxins, marks pathogens for destruction, activates the complement system, and aids in phagocytosis.
Location	Found on the surface of pathogens (bacteria, viruses), infected cells, or allergens.	Circulates in blood, lymph, and other bodily fluids.
Effect	May cause allergies, infections, or immune responses.	Provides immunity and defense against harmful antigens.

Monoclonal vs Polyclonal Antibodies

Feature	Monoclonal Antibodies (mAbs)	Polyclonal Antibodies
Nature	Homogeneous — identical antibodies against a single epitope	Heterogeneous — mixture of antibodies against multiple epitopes
Production	Produced from a single clone of B cells using	Produced by multiple B cell clones in

Source	**hybridoma** technology	response to an antigen
Target Specificity	Binds to a single, specific epitope	Binds to multiple epitopes on the same antigen
Production Process	Requires hybridoma cell lines	Does **not** require hybridoma technology
Applications	Disease diagnostics (e.g., ELISA), cancer therapy, autoimmune disease treatment, cell analysis (with fluorescent tags)	Widely used in immunological research, diagnostics, and some therapeutics

Immunotherapy

Definition: A medical treatment approach that modulates the immune system to fight diseases such as **cancer, autoimmune disorders, and allergies**.

Types of Immunotherapies:

- **Monoclonal Antibodies** (e.g., *Pembrolizumab – anti-PD-1*)
- **Immune Checkpoint Inhibitors**
- **Cancer Vaccines**
- **Adoptive T-cell Therapy** (e.g., CAR-T cells)
- **Cytokine Therapy**
- **Allergy Immunotherapy** (e.g., subcutaneous or sublingual)

Mechanism:

- Helps immune system recognize and eliminate **tumor cells**
- Suppresses overactive immune responses in **autoimmune diseases**
- Reduces **allergic sensitivity** by gradual exposure to allergens

Immune Imprinting (Original Antigenic Sin)

- Refers to the immune system's tendency to respond preferentially to **previously encountered variants** of a virus, rather than adapting to new ones.
- Commonly observed in **influenza** and **SARS-CoV-2**.
- Can reduce **vaccine effectiveness** as the immune system favors memory responses over generating **new, tailored antibodies**.
- Important consideration in **vaccine development** and booster strategies.

Allergies

- An **exaggerated immune reaction** to environmental antigens (*allergens*) like pollen, dust mites, or pet dander.
- Involves **IgE antibodies**, which trigger mast cells to release **histamine and serotonin**.
- Symptoms: sneezing, itchy eyes, nasal congestion, skin rashes, breathing issues.
- **Diagnosis**: Allergy testing via controlled exposure to suspected allergens.
- **Treatment**: Antihistamines, corticosteroids, adrenaline (in severe cases like anaphylaxis).

Blood and Its Components

1. Blood

- A fluid **connective tissue** composed of:
  - **55% Plasma**
  - **45% Formed elements** (RBCs, WBCs, Platelets)
- Transports **nutrients, gases, waste products**.
- **Average volume**: ~5 liters in a healthy adult.

2. Plasma

- **Straw-colored**, viscous fluid (90–92% water)
- Contains:
  - **Proteins**: Fibrinogen (clotting), Globulins (immunity), Albumins (osmotic pressure)

- **Electrolytes**: Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-
- **Nutrients**: Glucose, amino acids, lipids
- **Serum**: Plasma without clotting factors

3. Platelets (Thrombocytes)

- ❖ **Cell fragments** from **megakaryocytes** (bone marrow)
- ❖ Involved in **blood clotting**
- ❖ Low count leads to **clotting disorders**

4. Red Blood Cells (RBCs or Erythrocytes)

- ❖ Most **abundant** blood cells
- ❖ **Biconcave, enucleated** in mammals
- ❖ Contain **haemoglobin**: transports oxygen
- ❖ **Lifespan**: ~120 days; destroyed in spleen ("graveyard of RBCs")

5. White Blood Cells (WBCs or Leucocytes)

- ❖ **Nucleated, colorless**, and fewer than RBCs
- ❖ Types:
- **Granulocytes**: Neutrophils (60–65%), Eosinophils (2–3%), Basophils (0.5–1%)
- **Agranulocytes**: Lymphocytes (20–25%), Monocytes (6–8%)

WBC Roles:

- ❖ **Neutrophils**: First responders; phagocytic
- ❖ **Basophils**: Inflammatory mediators
- ❖ **Eosinophils**: Fight parasites, mediate allergies
- ❖ **Lymphocytes**:
  - **B Cells**: Produce antibodies
  - **T Cells**: Cell-mediated immunity
- ❖ **Monocytes/Macrophages**: Phagocytosis, antigen presentation

T Cells vs B Cells

Feature	T Cells (Thymocytes)	B Cells (B Lymphocytes)
Origin	Originate in bone marrow, **mature in the thymus**	Originate and **mature in the bone marrow**
Function	Directly attack infected cells, regulate immune responses	Produce specific antibodies to neutralize antigens
Types	Cytotoxic T cells (kill infected cells), Helper T cells (coordinate immune response)	Plasma cells (antibody-producing), Memory B cells (long-term immunity)
Mode of Action	**Cell-mediated immunity** (direct killing)	**Humoral immunity** (antibody secretion in blood and lymph)
Antigen Recognition	Recognize antigens only when presented by **APCs** (Antigen-Presenting Cells)	Recognize and bind **directly** to antigens in body fluids
Memory Function	Forms **memory T cells** for quicker future responses	Forms **memory B cells** for faster antibody production upon reinfection

Blood Groups and Donor Compatibility

1. Basic Concept

Blood groups are classified based on inherited differences in **antigens present on the surface of red blood cells (RBCs or erythrocytes)**. These surface antigens, also called **agglutinogens**, are genetically determined and vary among human populations.

- ❖ The **name of a blood group** is based on the specific **antigen** present on the RBC surface.
- ❖ Each blood group contains **antibodies in the plasma** that can attack the antigens not present on their own RBCs.

2. ABO Blood Group System

The **ABO system** is based on the **presence or absence of two surface antigens**, **A and B**, on red blood cells. It also involves natural

antibodies in the plasma that react against foreign antigens.

- ❖ This system was first identified by **Karl Landsteiner** in **1901**.
- ❖ There are four major blood groups in the ABO system:

Blood Group	Antigen on RBCs	Antibodies in Plasma	Can Receive Blood From
A	A	Anti–B	A, O
B	B	Anti–A	B, O
AB (Universal Recipient)	A, B	None	AB, A, B, O
O (Universal Donor)	None	Anti–A, Anti–B	O

3. Rh Blood Group System

In addition to the ABO system, the **Rh factor** is another important antigen found on the surface of red blood cells.

- ❖ **Rh-positive (Rh^+)**: Presence of Rh antigen on RBCs.
- ❖ **Rh-negative (Rh^-)**: Absence of Rh antigen; such individuals may produce **anti-Rh antibodies** if exposed to Rh-positive blood.

Approximately **two-thirds** of the population is **Rh-positive**. Rh compatibility is crucial during **blood transfusions and pregnancy**.

4. Bombay Blood Group (hh Phenotype)

- ❖ Also known as the **hh blood group**, it is an **extremely rare** blood type that lacks the **H antigen**, a precursor required for the expression of A and B antigens.
- ❖ Unlike the O group (which lacks A and B antigens but **has H antigen**), the hh group **lacks even the H antigen**.
- ❖ As a result, individuals with Bombay blood group:
  - **Cannot receive blood from any ABO blood group**, including O.
  - **Can only receive blood from another Bombay (hh) individual**.
  - **Can donate to individuals with A, B, AB, or O blood groups** if Rh compatibility is ensured.

Key Facts:

- ❖ Discovered in **1952** in **Mumbai (then Bombay)** by **Dr. Y. M. Bhende**.
- ❖ More prevalent in **South Asia**, especially in populations with **inbreeding or close-community marriages**.
- ❖ **Prevalence**:
  - **India**: ~1 in 7,600 to 10,000 individuals.
  - **Globally**: ~1 in 4 million.

Understanding blood group systems, especially **ABO**, **Rh**, and **Bombay**, is essential for **safe blood transfusions**, **organ transplantation**, and **maternal-fetal medicine**. Proper compatibility prevents immune reactions that can be life-threatening.

Inducing Immune Response in Cells – Vaccines

1. Basics of Vaccination and Immunization

- ❖ **Vaccination** and **immunization** are based on the immune system's ability to **remember** and **recognize pathogens**.
- ❖ Vaccines introduce **antigenic proteins** or **weakened/inactivated pathogens** into the body to stimulate **antibody production**.
- ❖ This leads to the formation of **memory B cells and T cells**, ensuring a **faster and stronger immune response** upon future exposure.
- ❖ In cases requiring an immediate immune response, **preformed antibodies or antitoxins** are injected – a process known

as **passive immunization** (e.g., for **tetanus** or **snakebites**).

- **Recombinant DNA technology** has enabled the **large-scale production** of vaccines by engineering **antigenic polypeptides** in **bacteria or yeast** (e.g., **hepatitis B vaccine** from yeast).

2. Types of Vaccines

a. Inactivated Vaccines

- Contain pathogens that have been **killed** using **heat** or **chemical agents** like formaldehyde.
- These pathogens **cannot replicate** but retain their **structure** to trigger an immune response.
- Generate a **weaker immune response** than live vaccines; thus, **multiple doses or boosters** are required.
- Used against diseases like:
    - **Hepatitis A**
    - **Influenza** (injection form)
    - **Polio** (injection form)
    - **Rabies**

b. Live-Attenuated Vaccines

- Contain **weakened** but **living** forms of the pathogen.
- Mimic a **natural infection**, thereby producing a **strong, long-lasting** immune response.
- **Not suitable** for individuals with **weakened immune systems**.
- Provide protection against:
    - **Measles, Mumps, Rubella (MMR)**
    - **Rotavirus**
    - **Smallpox**

c. Subunit, Recombinant, Polysaccharide, and Conjugate Vaccines

- Use **specific parts** of the pathogen (e.g., **proteins, sugars**, or **capsid structures**).
- Induce a **strong immune response** and are **safe for immunocompromised individuals**.
- Often used to prevent:
    - **Haemophilus influenzae type b (Hib)**
    - **Hepatitis B**
    - **Human papillomavirus (HPV)**
    - **Pneumococcal disease**

d. Messenger RNA (mRNA) Vaccines

- Deliver **messenger RNA (mRNA)** instructions to host cells to **produce a protein** from the pathogen.
- The cells produce the protein, which triggers an **immune response**.
- The immune system **learns to recognize and fight** the actual pathogen in future encounters.
- Example: **mRNA-based COVID-19 vaccines**.

e. Viral Vector Vaccines

- Use a **modified virus (vector)** to deliver **genetic material** encoding antigens of the target pathogen.
- Common vectors include **adenovirus**, **measles virus**, **vesicular stomatitis virus (VSV)**.
- These vectors **do not cause disease** themselves but serve to introduce the pathogen's genes.
- Used in some **COVID-19 vaccines**, such as those using **adenovirus-based vectors**.

3. Adjuvants

- **Adjuvants** are substances added to vaccines to **enhance the body's immune response** to the antigen.
- They help:
    - Improve **recognition** of the vaccine by the immune system.

- Increase **duration** and **strength** of immunity.

❖ Example: **Matrix-M** adjuvant

- Derived from **saponins**, compounds found in the **bark of the Quillaja saponaria tree** in Chile.
- Known for their **medicinal use** and immune-enhancing properties.

HEALTH → DISEASES (ATTACK ON CELLS)

1. Pathogens: The Cause of Diseases

Pathogens are microorganisms that cause diseases in plants and animals. Most are **parasites** that harm their host. The primary categories include:

❖ **Bacteria**: Prokaryotic microorganisms capable of producing toxins and triggering strong immune responses. *Example: Streptococcus* species cause strep throat.

❖ **Viruses**: Acellular, obligate intracellular parasites that can replicate only inside a host cell. *Example:* Influenza virus causes seasonal flu.

❖ **Fungi** *(PYQ 2021)*: Eukaryotic organisms that absorb nutrients from their environment. *Example: Candida* species cause opportunistic infections.

❖ **Protozoans**: Unicellular eukaryotes, either free-living or parasitic. *Example: Plasmodium*, which causes malaria and is transmitted by mosquitoes.

❖ **Helminths**: Multicellular parasitic worms visible to the naked eye that live in the human body. *Example:* Tapeworms that inhabit the gastrointestinal tract.

2. Comparison: Bacteria vs Fungi vs Viruses

Feature	Bacteria	Fungi	Viruses
Cell Type	Prokaryotic (no nucleus)	Eukaryotic (nucleus present)	Acellular (not a true cell)
Structure	Single-celled with peptidoglycan cell wall	Uni-/Multicellular with chitin cell wall	Protein coat (capsid) + genetic material
Size	0.1–5 µm	2 µm to several cm	20–300 nm
Reproduction	Asexual (Binary fission)	Asexual (spores), Sexual (some)	Replicates only inside host
Metabolism	Independent metabolism	Own metabolism (saprophytic/parasitic/symbiotic)	No metabolism; depends on host
Genetic Material	Both DNA and RNA	DNA (linear chromosomes)	Either DNA or RNA (not both)
Living Status	Living	Living	Non-living outside host
Mode of Nutrition	Autotrophic or Heterotrophic	Heterotrophic	Obligate parasite
Infection Mode	Contact, air, water, food	Spores, contact, air	Droplets, host invasion, vectors
Importance	Decomposers, nitrogen fixation, biotech	Antibiotics (Penicillin), decomposers	Vaccines, gene therapy
Diseases	TB, Cholera, Typhoid	Ringworm, Candidiasis	Flu, HIV, COVID-19

Caused			
Examples	*E. coli, Streptococcus*	*Aspergillus, Penicillium*	*Influenza virus, HIV, SARS-CoV-2*

3. Major Bacterial Diseases

Disease	Causative Agent	Transmission	Affected System	Treatment & Prevention	Key Features
Shigellosis	*Shigella* spp.	Contaminated food/water, fecal-oral, sexual contact	Digestive System	No vaccine, symptomatic treatment	Common in children under 5
Syphilis	*Treponema pallidum*	Sexual contact, mother-to-child	Reproductive & Nervous Systems	Penicillin; no vaccine	Progressive stages, congenital risk
Salmonellosis	*Salmonella* spp.	Food/water contamination, person-to-person contact	Digestive System	Self-limiting; antibiotics in severe cases	Multiple transmission routes
Typhoid	*Salmonella Typhi*	Fecal-oral route	Intestinal Tract & Circulatory System	Vaccine (oral/injectable), antibiotics, hygiene	Human carriers only
Klebsiella Pneumonia	*Klebsiella pneumoniae*	Human waste, GIT, respiratory secretions	Respiratory & Urinary Systems	Antibiotics	Friedlander's pneumonia
Cholera	*Vibrio cholerae*	Contaminated food/water	Small Intestine	Oral vaccine (Dukoral, Shanchol), ORS	Endemic in Asia & Africa
Diphtheria *(PYQ)*	*Corynebacterium diphtheriae*	Respiratory droplets	Respiratory System	DPT vaccine, antibiotics (azithromycin, erythromycin)	Vaccine-preventable
Trachoma	*Chlamydia trachomatis*	Eye, nose, throat secretions	Eyes	SAFE strategy (Surgery, Antibiotics, Facial hygiene, Environment)	Leading cause of preventable blindness
Tuberculosis (TB)	*Mycobacterium tuberculosis*	Airborne (droplets)	Lungs (also other organs)	BCG vaccine, antibiotics (Rifampicin, Isoniazid)	India among worst-affected countries

Extrapulmonary TB	*Mycobacterium tuberculosis*	Same as pulmonary TB	Brain, bones, lymph, kidneys, etc.	CBNAAT (PCR test), TB drugs	Common in HIV patients
Leprosy (Hansen's)	*Mycobacterium leprae*	Respiratory droplets	Skin, nerves, eyes, respiratory tract	Multi-Drug Therapy (MDT)	India: 50%+ of global cases
Meningitis	*N. meningitidis, S. pneumoniae*	Respiratory droplets	Brain & spinal cord	Vaccines (Meningococcal, Hib, Pneumococcal)	Can be bacterial or viral

4. Bacterial Sexually Transmitted Diseases (STDs)

Disease	Pathogen	Transmission	Affected System	Treatment	Key Notes
Gonorrhea	*Neisseria gonorrhoeae*	Sexual contact	Reproductive & Urinary Tract	Antibiotics (ceftriaxone); safe sex	More common in women, highly contagious
Syphilis	*Treponema pallidum*	Sexual contact, mother-to-child, contact	Systemic: circulatory, skin, nervous	Penicillin; early diagnosis crucial	Serious late-stage complications

Fungal Diseases

Fungal infections range from mild skin conditions to serious systemic diseases. They are caused by various species of fungi and may affect different parts of the body, especially in individuals with weakened immunity or pre-existing conditions.

1. Chronic Pulmonary Aspergillosis (CPA)

- **Causative Agent:** *Aspergillus fumigatus* (airborne fungal spores)
- **Transmission:** Inhalation of spores (non-contagious)
- **Affected System:** Lungs (Respiratory System)
- **Treatment & Prevention:** Antifungal therapy with **Itraconazole** or **Voriconazole**
- **Key Features:**
  - More common in patients with a history of tuberculosis (TB)
  - Higher incidence reported in **Assam, India**

2. Trichophyton Indotineae Infection

- **Causative Agent:** *Trichophyton indotineae*
- **Transmission:** Skin-to-skin contact; exacerbated by misuse of topical steroid creams
- **Affected System:** Skin (Dermatophytosis)
- **Treatment & Prevention:**
  - Often **resistant to Terbinafine**
  - Requires alternative antifungal medications
- **Key Features:**
  - An **emerging drug-resistant fungal infection**

- Increasingly reported across **India**

3. Athlete's Foot (Tinea Pedis)

- **Causative Agent:** *Trichophyton* species
- **Transmission:** Direct contact with infected surfaces such as floors, socks, or shoes
- **Affected System:** Skin (especially feet)
- **Treatment & Prevention:**
  - Topical antifungal agents such as **Miconazole** or **Clotrimazole**
  - Keep feet dry and wear breathable footwear
- **Key Features:**
  - Thrives in **warm, moist environments** inside shoes
  - Common in athletes and people with sweaty feet

4. Ringworm (Tinea Corporis)

- **Causative Agent:** Dermatophyte fungi (*Trichophyton*, *Microsporum*, *Epidermophyton*)
- **Transmission:**
  - Skin-to-skin contact
  - Contact with contaminated surfaces or infected animals
- **Affected System:** Skin, hair, and nails
- **Treatment & Prevention:**
  - Use of antifungal creams
  - Maintain proper hygiene and avoid sharing personal items
- **Key Features:**
  - **Highly contagious**
  - Causes characteristic **ring-shaped red rashes**

5. Jock Itch (Tinea Cruris)

- **Causative Agent:** *Tinea* fungi
- **Transmission:**
  - Direct contact
  - Favors **warm, humid areas**, such as groin and inner thighs
- **Affected System:** Skin (Groin, Thighs, Buttocks)
- **Treatment & Prevention:**
  - Antifungal creams
  - Keep the affected areas dry and clean
- **Key Features:**
  - Common among **athletes**
  - Worsens with excessive **sweating and tight clothing**

6. Black Fungus (Mucormycosis)

- **Causative Agent:** *Mucormycetes* (a group of molds)
- **Transmission:** Inhalation of spores (non-contagious)
- **Affected System:** Sinuses, lungs, brain
- **Treatment & Prevention:**
  - Prompt administration of antifungal medication, especially **Amphotericin B**
  - Early diagnosis and surgical debridement if necessary
- **Key Features:**
  - Associated with **weakened immunity**, especially in diabetic or post-COVID patients
  - **High mortality rate** if untreated or diagnosed late

Viral Diseases

(Important for UPSC – PYQs: 2021, 2016, 2013, 2014, 2019)

Introduction to Viruses

- A virus is a nucleic acid molecule (DNA or RNA) enclosed within a protein coat called a **capsid**.
- It is **not a complete cell** and can only replicate inside a living host cell (bacteria, fungi, plants, animals, humans).
- The **capsid** may have an **outer lipid envelope**, which helps in attachment and

penetration into host cells and often carries **virulence factors**.

- ❖ **Viral replication** occurs by hijacking the host cell's molecular machinery.

Types of Viruses

1. **DNA Viruses**
    - Mostly double-stranded DNA (dsDNA); some have single-stranded DNA (ssDNA).
    - Use **DNA-dependent DNA polymerase** for replication.
2. **RNA Viruses**
    - Generally have **single-stranded RNA (ssRNA)**; some may contain double-stranded RNA (dsRNA).
3. **Retroviruses**
    - Contain **single-stranded RNA**, but replicate via a **DNA intermediate** using **reverse transcriptase**.
    - Example: **HIV** (PYQ-2021).

RNA Virus vs Retrovirus (PYQ-2021):

- ❖ RNA viruses use RNA as genetic material directly.
- ❖ Retroviruses transcribe their RNA into DNA during replication.

List of Key Viral Diseases

Disease	Virus Type & Family	Transmission	Affected System	Treatment & Prevention	Key Facts
Marburg Virus Disease (MVD)	RNA Virus (Filoviridae)	Fruit bats to humans, human-to-human	Multiple organs (Hemorrhagic fever)	No vaccine or antiviral	Highly virulent; first outbreak in Germany & Serbia (1967)
Norovirus	RNA Virus (Caliciviridae)	Contaminated food, water (oral-fecal)	Gastrointestinal	No vaccine; supportive care	"Winter vomiting bug", resistant to heat (up to 60°C)
Chandipura Virus	RNA Virus (Rhabdoviridae)	Sandflies, mosquitoes	Nervous system	No antiviral or vaccine	Endemic to Central India; affects children
Nipah Virus	RNA Virus (Paramyxoviridae)	Fruit bats, animals, person-to-person	Brain (Encephalitis), Respiratory	No vaccine; supportive care	First outbreak: Malaysia (1999), BSL-4 pathogen, Kerala outbreaks
Chikungunya *(PYQ-2013)*	RNA Virus (Togaviridae)	Aedes mosquitoes	Joints (Arthralgia), Fever	No cure; vector control	First identified in Tanzania (1952); part of India's VB disease program
Hepatitis (A–G) *(PYQ-2019, 2013)*	RNA (except B = DNA)	A, E: fecal-oral; B, C, D, G: blood, body fluids	Liver	Vaccines for A & B, antivirals for B & C	Affects liver; HEV severe in pregnant women
Hepatitis E Virus (HEV)	RNA Virus (Hepeviridae)	Contaminated water/food	Liver	Vaccine (Hecolin) in	4 genotypes; zoonotic;

(PYQ-2019)				China; not globally available	Rocahepevirus Ratti in rats
Rabies	RNA Virus	Animal bites, saliva	CNS (Brain & Spinal cord)	100% vaccine-preventable (PEP + vaccine + HRIG)	100% fatal post symptoms; 33% deaths in India; ABC (Dogs) Rules, 2023
H5N1 Avian Influenza	RNA Virus (Influenza A, HPAI)	Infected birds/poultry	Respiratory	Supportive care; antivirals (oseltamivir)	2024 U.S. cattle outbreak; panzootic virus
West Nile Fever	RNA Virus (Flaviviridae)	Culex mosquito bites	Nervous system	Supportive care	Found in Africa, West Asia, North America
Mpox (Monkeypox)	DNA Virus (Poxviridae)	Contact with lesions, fluids, droplets	Skin, Respiratory	Vaccines (JYNNEOS), antivirals (Tecovirimat)	Not related to chickenpox; Public Health Emergency by WHO
Chickenpox *(PYQ-2014)*	DNA Virus (Varicella Zoster)	Airborne, direct contact	Skin	Vaccine (Varicella)	Highly contagious skin rash
Smallpox *(PYQ-2014)*	DNA Virus (Variola)	Droplet, close contact	Skin, Respiratory	Eradicated by vaccination	First disease eradicated globally (WHO, 1980)
Oropouche Virus	RNA Virus (Arbovirus)	Midges, Culex mosquitoes	Multi-organ, Neuro	No treatment; supportive care	Endemic to Amazon; 2024 outbreak in South America
HIV/AIDS *(PYQ-2019, 2013)*	Retrovirus	Unprotected sex, needles, mother-to-child	Immune (CD4+ cells)	ART, HAART (cocktail therapy)	Causes AIDS; discovered by Luc Montagnier (Nobel 2008)
Cervical Cancer	Associated with HPV	High-risk HPV (16, 18); sexually transmitted	Reproductive (Cervix)	HPV vaccines (Cervavac, Gardasil)	2nd most common cancer in Indian women
HPV Infections	DNA Virus (HPV types)	Sexual, skin-to-skin	Skin, Genitals, Throat	Vaccines; no treatment for virus	Over 200 strains; only high-risk types cause cancer
Ebola	RNA Virus	Body fluids,	Multiple	Experimental	First outbreak in

	(Filoviridae)	animal contact	organs (Hemorrhagic fever)	vaccines; ELISA/RT-PCR for diagnosis	DR Congo & Sudan (1976)
Polio	RNA Virus (Poliovirus types 1–3)	Fecal-oral route, person-to-person	Nervous system (Paralysis)	Oral/Injectable Polio Vaccine	India polio-free (WHO, 2014); WPV2/3 eradicated
Influenza (Flu)	RNA Virus (Types A, B, C)	Airborne, contact	Respiratory	Annual flu shot; supportive care	A causes pandemics; B affects humans only
Dengue	RNA Virus (Flavivirus)	Aedes aegypti mosquito	Immune, Vascular	No cure; supportive care (no NSAIDs)	"Breakbone fever"; uses Wolbachia & Guppy fish for control
Zika Virus	RNA Virus (Flaviviridae)	Mosquitoes, sexual, transplacental	Nervous, Fetal Dev.	No treatment; vector control	Linked to microcephaly; major outbreaks in Americas
Japanese Encephalitis (JE)	RNA Virus (Flavivirus)	Culex mosquito	CNS (Brain)	No antivirals; supportive care	Children most affected; humans are dead-end hosts

PARASITIC DISEASES

Definition: Parasitic diseases are caused by organisms such as **protozoa**, **helminths**, and **arthropods** that live on or inside a host and derive nutrients at the host's expense.

Classification:

- **Protozoa**: Unicellular organisms like *Giardia*, *Trichomonas* (flagellates), and *Entamoeba* (amoebae) causing enteric and gynecological disorders.
- **Helminths**: Multicellular parasitic worms that infest human hosts.
- **Arthropods**: Lice, fleas, sandflies, blackflies, and ticks — often act as vectors for parasitic diseases.

Key Parasitic Diseases:

Disease	Causative Agent	Transmission	Affected System	Treatment & Prevention	Key Features
Primary Amoebic Meningoencephalitis (PAM)	*Naegleria fowleri* (free-living amoeba)	Contaminated warm freshwater entering the nose (not	Central Nervous System (Brain & Spinal Cord)	No standard treatment; experimental drugs used	Rare but almost always fatal (survival rate ~3%); found in poorly

		person-to-person)			maintained pools, hot tubs
Malaria	*Plasmodium* spp. (*P. falciparum*, *P. vivax*)	Bite of female *Anopheles* mosquito	Blood, Liver	ACTs (Artemisinin-Based Combination Therapies), Mosquirix & R21/Matrix-M vaccines	High burden in Odisha, Chhattisgarh, NE India; India aims malaria-free by 2027; MERA-India (ICMR), E-2025 initiative
Scabies	*Sarcoptes scabiei* (mite)	Direct skin contact or contaminated clothing	Skin	Permethrin, Ivermectin	Declared neglected skin disease by WHO (2009)
Diarrhoea (Parasitic)	*Entamoeba histolytica* (among others)	Fecal-oral route, contaminated water	Intestines	ORS, zinc, nutrient-rich diet	Major waterborne disease; causes dehydration, blood loss
Kala-azar (Visceral Leishmaniasis)	*Leishmania donovani* (protozoa)	Bite of female *Phlebotomine* sandfly	Reticuloendothelial System (bone marrow, spleen, liver)	Curable with antiparasitic drugs	Known as "Black Fever"; 2nd deadliest parasitic disease in India; 70% cases in Bihar; elimination goal: 2030

NON-COMMUNICABLE DISEASES (NCDs)

Definition: NCDs are chronic diseases not spread from person to person. They result from a combination of genetic, physiological, environmental, and behavioral factors.

Key Non-Communicable Diseases:

Disorder	Cause	Type	Affected System	Treatment & Management	Key Features
Kawasaki Disease	Unknown; possible autoimmune response	Autoimmune, inflammatory	Cardiovascular, immune	IVIG, aspirin, corticosteroids	Affects children <5 years; major cause of pediatric heart disease

Nephrotic Syndrome	Kidney damage due to infection/drugs	Kidney disorder	Renal, urinary system	Steroids, diuretics, BP control, diet	Linked to skin-lightening cream misuse (notably in Kerala)
Thrombosis (VITT/TTS)	Autoimmune response post-vaccine (e.g., AstraZeneca)	Hematological	Blood & circulatory system	Anticoagulants (non-heparin), IVIG, platelet transfusion	Rare but serious; also called Vaccine-Induced Thrombotic Thrombocytopenia
Anosmia	Viral infections (e.g., COVID-19), nasal blockage, nerve damage	Neurological	Olfactory pathway, nervous system	Nasal steroids, smell training, treat underlying cause	Temporary or permanent loss of smell; differs from hyposmia (partial loss)
Inflammatory Bowel Disease (IBD)	Autoimmune attack on gut lining	Autoimmune, inflammatory	Digestive & immune system	Immunosuppressants, biologics, Crohn's Diet	Includes Crohn's Disease and Ulcerative Colitis
Fatty Liver Disease (MASLD)	Excessive sugar/carbs; linked to metabolic dysfunction	Metabolic, liver	Liver, metabolic system	Lifestyle change, weight loss, dietary interventions	Now termed MASLD (Metabolic Dysfunction-Associated Steatotic Liver Disease)
Dementia	Neurodegeneration (e.g., Alzheimer's)	Neurological, cognitive	Brain, nervous system	Supportive care, cognitive therapy	WHO Global Action Plan (2017–2025); ADI seeks 10-year extension
Osteoporosis	Aging, estrogen loss, reduced bone density	Skeletal, metabolic	Musculoskeletal system	Calcium, Vitamin D, exercise, medication	Silent until fractures occur; affects postmenopausal women more
Obstructive Sleep Apnea (OSA)	Blocked airway during sleep	Sleep-related	Respiratory, nervous system	CPAP, weight loss, lifestyle changes	Linked to dementia risk, especially in women
Thrombotic Thrombocytopenic Purpura (TTP)	Deficiency of ADAMTS13 enzyme	Hematological	Circulatory, blood system	Plasma exchange, medications	Rare but life-threatening; linked to COVID vaccine autoimmunity
Snakebite	Toxic venom	Toxic, NTD	Circulator	Antivenom,	India has highest

Envenomation	from snakebite	(Neglected Tropical Disease)	y, nervous system	supportive care	global deaths; 90% by 'Big Four' snakes; notifiable in Tamil Nadu

Nutritional Diseases

Nutritional diseases result from deficiencies or imbalances in the intake of essential nutrients. These disorders impair the body's normal functions and can affect growth, immunity, and metabolism.

Key Nutritional Disorders:

- **Ketosis:** Caused by prolonged deficiency of carbohydrates, leading to excess ketone body production. It is often identified by a characteristic sweet or fruity odor in the patient's breath.
- **Protein-Energy Malnutrition (PEM):** Common in developing countries due to inadequate intake of both protein and calories. Two major types include:
  - **Marasmus:** Caused by total calorie and protein deficiency.
    Features: Severe wasting, underweight appearance, almost no subcutaneous fat — skin and bones appearance.
  - **Kwashiorkor:** Caused by severe protein deficiency, usually after weaning.
    Features: Swollen belly due to edema, hypoproteinemia, suppressed insulin production, immune deficiency, and diarrhea.

Vitamin and Mineral Deficiency Disorders

Disease	Deficiency	Common Sources	PYQ Mention
Rickets	Vitamin D	Dairy products, fish, sunlight	Yes (2014)
Pellagra	Vitamin B3 (Niacin)	Tuna, peanuts, mushrooms, chicken	
Scurvy	Vitamin C	Citrus fruits, broccoli	Yes (2014)
Beri-Beri	Vitamin B1 (Thiamine)	Meat, eggs, legumes	
Night Blindness	Vitamin A	Carrots, green leafy vegetables	
Goitre	Iodine	Iodized salt, sea fish	
Anaemia	Iron	Nuts, tofu, bran, squash	
Reduced Reflexes	Vitamin E	Wheat germ oil	Yes (2014)
Coagulation Disorders	Vitamin K	Green leafy vegetables (kale, spinach), soybeans	

Genetic Disorders: These diseases are caused by abnormalities in genes or chromosomes and may be inherited or arise spontaneously.

Disorder	Cause	Type	Symptoms	Treatment	Key Facts
Edwards Syndrome	Trisomy 18 (extra chromosome 18)	Chromosomal Anomaly	Growth delay, severe developmental problems	Supportive care only	Rare, often fatal in infancy
Spinal	Mutation in SMN1	Motor Neuron	Muscle weakness,	Risdiplam,	5 types based

Muscular Atrophy (SMA)	gene	Disease	loss of motor neurons	Zolgensma (FDA-approved)	on onset and severity
Down Syndrome	Trisomy 21 (extra chromosome 21)	Chromosomal Anomaly	Intellectual disability, facial features, heart defects	Supportive therapy, early intervention	Most common chromosomal disorder
Turner's Syndrome	Missing/abnormal X chromosome (females)	Chromosomal Anomaly	Short stature, infertility, cardiac anomalies	Hormone and fertility therapies	Affects only females
Klinefelter's Syndrome	Extra X chromosome (XXY, males)	Chromosomal Anomaly	Long limbs, small testes, gynecomastia	Testosterone, fertility treatments	Common cause of male infertility
Thalassemia	Mutation in hemoglobin gene	Blood Disorder	Severe anemia, fatigue, organ damage	Blood transfusions, iron chelation therapy	India has highest global burden
Sickle Cell Anaemia	Mutation in HBB gene (Hemoglobin S)	Blood Disorder	Sickle-shaped RBCs, organ damage, severe pain	Bone marrow transplant, hydroxyurea, gene therapy	Gene therapy approved in UK
Hemophilia A	Deficiency of clotting factor VIII (X-linked)	Blood Disorder	Prolonged bleeding, joint damage	Factor VIII replacement therapy	More common in males
Bubble Baby Syndrome (SCID)	T-cell and B-cell immune deficiency	Immunodeficiency Disorder	Severe infection risk, failure to thrive	Stem cell (bone marrow) transplant	Infants require sterile environments

Rare Diseases

- **Definition:** Diseases that affect fewer than 1 in 1,000 people, often chronic, debilitating, and life-threatening.
- **Alternate Name:** Orphan Diseases
- **National Policy:** As per **National Policy for Rare Diseases (NPRD) 2021**, diseases are classified into three groups:
  - **Group 1:** Curable with one-time treatment (e.g., Urea cycle disorders, Fabry disease)
  - **Group 2:** Require long-term, cost-effective treatment (e.g., Phenylketonuria, Homocystinuria)
  - **Group 3:** Require lifelong high-cost treatment (e.g., Gaucher Disease, Pompe Disease)

- **Other Examples:** Cystic fibrosis, Lou Gehrig's disease, Tourette's syndrome, Duncan's Syndrome, Madelung's disease, Acromegaly
- **Orphan Drugs:** Specially developed drugs for treatment of rare diseases. *Recent Development:* CDSCO (India) approved the first **anti-complement therapy** for rare diseases.

Neglected Tropical Diseases (NTDs)

- **Definition:** A group of infectious diseases prevalent in tropical regions, mainly affecting impoverished populations.
- **Causing Agents:** Viruses, bacteria, protozoa, and helminths.
- **Global Impact:** India bears the highest **absolute burden of at least 11 major NTDs** (as of 2018).
- **India's Successes:** Elimination of **guinea worm disease**, **trachoma**, and **yaws**.
- **Key Fact: World Neglected Tropical Diseases Day** is observed on **January 30** every year by WHO.