ONLYIAS BY PHYSICS WALLAH

UDAAN

PRELIMS WALLAH (STATIC)

PRELIMS 2025

SCIENCE & TECHNOLOGY

QUICK AND COMPREHENSIVE REVISION SERIES

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The publication has designed the content to provide accurate and authoritative information with regard to the subject matter covered.

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PREFACE

A highly skilled professional team of PW ONLY IAS works arduously to ensure that the students receive the best content for the UPSC exam.

A plethora of UPSC study materials are available in the market, but PW ONLY IAS professionals continuously work to provide supreme-quality study material for our UPSC students.

From the beginning, the whole content team comprising Content Creators, Reviewers, DTP operators, Proofreaders and others are involved in shaping the material to their best knowledge and experience to produce powerful content for the students.

Faculties have adopted a new style of presenting the content in easy-to-understand language and have provided the team with guidance and supervision throughout the creation of this book.

PW ONLY IAS strongly believes in conceptual and fun-based learning and provide highly exam-oriented content to bring quality and clarity to the students.

This book adopts a multi-faceted approach to mastering and understanding the concepts and equipping the students with the knowledge for this competitive exam.

The main objective of the study material is to provide short, crisp, concise and high-quality content to our students.

BOOK FEATURES

- Holistic coverage of topics, strictly as per exam syllabus.
- One-stop solution for prelims based, subject-wise coverage.
- Diagrams and timelines for quick understanding and revision.
- Quick revision module for the UPSC prelims examination.
- Every topic is structured in headings and bullets for easy understanding of the students.

CONTENTS

1 General Physics and Everyday Chemistry

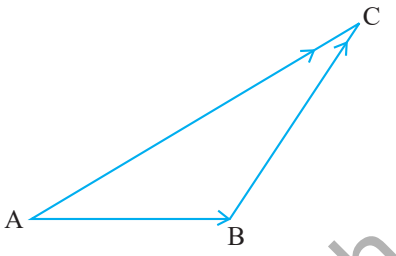
GENERAL PHYSICS

MECHANICS

Scalar and Vector Quantities

- **Scalar:** Has only magnitude (size).
  - **Examples:** Distance (5 m), Speed (60 km/h), Mass (10 kg).
- **Vector:** Has both magnitude and direction.
  - Vectors follow **Triangle law of addition.**
    A vector simply means the displacement from a point A to the point B. Now consider a situation that a girl moves from A to B and then from B to C. The net displacement made by the girl from point A to the point C, is given by the vector and expressed as

$$\overline{AC} = \overline{AB} + \overline{BC}$$



This is known as the triangle law of vector addition.
  - **Examples:** Displacement (5 m east), Velocity (60 km/h north), Force (10 N downward).

Some Key Terms

Velocity

- Velocity is a vector quantity that represents the rate of change of an object's position with respect to time in a specific direction. It tells both how fast an object is moving (speed) and in which direction.
- $v = \Delta s/\Delta t$, Where: v = velocity, Δs = displacement (change in position), Δt = time interval
- Velocity differs from speed because it includes direction, making it a vector quantity.

Acceleration

- It is defined as the rate of change of velocity with respect to time.
- $a = \Delta v/\Delta t$, where: a = acceleration, Δv = change in velocity, Δt = time interval

Momentum [UPSC 1997, 2000]

- Momentum is a vector quantity that represents the product of an object's mass and its velocity.
- It indicates how much motion an object possesses and is given by the equation:
  - **P = mv,** where P = momentum, v = velocity and m = mass
- **Law of Conservation of Momentum:** According to the law of conservation of momentum, the total momentum of an isolated system remains constant if no external forces act on it.
  - **Application:** Suppose a person is stuck in the middle of a frozen lake which offers almost no friction with his shoes. He cannot simply walk and come out as friction is required for walking. How can he come out if he has got just his bag and no other tool?
  - **Solution:** He can apply conservation of momentum here, if he throws the bag in one direction, the bag will get a velocity and thus a momentum in that direction. The man will attain velocity and momentum in the opposite direction so that net momentum of Man + Bag remains zero as no external force is applied on the Man + Bag system (friction is zero).

Force and Newton's Laws of Motion

Force

- Force is a push or pull exerted on an object that causes it to change its velocity (accelerate) or shape.
- It is a vector quantity and is measured in Newtons (N).

Newton's First Law (Law of Inertia)

- A body remains in a state of rest or uniform motion in a straight line unless acted upon by an external force.
- **Example:** A book on a table stays still until you push it.

Newton's Second Law (Law of Acceleration)

- The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. This means to give equal acceleration to two objects, one needs to apply greater force on the heavier object.
- **Equation: F = ma**, where: m is mass, and a is acceleration.
  - This equation can be expressed in terms of momentum also. **$F = \Delta P/\Delta t$ meaning Force is rate of change of momentum.**
- **Example:** A car accelerates faster when pushed with greater force.

Newton's Third Law (Action-Reaction)

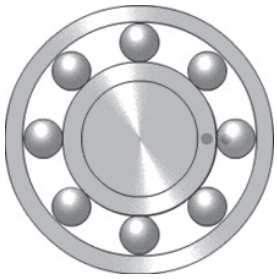
- For every action, there is an equal and opposite reaction.
- **Example:** A rocket moves upward by expelling gases downward. The gases being forced downward push the rocket upwards as explained by Third Law.

Friction

Friction is a force that opposes the relative motion between two surfaces in contact. It arises due to the interactions at the microscopic level of the surfaces involved. Greater the surface area in contact greater will be the friction.

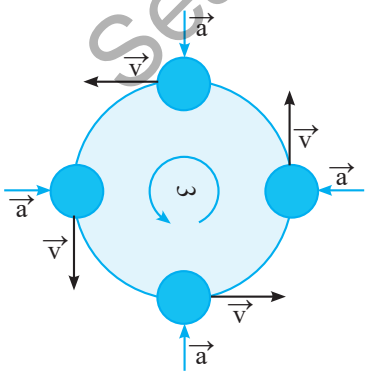
Types of Friction

1. **Static Friction:**
   - The force that must be overcome to start moving an object at rest.
2. **Kinetic (Sliding) Friction**
   - The force that opposes the motion of two surfaces sliding against each other.
3. **Rolling Friction**
   - The resistance encountered when an object rolls over a surface. Here the surface area of contact is reduced and thus movement becomes easy.



   - **Example: Ball bearing.** The balls roll between the inner and outer ring. Contact surface is limited to a single point at both surfaces thus greatly reducing the friction and making the motion smooth.**[UPSC 2013]**

Circular Motion and Centrifugal Force



Circular motion is the movement of an object along a circular path. It can be **uniform** (constant speed) or **non-uniform** (changing speed). A circular motion is always accelerated as direction of speed changes at every instant.

Imagine rotating a stone tied to a string in a horizontal circle. You will have to apply a force on the string towards the centre of the circle at every instant so that it remains in the circle.

v shows direction of velocity, **a** shows centripetal acceleration and also the direction of force applied by string on the stone.

ω is angular velocity and is given by angle covered per unit time in the circular motion.

1. **Centripetal Acceleration:**
   - Acceleration directed toward the centre of the circle, calculated as: v = velocity, r = radius

$$a_c = \frac{v^2}{r}$$

2. **Centripetal Force = mass × Centripetal acceleration**
   - The net force required to keep an object in circular motion:

$$F_c = \frac{mv^2}{r}$$

Centrifugal Force

Definition: Centrifugal force is an apparent outward force felt by an object moving in a circle, caused by inertia.It is directed away from the centre of the circle

Applications **[UPSC 2003]**

1. **Skimming of Milk:** In milk processing, when a container is spun, cream (less dense) moves outward due to centrifugal force, allowing separation from the milk.
2. **Vehicles on Curved Roads:** Centripetal force keeps cars on the road; insufficient friction can lead to skidding.
3. **Satellites:** Remain in orbit due to centripetal force from gravity.
4. **Shape of Earth:** Oblate spheroid shape is due to greater centrifugal force near the equator.
5. **Centrifuges:** Separate substances by spinning them rapidly, utilising centrifugal force.
6. **Tides:** Combined effect of gravitational pull of Sun, Moon and centrifugal force due to rotation of earth on its axis. **[UPSC 2015]**

PRESSURE

Definition: Pressure is the force exerted per unit area:

$$P = F/A$$

where P is pressure, F is force, and A is the area. It is measured in Pascals (Pa), Atmospheric pressure(atm) etc.

1 Pa = 1 Newton/metre square, 1 atm = 1.013 × 10^5 Pa.

Flow of Fluids

- **Pressure Difference:** Fluids flow from areas of higher pressure to areas of lower pressure. This principle governs many systems, such as water supply in pipes and blood circulation in the body.

Pressure and Altitude

- **Pressure Variation:** Atmospheric pressure decreases with altitude because the density of air decreases as altitude increases. This phenomenon explains why higher altitudes have lower oxygen availability, impacting human physiology and performance.
- **Cooking of Rice at Higher Altitude**
  - **Cooking Challenges:** At higher altitudes, the atmospheric pressure is lower, resulting in a lower boiling point for water (below 100°C). This means rice and other foods **take longer to cook,** as water does not reach as high a temperature.

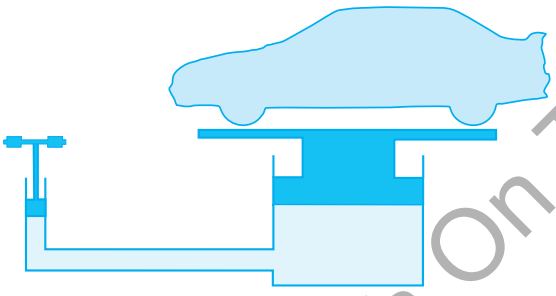
Boiling Point of Water and Increased Pressure

- The boiling point of water **increases with an increase in pressure**. At higher pressures, water molecules require more energy (higher temperature) to escape into the vapour phase, meaning **water boils at a temperature higher than 100°C.**

Cooking of Rice in Pressure Cookers [UPSC 2021]

- **Pressure Cookers:** Pressure cookers **raise the boiling point of water** due to increased pressure inside the cooker. This allows rice and other foods to cook faster, as the **temperature inside the cooker can exceed 100°C.**

Application of Pressure in Hydraulic Lifts



- **Hydraulic Lifts:** These devices use the principles of fluid pressure to lift heavy objects. By applying a small force on a piston, a large force is generated through a fluid, allowing for lifting capabilities in hydraulic systems, such as car lifts and elevators.

Practical Applications of Pressure

- **Straw Use:** When you suck on a straw, you create a **low-pressure area inside the straw.** The higher atmospheric pressure outside pushes the liquid up into the straw, allowing you to drink. **[UPSC 2012]**

Land and Sea Breezes

- **Breezes Formation:**
  - **Land Breeze:** At night, land cools faster than water, creating higher pressure over land and lower pressure over the sea. The wind blows from the land to the sea.
  - **Sea Breeze:** During the day, the land heats up faster than the sea, causing lower pressure over land and higher pressure over the sea. The wind blows from the sea to the land.

Cloud Formation and Rainfall

- **Cloud Formation:** Clouds form in areas of low pressure when warm, moist air rises and cools, reducing its capacity to hold moisture. As the air cools, water vapour condenses into tiny droplets, forming clouds.
- **Rainfall:** When cloud droplets coalesce and grow heavy enough, they fall as precipitation (rain). This process is influenced by atmospheric pressure variations.

Desert Formation

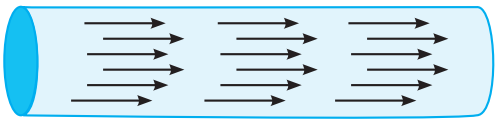
- **Desert Conditions:** Deserts often form in areas of high pressure, where dry air descends, inhibiting cloud formation and precipitation. This leads to arid conditions and limited rainfall.

FLUID DYNAMICS

Laminar Flow:

- In laminar flow, the fluid moves in parallel layers without mixing. Velocity at any point in the fluid remains constant over time, and the flow lines are smooth and orderly. This type of flow occurs when the Reynolds number (a dimensionless number that indicates flow type) is low.
- **Example: Blood flowing through narrow capillaries** follows laminar flow, where each layer of blood moves smoothly past the others.

Laminar Flow



Turbulent Flow:

- Turbulent flow is chaotic, with irregular velocity at different points in the fluid. Eddies and vortices form, and the flow becomes highly mixed. Turbulent flow occurs when the Reynolds number is high, indicating that inertial forces dominate over viscous forces.
- **Example:** Water rushing through a large pipe or river exhibits turbulence, with swirling currents and unpredictable flow paths.

Turbulent Flow

Diffusion

- Diffusion is the random movement of particles (like atoms or molecules) due to thermal energy. Over time, particles spread out from regions of high concentration to low concentration until equilibrium is reached. It is governed by **Fick's Law,** which states that the rate of diffusion is proportional to the concentration gradient.

- **Example:** The **diffusion of oxygen into red blood cells** across the alveolar membrane in the lungs, where the concentration of oxygen is higher in the alveoli than in the blood.

Osmosis

- Osmosis is a special case of diffusion involving the movement of water across a semipermeable membrane. Water moves from a region of low solute concentration to one of high solute concentration to balance the concentration on both sides of the membrane. It is driven by osmotic pressure.
- **Example:** Plant roots absorb water from the soil through osmosis, as the concentration of water is higher in the soil than in the root cells.

Dialysis

- Dialysis involves the selective movement of solute particles through a semipermeable membrane based on size or concentration. It uses diffusion to remove unwanted particles (such as toxins or waste products) from a solution, allowing only small molecules to pass through the membrane.
- In **kidney dialysis**, a machine uses a semipermeable membrane to remove waste products from the blood of patients with kidney failure.

Surface Tension

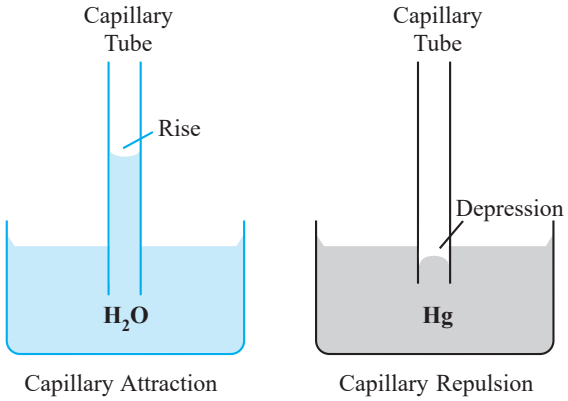
- Surface tension arises because molecules at the surface of a liquid experience a **net inward force due to cohesion** (attractive forces between similar molecules). This creates a "skin" on the liquid's surface, minimising its surface area.
- **Example:** Water droplets on a leaf **bead up** due to surface tension, and small insects like water striders can walk on water without sinking.

- Water droplets take a spherical shape because surface tension pulls the water molecules inward, reducing the surface area as much as possible. **A sphere has the smallest surface area for a given volume, so it's the most efficient shape.**

Capillarity (Capillary Action)

- **Physics Explanation:** Capillarity occurs when a liquid spontaneously rises or falls in a narrow tube due to adhesive forces between the liquid and the tube's walls and cohesive forces within the liquid itself. **[UPSC 2012]**

Capillary Action



- **Shape of Meniscus:** concave up, convex up or flat depends upon whether cohesive forces among molecules of liquid dominate over adhesive force between capillary tube and molecules of the liquid.
  - Cohesive > Adhesive = convex up, Mercury, liquid level falls as shown.
  - Adhesive > Cohesive = concave up, Water, liquid level rises in the capillary tube as shown.
- **Example:** Capillary action helps water travel up the xylem in plants, allowing water to reach the top leaves.

HEAT AND THERMODYNAMICS

Temperature and Heat

- **Temperature:**
  - **Definition:** Temperature measures the average kinetic energy of particles in a substance, determining how hot or cold something is.
  - **Units:** Measured in Celsius (°C), Fahrenheit (°F), or Kelvin (K). Kelvin is the SI unit, directly related to absolute temperature.
- **Heat vs. Temperature:**
  - **Heat:** The energy transferred due to temperature difference, measured in joules (J).
  - **Temperature:** A measure of the average motion of particles in a substance.
  - **Difference:** Heat depends on mass and temperature difference, whereas temperature is an intensive property (does not depend on the amount of substance).

Heat Transfer and Conductivity

- **Good and Bad Conductors of Heat:**
  - **Good Conductors:** Materials like metals that quickly transfer heat, due to free electrons.
  - **Bad Conductors (insulators):** Materials like wood or rubber, which restrict heat flow, making them useful for insulation.

- **Modes of Heat Transfer:**
  - **Conduction:** Transfer of heat through direct contact (e.g., metal rod in a flame).
  - **Convection:** Heat transfer through fluid motion (e.g., boiling water).
  - **Radiation:** Heat transfer without a medium, through electromagnetic waves (e.g., heat from the sun).

Specific Heat Capacity and Its Applications

- **Specific Heat Capacity:**
  - **Definition:** The amount of heat needed to raise the temperature of 1 kg of a substance by 1°C.
  - **High Specific Heat of Water:** Water requires more energy to change its temperature, which stabilises Earth's climate.
- **Applications:**
  - **Oceans and Climate:** Oceans store large amounts of heat due to water's high specific heat. During winters, oceans release this heat slowly, keeping coastal regions warmer.
- **Relation Between Surface Area and Rate of Cooling:**
  - **Newton's Law of Cooling:** The rate of heat loss is proportional to surface area and the temperature difference between the object and its surroundings. Larger surface areas result in faster cooling. Larger temperature difference between object and surrounding leads to larger rate of cooling.
  - **Example:** A 60 degree celsius iron rod cools faster in a room at 5 degree celsius than in a room at 15 degree celsius.

Water: Phases and Special Properties

- **Phases of Water:**
  - Water exists in three phases: Solid (ice), liquid, and gas (vapour). Phase changes involve latent heat, energy absorbed or released without changing temperature.
- **Latent Heat:**
  - **Definition:** Energy required for a substance to change its phase (e.g., from ice to water) without temperature change.
  - **Significance:** Latent heat explains why ice absorbs large amounts of energy when melting, stabilising temperatures.
- **Water's Maximum Density and Frozen Lakes:**
  - **Density Anomaly:** Water is **densest at 4°C**. This causes lakes to freeze on the surface first while the denser, warmer water stays below, allowing aquatic life to survive.

Black Body Radiation

Black Body: It is a perfect absorber and emitter of all wavelengths of radiation. A black body emits radiation based on its temperature. This principle is fundamental to understanding the heat emission of stars and planets.

Greenhouse Effect

- **Mechanism:**

  Definition: The greenhouse effect is the trapping of the sun's heat by Earth's atmosphere, through gases like CO_2, water vapour, and methane.

  Importance: It keeps Earth warm enough for life by preventing excessive heat from escaping into space.
- **Cloudy Nights and Greenhouse Effect: Warmer Nights:** Clouds act as a thermal blanket, trapping heat during the night, which prevents rapid cooling. This is an extension of the greenhouse effect.

Cryogenics and its Application

Cryogenics is the study of materials at very low temperatures such as below -150°C, revealing unique properties like superconductivity.

Key Applications **[UPSC 1999, 2008, 2002]**

- **Cryogenic Refrigeration:** Used for freezing biological samples (e.g., liquid nitrogen).
- **Superconducting Materials:** Critical in MRI machines and particle accelerators (e.g., Large Hadron Collider).
- **Space Exploration:** Utilizes cryogenic fuels (liquid hydrogen/oxygen) for rocket propulsion.
- **Medical Applications:** Cryosurgery employs liquid nitrogen to remove tumors.
- **Cryopreservation:** Cells and tissues stored at ultra-low temperatures for fertility treatments.
- **Scientific Research:** Studying materials in condensed matter physics and quantum mechanics.
- **Industrial Applications:** Natural gas liquefaction for efficient transport.

OPTICS AND SOUND

Optics

Light: Light is radiant energy that travels in waves. Scientists have long debated its nature, and now understand that it behaves both like waves and particles. In a vacuum, light moves at a constant speed of about 299,792 kilometers (186,281 miles) per second, with measurable wavelengths.

Reflection

- **Definition:** The bouncing back of light when it hits a smooth surface, governed by the laws of reflection.
- **Laws of Reflection:**
  - The angle of incidence equals the angle of reflection.
  - The incident ray, reflected ray, and normal to the surface lie in the same plane.

- **Practical Applications of Reflection**
  - **Mirrors:** Used for grooming, safety, and optical devices.
  - **Solar Cookers:** Employ parabolic mirrors to concentrate sunlight for efficient cooking.
  - **Periscopes and Optical Instruments:** Utilize reflection principles for viewing from concealed positions.

Refraction

- **Definition:** The bending of light as it passes from one medium to another,it is described by Snell's Law.
- **Core Physics Principle:** The change in speed of light in different media results in refraction.
- The refractive index (n) of a medium is defined as the ratio of the speed of light in a vacuum (c) to the speed of light in that medium (v):
  - $n = c/v$
- **Convergence**
  - **Denser Medium:** Light slows down and bends towards the normal when entering a denser medium (e.g., air to glass). This causes parallel rays to converge through a convex lens.
  - **Applications:** Used in cameras, microscopes, and corrective lenses for hyperopia (farsightedness).
- **Divergence**
  - **Less Dense Medium:** Light speeds up and bends away from the normal when exiting a denser medium. This causes rays to diverge through a concave lens.
  - **Applications:** Used in glasses for myopia (nearsightedness) and in expanding laser beams.
- **Practical Applications and Observations**
  - **Lenses in Glasses and Cameras:** Correct vision and focus images, employing advances in optics and material science.
  - **Contact Lenses:** Made from hydrophilic materials that maintain moisture, improving comfort and clarity.
  - **Red Sky at Dawn and Dusk:** The scattering of shorter wavelengths of light during sunrise and sunset leads to vibrant colors in the sky, demonstrating the principles of light refraction and scattering.

Total Internal Reflection (TIR)

- **Definition:** Occurs when light travelling from a denser to a less dense medium is completely reflected at a boundary above a critical angle.
- **Practical Applications**
  - **Optical Fibers:** Use TIR to transmit data over long distances with minimal loss, revolutionising telecommunications and internet technology.
  - **Diamond Sparkle:** The brilliance of diamonds is enhanced by TIR, causing them to reflect light in multiple directions.
  - **Mirage:** A mirage is a naturally-occurring optical phenomenon in which light rays bend via refraction to produce a displaced image of distant objects or the sky. It creates an illusion of water in deserts when looked from far away.

Dispersion

- **Definition:** The separation of white light into its component colours when passing through a prism due to varying refractive indices. **[UPSC 2013]**
- **Practical Applications**
  - **Spectroscopy:** Analyses light spectra from celestial bodies, crucial in astrophysics for understanding the universe's composition.
  - **Rainbow Formation:** A natural display resulting from light dispersion, refraction, and reflection in raindrops.

Mirrors

- **Definition:** Reflective surfaces that form images, classified into plane, concave, and convex mirrors.
- **Practical Applications**
  - **Concave Mirrors:** Used in telescopes to gather and focus light for enhanced astronomical observations.
  - **Convex Mirrors:** Provide a wider field of view in safety applications, improving traffic safety and surveillance.

Lenses

- **Definition:** Transparent objects that refract light to converge (convex) or diverge (concave) rays.
- **Practical Applications**
  - **Microscopes and Telescopes:** Employ combinations of lenses to magnify small or distant objects, advancing biological and astronomical research.
  - **Bionic Eyes:** Utilise advanced optics to restore vision, integrating biomedical engineering and electronic sensors.
    - Monash University in Australia has unveiled the 'Gennaris Bionic Vision System', a pioneering bionic eye designed to restore vision by bypassing damaged optic nerves and sending signals directly to the brain. Following promising animal studies, human clinical trials are set to commence in Melbourne.

Prisms

- **Definition:** Geometric optical devices that refract light, often leading to dispersion.
- **Practical Applications**
  - **Prism Binoculars:** Use prisms to shorten optical paths while maintaining clarity, essential in outdoor and military applications.

Brownian Motion

- **Definition:** Random motion of microscopic particles suspended in a fluid, resulting from collisions with molecules in the medium.
- **Practical Applications**
  - **Nanotechnology:** Understanding Brownian motion is crucial in developing nanomaterials and drug delivery systems, optimising their movement and interaction with cells.

Doppler Effect

- **Definition:** The change in frequency or wavelength of a wave in relation to an observer moving relative to the source of the wave.
- **Practical Applications/Observations**
  - **Astronomy:** Used to measure the velocity of stars and galaxies, determining their movement and helping to reveal the expansion of the universe. The redshift indicates objects moving away, while blueshift indicates objects moving closer. **[UPSC 2002]**
  - **Medical Imaging:** Employed in Doppler ultrasound to assess blood flow, providing critical data for cardiovascular health diagnostics.
  - **Sound of a Passing Train:** The frequency of the sound waves increases as the train approaches (higher pitch) and decreases as it moves away (lower pitch).

Human Eye and Vision

- **Structure:** Light enters through the cornea, refracts through the lens, and forms an image on the retina, which is converted into signals for the brain.
- **Practical Applications**
  - **Optical Technologies:** Lens design for vision correction is informed by understanding optical physics, enhancing safety and quality of life.
  - **Bionic Eye Technology:** Merges optics and electronics, using sensors to convert light into electrical signals, aiming to restore vision in individuals with retinal diseases.

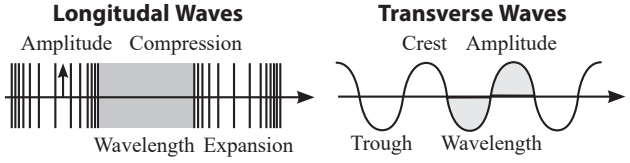
Sound

Definition: Sound is a form of mechanical energy that travels in waves through different mediums such as air, water, and solids.

Comparison to Light

- **Nature:** Sound is a longitudinal wave, while light is a transverse wave.

Types of Waves



- **Medium Requirement:** Sound requires a medium to travel, whereas light can travel through vacuum.

Speed of Sound in Various Mediums

- **Air:** Approximately 343 metres per second.
- **Water:** About 1,480 metres per second.
- **Solids (e.g., steel):** Approximately 5,960 metres per second.

Reason for Difference in Speed

The speed of sound varies based on the medium's density and elasticity. Sound travels faster in solids than in liquids and faster in liquids than in gases because particles in solids are closer together and can transmit vibrations more quickly.

Unit of Sound

The loudness of sound is measured in **decibels (dB).** The frequency of sound is measured in Hertz(Hz).

Range of Audible Sound

Humans can typically hear sounds in the range of **20 Hz to 20,000 Hz (20 kHz).**

Hypersonic and Mach Definitions

- **Hypersonic:** Refers to speeds greater than **Mach 5** (five times the speed of sound).
- **Mach Number:** A dimensionless unit representing the ratio of the speed of an object to the speed of sound in the surrounding medium.

Sonic Boom

A sonic boom occurs when an object travels faster than the speed of sound, creating shock waves that produce a loud sound, similar to an explosion.

Organ Pipes and Principle

Organ pipes produce sound through the vibration of air columns within a hollow tube. The sound is generated by the movement of air, which creates standing waves, leading to the production of musical notes. **Example:** Flute,Saxophone,Harmonium etc.

Doppler Effect

The Doppler Effect is the change in frequency (or pitch) of sound as the source moves relative to an observer. For example, when an ambulance approaches, the siren sounds higher in pitch, and as it moves away, the pitch lowers.

Applications of Sound in Modern Science and Technology

1. **Medical Imaging:** Ultrasound uses high-frequency sound waves to create images of internal organs.
2. **Navigation:** Sonar (Sound Navigation and Ranging) employs sound propagation to navigate and detect objects underwater.
3. **Acoustic Levitation:** Using sound waves to lift small particles or droplets in the air without physical contact.
4. **Audio Technology:** Speakers and microphones convert electrical signals into sound and vice versa, essential for communication devices.

ELECTRICITY AND MAGNETISM

Basic Concepts

- **Electric Charge**
  - **Definition:** A property of matter that causes it to experience a force in an electromagnetic field. There are two types of charges: positive and negative.
  - **Applications:** Used in capacitors to store energy, crucial for electronic circuits and devices.
- **Electric Current**
  - **Definition:** The flow of electric charge through a conductor, measured in amperes (A). It can be direct (DC) or alternating (AC).
  - **Applications:** Powers household appliances, electronic devices, and industrial machinery. DC is used in batteries, while AC is used for home electricity supply.
- **Voltage (Electric Potential)**
  - **Definition:** The difference in electric potential between two points in a circuit, measured in volts (V).
  - **Applications:** Essential for the operation of electrical systems; higher voltage allows for efficient power transmission over long distances, reducing energy loss.
- **Resistance**
  - **Definition:** Opposition to the flow of electric current, measured in ohms (Ω). It varies with material, length, and cross-section.
  - **Applications:** Used in heating elements (like toasters), light bulbs, and electronic devices where controlled resistance is needed.
- **Ohm's Law**
  - **Definition:** States that current (I) is directly proportional to voltage (V) and inversely proportional to resistance (R).
  - **Equation:** $V = I \times R$
  - **Applications:** Fundamental in designing circuits, ensuring components operate within safe limits.
- **Series and Parallel Circuits**

  Definition:
  - **Series Circuit:** Components connected end-to-end; same current flows through all.
  - **Parallel Circuit:** Components connected across common points; same voltage across all.

  Applications: Series circuits are used in string lights, while parallel circuits are used in home wiring to ensure appliances can operate independently.
- **Magnetic Field**
  - **Definition:** A region around a magnetic material or moving electric charge where magnetic forces are experienced, measured in Tesla (T).
  - **Natural Phenomenon:** Earth's magnetic field protects the planet from solar radiation and helps animals navigate during migration.
- **Electromagnetism**
  - **Definition:** The interaction between electric charges and magnetic fields; changing electric fields generate magnetic fields and vice versa.
  - **Applications:** Used in electric motors, generators, and transformers. Electromagnets are essential in various applications, including maglev trains and MRI machines.
- **Faraday's Law of Electromagnetic Induction**
  - **Definition:** A change in magnetic flux through a circuit induces electromotive force (EMF).
  - **Applications:** Utilised in electric generators, where mechanical energy is converted into electrical energy. Also crucial in wireless charging technology.
- **Applications in Modern Science and Technology**
  - **Electric Motors:** Convert electrical energy into mechanical energy, found in electric vehicles and household appliances.
  - **Transformers:** Adjust voltage levels for efficient power transmission, minimising energy loss over long distances.
  - **Magnetic Resonance Imaging (MRI):** Utilises strong magnetic fields to create detailed images of tissues, revolutionising medical diagnostics.
  - **Wireless Communication:** Electromagnetic waves are fundamental in technologies like Wi-Fi, Bluetooth, and mobile communications.
- **Natural Phenomena**
  - **Auroras:** Caused by charged particles from the sun interacting with Earth's magnetic field, creating stunning displays of light in polar regions. **[UPSC 2012]**
  - **Lightning:** A natural discharge of electricity that occurs due to differences in electrical charge between clouds and the ground.

CHEMISTRY IN EVERYDAY LIFE

Chemistry touches every facet of life, from medicines and foods to cleaning agents and cosmetics. This chapter delves into the role of chemistry in our daily lives, focusing on **medicines**, **food materials**, **cleansing agents**, and important chemicals in the news for various reasons.

MEDICINES AND DRUGS

Medicines are chemical compounds that interact with biological systems to treat ailments. Incorrect usage can lead to toxic effects. The field of **chemotherapy** refers to the use of chemicals in therapeutic treatment. This section also includes recent drug discoveries and essential medical chemicals.

Classification of Drugs

Classification based on:

- **Pharmacological effect**: Examples include **paracetamol** (antipyretic), **ibuprofen** (analgesic), and **chloroquine** (antimalarial). Newer drugs like **Remdesivir** and **Paxlovid** (for COVID-19) are also gaining attention.
- **Drug action**: Drugs like **antiviral medications** (such as **Favipiravir**) act on viral replication, while **antihistamines** (e.g., **Loratadine** and **Cetirizine**) inhibit the action of histamine in allergic reactions.
- **Chemical Structure**: Drugs such as **sulphonamides** (e.g., **sulfadiazine**) are classified based on structural similarities, making it easier to predict their activity.
- **Molecular Targets**: In addition to proteins and nucleic acids, newer drug developments target **enzymes** (e.g., **Protease inhibitors** used in HIV treatment) and **receptors** (like **ACE2** in COVID-19).

Drug-Target Interaction

- **Enzymes as drug targets**: Enzyme inhibitors, such as **Nevirapine** (HIV), and newer drugs like **Nirmatrelvir** (a protease inhibitor for COVID-19), show how drugs interact with active sites.
- **Receptors as drug targets**: **Opioid receptors** targeted by drugs like **Naloxone** (used in opioid overdose treatment) are crucial in managing pain and addiction.

Recent Developments in Medicines

- **Monoclonal Antibodies**: Drugs like **Tocilizumab** and **Regeneron's antibody cocktail** have been highlighted for treating COVID-19.
- **Immunotherapy**: Drugs such as **Pembrolizumab** (for cancer) have gained attention for harnessing the body's immune system.

THERAPEUTIC ACTION OF DRUGS

This section expands on specific drugs used to manage medical conditions, incorporating modern breakthroughs and widely used treatments.

Antacids

Along with **cimetidine** and **ranitidine**, newer antacids like **esomeprazole** and **pantoprazole** are popular proton pump inhibitors (PPIs) that effectively reduce stomach acid.

Antihistamines

In addition to **brompheniramine** and **terfenadine**, modern antihistamines like **Fexofenadine** (Allegra) are widely used due to fewer sedative side effects.

Neurologically Active Drugs

- **Tranquilizers**: New drugs like **Clonazepam** and **Alprazolam** are commonly prescribed to manage anxiety and panic disorders.
- **Analgesics**: **Oxycodone** and **Fentanyl**, though effective for pain relief, have gained attention due to their role in the opioid crisis.

Antimicrobials

- **Antibiotics**: Beyond **penicillin** and **chloramphenicol**, drugs like **azithromycin**, **doxycycline**, and **carbapenems** are used for their broad-spectrum effects. **Colistin**, a powerful antibiotic, has recently been in the news due to its use as a last-resort drug against resistant infections.
- **Antiseptics and disinfectants**: **Hydrogen peroxide** and **isopropyl alcohol** have become critical, especially in the COVID-19 pandemic for disinfection and hand sanitizers.

Antifertility Drugs

- **Levonorgestrel** and **mifepristone** are commonly used alongside **norethindrone** and **ethynylestradiol** in modern contraceptives.

CHEMICALS IN FOOD

Chemical additives in food include preservatives, sweeteners, and flavoring agents. Recent concerns have arisen around some food additives, sparking discussions on food safety.

Artificial Sweeteners

Apart from **saccharin** and **aspartame**, **sucralose** (Splenda) and **stevia** are now popular as low-calorie sweeteners. Stevia, a plant-based sweetener, is often promoted for its natural origins.

Food Preservatives

While **sodium benzoate** and **potassium sorbate** are commonly used, concerns about **BHA** (butylated hydroxyanisole) and **BHT** (butylated hydroxytoluene) as potential carcinogens have been raised.

Titanium Oxide and BPA

Titanium dioxide (used in candies and toothpaste) has been controversial due to safety concerns in some studies, leading to a potential ban in several countries. **Bisphenol A (BPA)** in food packaging has also been widely discussed for its possible hormonal effects. **[UPSC 2021]**

CLEANSING AGENTS

Cleansing agents, both natural and synthetic, play a crucial role in hygiene. However, recent concerns about their environmental impact have drawn attention to safer, biodegradable alternatives.

Soaps

Traditional soaps like **sodium palmitate** and **sodium stearate** continue to be used, but the environmental impact of soap production, including palm oil related deforestation, has been debated.

Synthetic Detergents

Synthetic detergents, such as **sodium dodecylbenzenesulfonate**, are preferred for their efficiency in hard water. Newer formulations now focus on being biodegradable to prevent pollution.

Environmental Concerns

The use of **phosphates** in detergents has been reduced due to their role in water pollution. **Microplastics** in scrubbing agents, found in cosmetics and cleaning products, have been banned in many countries due to environmental hazards.

IMPORTANT CHEMICALS IN DAILY LIFE AND IN THE NEWS

Certain chemicals, often used in various industries and products, have gained attention recently due to environmental, health, or legal concerns.

PFAS (Per- and Polyfluoroalkyl Substances)

Known as **"forever chemicals,"** PFAS have been in the spotlight for contaminating water supplies. Used in **non-stick cookware, food packaging, and firefighting foam**, they pose significant health risks.

Glyphosate

This widely used herbicide has been the subject of lawsuits due to its potential link to cancer. Countries around the world are reviewing its use in agriculture.

BPA and Phthalates

Both of these chemicals, found in **plastics**, have been under scrutiny for their **hormone-disrupting properties.** BPA-free products are now in high demand as consumers seek safer alternatives.

Aspartame [UPSC 2011]

Aspartame is an artificial sweetener sold in the market. It consists of amino acids and provides calories like other amino acids. Yet, it is used as a low-calorie sweetening agent in food items because aspartame is several times sweeter than table sugar, hence food items made with small quantities of aspartame yield fewer calories on oxidation.

Formaldehyde

Used in household products like glue and furniture, formaldehyde is classified as a carcinogen. Concerns about its presence in air fresheners and cosmetics have led to tighter regulations.

Triclosan [UPSC 2021]

'Triclosan', considered harmful when exposed to high levels for a long time, is most likely present in Toiletries.

Oxybenzone

This chemical, found in **sunscreens**, has been linked to **coral reef damage**. Hawaii and other regions have passed laws banning sunscreens containing oxybenzone to protect marine life.

Plastics

Plastic is widely used for packaging, particularly for bottles and containers. The quality and properties of plastics are classified into various grades depending on their application, molecular weight, and production process.

Code	Plastic Type	Common Uses	Recycling Potential
1	Polyethylene Terephthalate (PET or PETE)	Water bottles, soft drink bottles, food packaging	Easily recycled into fibers, containers
2	High-Density Polyethylene (HDPE)	Milk jugs, detergent bottles, grocery bags	Recycled into pipes, plastic lumber
3	Polyvinyl Chloride (PVC)	Pipes, vinyl flooring, toys, shower curtains	Rarely recycled due to toxic additives
4	Low-Density Polyethylene (LDPE)	Plastic bags, shrink wraps, squeezable bottles	Difficult to recycle, used for liners, tiles
5	Polypropylene (PP)	Yogurt containers, bottle caps, straws, medicine bottles	Recycled into trays, cables, lights
6	Polystyrene (PS)	Disposable cups, plates, food trays, egg cartons	Hard to recycle, used for insulation, packaging

2 Basic Biology

Biology is **the study of living organisms** and **is divided into many specialised fields that cover their morphology**, **physiology**, **anatomy**, **behaviour**, **origin** and **distribution**.

CELL BIOLOGY

Definition of Cell: A cell is defined as the smallest, basic unit of life that is responsible for all of life's processes. Cells are the structural, functional, and biological units of all living beings. A cell can replicate itself independently. Hence, they are known as the building blocks of life.

- **Robert Hooke** first **saw and described a live cell**.
- **Robert Brown** later **discovered the nucleus**.
- Cells are characteristically microscopic in size (**with exceptions-The largest isolated single cell is the egg of an ostrich**).

Origin of Life **[UPSC 2012]**

Carbon, Hydrogen, Nitrogen are sets of elements was primarily responsible for the origin of life on the Earth.

Classification of Cells

On the basis of complexity, cells can be classified as:

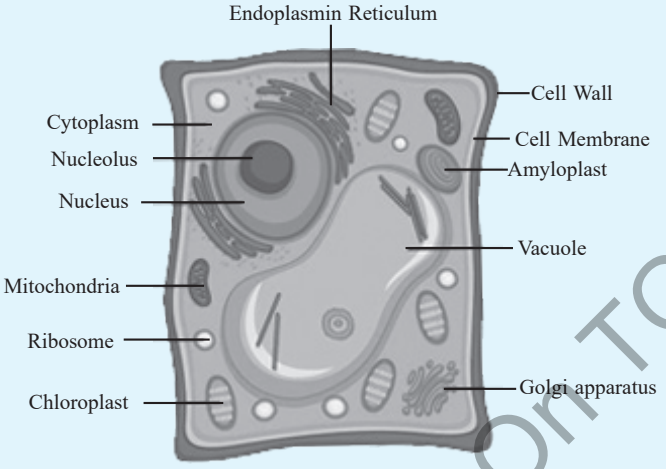
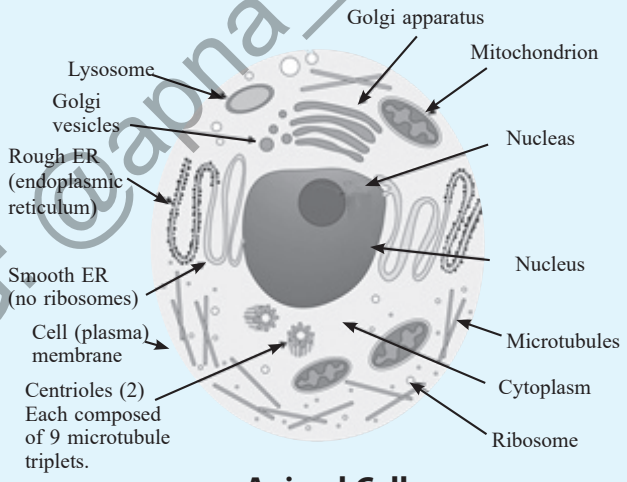
- **Eukaryotic Cells:** Contain well-defined membrane-organelles and nuclei. On the basis of components, Eukaryotes are further divided into Animal cells and Plant cells. Plant cells have a cell wall outside the cell membrane.
- **Prokaryotic Cells:** Do not have well-defined membrane-bound organelles and nuclei.

Table: Difference between Prokaryotic and 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

Plant Cell and Animal Cell [UPSC 2020]

Table: Difference between Plant and Animal Cells

Plant Cell	Animal Cell
Usually, they are larger than animal cells	Usually, smaller than plant cells
Cell wall present in addition to plasma membrane and consists of middle lamella, primary and secondary walls	Cell wall absent
Plasmodesmata present	Plasmodesmata absent
Chloroplast present	Chloroplast absent
Vacuole large and permanent	Vacuole small and temporary
Centrioles absent except motile cells of lower plants	Centrioles present
Nucleus present along the periphery of the cell	Nucleus at the centre of the cell
Lysosomes are rare	Lysosomes present
Storage material starch grains	Storage material a glycogen granule
 Plant Cell	 Animal Cell

Cell Organelles

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

- **Nucleus:** The nucleus is the control centre of the cell, containing the cell's **genetic material (DNA)**. It is surrounded by a nuclear membrane that contains pores allowing for the exchange of materials with the cytoplasm. The nucleus regulates gene expression and coordinates cell activities like growth and reproduction. In **animal cells** and **plant cells**, the nucleus is present, though plant cells often have multiple nuclei in certain conditions.
- **Mitochondria:** Often referred to as the **"powerhouse"** of the cell, **mitochondria** are responsible for generating **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. Both plant and animal cells contain mitochondria, but plant cells also have chloroplasts for photosynthesis.
- **Endoplasmic Reticulum (ER):** The ER is a network of membranes involved in the synthesis and transport of proteins and lipids. It is divided into two types:
  - **Rough ER:** Studded with **ribosomes** on its surface, it is involved in protein synthesis and modification. Proteins synthesised here are often secreted from the cell or sent to other organelles.
  - **Smooth ER: Lacks ribosomes** and is involved in lipid synthesis, metabolism, and detoxification of harmful substances. Both plant and animal cells contain both types of ER.
- **Golgi Apparatus:** The **Golgi apparatus** functions as the cell's **post office**, modifying, sorting, and packaging proteins and lipids for transport to their final destinations. It works closely with the ER. It is found in both **plant** and **animal cells**.

- **Lysosomes:** Lysosomes are membrane-bound organelles that contain **digestive enzymes**. They break down waste materials, cellular debris, and foreign substances. Lysosomes are more prominent in animal cells, but similar structures are found in plant cells. They are known as suicide bag of cells.
- **Ribosomes:** Ribosomes are small, non-membrane-bound structures that are the site of **protein synthesis**. They can be found either attached to the **rough ER** or freely floating in the **cytoplasm**. Ribosomes in both **plant** and **animal cells** perform the same basic function, translating messenger RNA (mRNA) into proteins.
- **Chloroplasts (in Plant Cells):** Chloroplasts are the site of **photosynthesis**, where plants convert sunlight into chemical energy stored in glucose. They contain the green pigment **chlorophyll**, which absorbs light energy. Chloroplasts are found only in **plant cells** and some algae. This organelle has a double membrane and is critical for energy production in plant cells.
- **Vacuoles:** Vacuoles are large, membrane-bound organelles responsible for storing nutrients, waste products, and maintaining cell **turgor pressure** in plants. **Plant cells** typically have a large central vacuole, while **animal cells** may have smaller vacuoles involved in storing water, nutrients, and waste.
- **Cytoplasm:** The **cytoplasm** is the jelly-like substance that fills the space between the cell membrane and the nucleus. Both **plant** and **animal cells** have cytoplasm, although the composition and appearance may differ slightly.
- **Cell Membrane:** The **cell membrane** is a semi-permeable lipid bilayer that surrounds the cell, providing structural support and controlling the movement of substances in and out of the cell. It is composed of phospholipids, proteins, and carbohydrates. In **animal cells**, the cell membrane is the outermost boundary, while in **plant cells**, the membrane lies beneath the rigid **cell wall**.

Stem Cells

- Special human cells that have the capability to develop into wide-ranging types of cells in the human body, from muscle cells to brain cells, are called stem cells.
- A stem cell is an immature or unspecialized cell that **can split to form similar cells and develop into different specialized cells** that perform a distinct function.
- **Cell potency** is a cell's ability to differentiate into other cell types.

Types of Stem Cells [UPSC 2020]

- **Totipotent Stem Cells:** These Stem Cells can transform into all kinds of cells in the human body. **Example:** Zygote
- **Pluripotent Stem Cells:** These Stem Cells can transform themselves into any type of cell in the human body except those kinds that are required to support and develop a fetus in the womb. **Example:** Embryonic stem cells
- **Multipotent Stem Cells:** These can give rise to only a few distinct types of cells. Adult stem cells and cord blood stem cells are considered multipotent.
- **Induced Pluripotent Stem Cells:** These are derived from skin or blood cells that have been reprogrammed back into an embryonic-like pluripotent state.

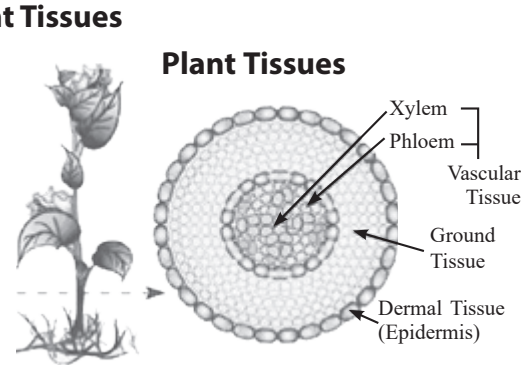
Deviation from Basic Cell Types

- **Virus (means poisonous fluid):** These are obligate parasites inert outside their specific host cell.
- **Virions:** The main difference between a virus and a virion is that **a virus is the nucleoprotein particle**, whereas **a virion is the active, infectious form of the virus.**
- **Viroids:** These are **infectious agents that consist only of naked RNA without any protective layer**, such as a protein coat.
- **Lichens:** Lichens are **symbiotic associations (mutually useful associations)** between algae and fungi.
  - Algae prepare **food for fungi**, and **fungi provide shelter** and **absorb mineral nutrients** and **water for their partners**.
  - Lichens are very **good pollution indicators- they do not grow in polluted areas**.

Tissues

A group of cells that are similar in structure and/or work together to achieve a particular function forms a tissue. There are two types of tissues- Plant Tissues and Animal Tissues.

Plant Tissues



Plants are stationary or fixed, and their supporting tissue is made up of dead cells. **Based on their ability to divide**, plant tissues can be divided into **two categories**:

- **Simple Permanent Tissue:** A few layers of cells beneath the epidermis are generally simple permanent tissue. Such tissues are called simple permanent tissue. Various types of tissues are:
  - **Parenchyma:** It consists of relatively unspecialised cells with thin cell walls.

- **Collenchyma:** It allows bending of various parts of a plant like tendrils and stems of climbers without breaking.
- **Sclerenchyma:** It is the tissue which makes the plant hard and stiff.

- **Complex Permanent Tissue:** Complex tissues are made of more than one type of cells. All these cells coordinate to perform a common function.
  - **Example:** Xylem and Phloem are examples of such complex tissues: They are both conducting tissues and constitute a vascular bundle.
  - **Xylem:** Xylem consists of tracheids, vessels, xylem parenchyma, Xylem fibers. Tracheids and vessels are tubular structures. This allows them to **transport water** and minerals vertically.
  - **Phloem:** Phloem is made up of five types of cells,sieve cells, sieve tubes, companion cells, phloem fibers. Phloem **transports food** from leaves to other parts of the plant.

Capillarity **[UPSC 2012]**

Capillarity refers to how a liquid can rise or fall in a small space that is wet or dry, and is caused by the intermolecular forces. When the adhesion force between the liquid and solid (pipe wall) exceeds the liquid's cohesion, the capillary rise phenomenon occurs. Plants use this property to transport water to different parts.

Transplanting of Plants **[UPSC 2013]**

Transplantation is essential for crops like **rice, tomato, onion, brinjal, marigold, chrysanthemum, papaya, and tobacco**. It helps ensure better root establishment, protects young plants from pests and weeds, and optimizes space utilization in nurseries before planting in fields. For rice, transplantation is traditionally used to manage water efficiently and promote robust growth in waterlogged conditions. However, the **System of Rice Intensification (SRI)** has revolutionized rice cultivation by eliminating the need for transplantation.

SRI involves planting single, young seedlings directly in the field at wider intervals to allow better root growth and canopy development. This method **minimizes water usage by keeping the soil moist rather than continuously flooded** and promotes microbial activity through intermittent drying. By reducing seed, water, and labor requirements while enhancing yields, SRI has emerged as a sustainable and resource-efficient alternative to traditional transplantation.

Vegetative Propagation of Plants **[(UPSC 2014]**

Vegetative propagation is a method of asexual reproduction in plants where new plants grow from vegetative parts such as stems, roots, leaves, or buds. This technique bypasses seed formation, ensuring genetically identical offspring and faster propagation.

Common crops and plants grown through vegetative propagation include **potatoes (tubers), sugarcane (stem cuttings), banana (suckers), ginger and turmeric (rhizomes), onion and garlic (bulbs), and sweet potato (root tubers)**. In ornamental plants, rose, hibiscus, and jasmine are propagated through **stem cuttings**, while bryophyllum reproduces via **leaf buds**.

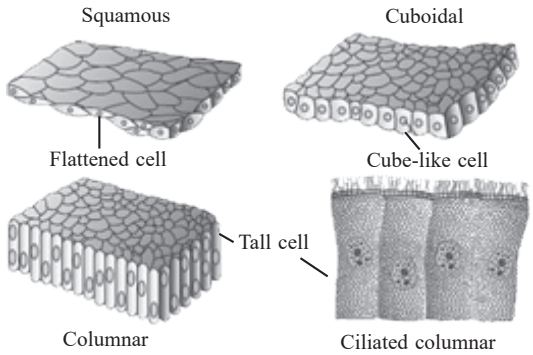
The process works by exploiting the plant's natural ability to regenerate from specialized tissues. For instance, adventitious roots develop from cuttings or buds under suitable conditions like moisture and temperature, leading to new growth. This method ensures uniformity, higher yields, and allows propagation of plants that do not produce viable seeds.

Sugarcane Production using Tissue Culture **[UPSC 2020]**

The bud chip method is an advanced propagation technique used to improve sugarcane cultivation efficiency. It involves cutting single buds (with a small portion of surrounding tissue) from sugarcane stalks and growing them in a controlled environment.

Animal Tissue

The animal cells are grouped together to form animal tissues. These tissues vary in their structure, function, and origin. Animal tissues are distinguished into four basic types as follows:



- **Epithelial Tissues:** They form the protective covering and inner lining of the body and organs. These tissues were the first to evolve during evolution and were first formed during embryonic development. They develop from the **ectoderm, mesoderm and endoderm** of the embryo.

- **Connective Tissues:** They develop from the **mesodermal** cells of the embryo. They support and bind other tissues in the body.
- **Muscle Tissue:** It develops from the **mesoderm** of the embryo. It helps in movement and locomotion, supports the bones and other structures
- **Nervous Tissue:** It makes up the peripheral and the central nervous system. It develops from the ectoderm of the embryo. It possesses the ability to initiate and transmit the nerve impulse.

HUMAN PHYSIOLOGY

Physiology is the study of normal function and vital processes of living organisms encompassing a range of subjects that include organs, anatomy, cells, biological compounds, and how they all interact to make life possible.

Human Physiology broadly includes the study of **Digestive System, Respiratory System, Circulatory System, Excretory System, Endocrine System, Reproductive System, Nervous System and Musculoskeletal System.**

Digestive System

- The digestive system includes the gastrointestinal (GI) tract and accessory organs (liver, pancreas, gallbladder).
- **GI tract organs:**
  - Mouth (Salivary Enzymes), Oesophagus (Transports Food),
  - Stomach (Mixes Food, Secretes Pepsin, HCl),
  - Small Intestine (Absorbs Nutrients),
  - Large Intestine (Absorbs Water, Forms Faeces).
- **Pepsin:** Pepsin is an enzyme that breaks down proteins into smaller peptides and amino acids during digestion.
- **Liver: Largest gland**; secretes bile for fat digestion; detoxifies harmful substances.
- **Pancreas:**
  - **Exocrine function:** Secretes enzymes for digestion of proteins, carbs, fats.
  - **Endocrine function:** Secretes insulin and glucagon to regulate blood sugar.

Respiratory System

- **Breathing** is the exchange of oxygen (O_2) from the atmosphere with carbon dioxide (CO_2) produced by cells.
- In animals, mechanisms vary by habitat and complexity. Lower invertebrates use diffusion, insects use trachea, aquatic arthropods and mollusks use gills, and terrestrial ones use lungs. Vertebrates respire using lungs, and some amphibians use their moist skin.

Human Respiratory System

- It includes the nose, pharynx, larynx, trachea, bronchi, bronchioles, and alveoli. It comprises a conducting part (nostrils to bronchioles) and a respiratory part (alveoli for gas exchange). The lungs are covered by pleura and aided by the diaphragm for respiration.

Mechanism of Breathing: Involves inspiration (inhalation) and expiration (exhalation). During inspiration, the diaphragm and intercostal muscles contract, increasing thoracic volume, reducing pressure, and drawing air in. In expiration, these muscles relax, decreasing volume and expelling air.

Oxidative Stress

Oxidative stress occurs when there is an imbalance between reactive oxygen species (ROS) and antioxidants in the body. ROS are unstable molecules that can damage cells, proteins, and DNA, contributing to various diseases and aging.

Oxidative stress is linked to conditions like cardiovascular diseases, diabetes, neurodegenerative disorders, and cancer. Understanding this process has led to therapeutic applications aimed at boosting antioxidant defenses to prevent or manage these diseases. **[UPSC 2011]**

Circulatory System

Organisms have evolved different **transport methods** to provide nutrients, O_2, and other essentials, while removing waste and harmful substances.

Circulatory patterns are of two types:

- **Open Circulatory System:** Present in arthropods and molluscs; blood is pumped into open spaces or sinuses.
- **Closed Circulatory System:** Present in annelids and chordates; blood is circulated through a network of vessels.

Vertebrates possess a **muscular chambered heart:**

- **Fishes:** Have a **2-chambered heart** (one atrium, one ventricle); the heart pumps deoxygenated blood, oxygenated at gills, with **single circulation**.
- **Amphibians and Reptiles (Except Crocodiles):** Have a **3-chambered heart** (two atria, one ventricle); oxygenated and deoxygenated blood mix in the ventricle, leading to **incomplete double circulation**.
- **Crocodiles, Birds, and Mammals:** Possess a **4-chambered heart** (two atria, two ventricles); oxygenated and deoxygenated blood do not mix, resulting in **complete double circulation**.

Human Circulatory System

Definition: Also called the blood vascular system; consists of a muscular chambered heart, closed branching blood vessels, and circulating blood.

Heart

- Located in the thoracic cavity between the lungs, slightly tilted to the left, about the size of a clenched fist.
- Comprises four chambers: Two atria (upper chambers) and two ventricles (lower chambers).
- Chambers separated by septa with openings guarded by valves for unidirectional blood flow.

Cardiac Cycle

- Cyclic sequence of heart pumping involving systole (contraction) and diastole (expansion).
- Heart beats approximately 72 times per minute, with each ventricle pumping about 70 ml of blood (stroke volume).

Blood Vessels

- Blood flows through arteries, veins, and capillaries.
- Arteries (except pulmonary artery) carry oxygen-rich from the heart to the periphery; veins (except pulmonary vein) carry deoxygenated from the periphery to the heart.
- Capillaries facilitate material exchange between blood and tissue cells.
- Nitric oxide (NO) is a substance produced in the human body that causes blood vessels to dilate and enhances blood flow. It is essential for vascular regulation, as it relaxes the smooth muscles in blood vessels, resulting in improved circulation. **[UPSC 2024]**

Excretory System

- Animals accumulate waste products such as ammonia, urea, uric acid, carbon dioxide, water, and ions (Na+, K+, Cl-, phosphate, sulfate) through metabolic activities and excess ingestion. These substances must be removed from the body.
- **Types of Excretion:**
  - **Ammonotelism:** Excretion of ammonia; common in bony fishes, aquatic amphibians, and aquatic insects.
  - **Ureotelism:** Excretion of urea; adapted for terrestrial life to conserve water.
    - Mammals, many terrestrial amphibians, and marine fishes are ureotelic.
    - Ammonia is converted to urea in the liver, released into the blood, filtered, and excreted by the kidneys.
  - **Uricotelism:** Excretion of uric acid; seen in reptiles, birds, land snails, and insects.
    - Uric acid is excreted as a pellet or paste, minimizing water loss.
- **Human Excretory System:**
  - Consists of a pair of kidneys, which filter the blood and remove toxins; two ureters which carry urine from the kidneys to the urinary bladder and the urethra will helps in relieving the urine.
  - Nephron is the fundamental unit of human excretory system.

Endocrine System

Endocrine glands are ductless glands that secrete hormones, acting as intercellular messengers produced in trace amounts.

Major Endocrine Glands and Their Functions

- **Hypothalamus:** Contains neurosecretory cells (nuclei) that produce hormones regulating the anterior pituitary.
- **Pituitary Gland**
  - **Posterior Pituitary:** Secretes oxytocin and arginine vasopressin (AVP).
  - **Anterior Pituitary:** Produces hormones like:
    - **Growth Hormone (GH):** Promotes growth; excess leads to acromegaly (adults) or gigantism (children).
    - **Luteinizing Hormone (LH):** Stimulates androgen production in males; regulates menstrual cycle in females.
    - **Follicle Stimulating Hormone (FSH):** Involved in reproductive processes.
- **Thyroid Gland:** Secretes thyroxine, regulating appetite and metabolism.
- **Thymus:** Secretes hormones (e.g., thymopoietin, thymosin) that aid in T-cell production and immune function.
- **Pancreas: Insulin** (β-cells) and **Glucagon** (α-cells): Regulate blood sugar levels and glucose homeostasis.
- **Adrenal Glands:** Produce hormones like cortisol, aldosterone, epinephrine (adrenaline), and norepinephrine (noradrenaline), affecting heart rate, blood pressure, and stress responses.
- **Testes:** Secretes testosterone, regulating male secondary sexual characteristics.
- **Ovaries:** Secretes estrogen and progesterone, regulating the female reproductive cycle.
- **Pineal Gland:** Secretes melatonin, regulating the sleep cycle.

Endocrine Disruptors

- **Definition:** Environmental contaminants that interact with hormones, potentially causing adverse effects.
- **Sources of Exposure:** Contaminated food chain, inhalation of contaminated dust, or occupational exposure.
- **Types of Endocrine Disruptors**:
  - **Pesticides:** DDT and its metabolites, methoxychlor.
  - **Plastic Contaminants:** Bisphenol A.
  - **Pharmaceuticals:** Diethylstilbestrol, 17 alpha ethinylestradiol (EE2).
  - **Dietary Components:** Phytoestrogens.

Reproductive System

- **Primary Function:** Production of male (sperm) and female (secondary oocyte) gametes.
- **Male Reproductive System:** Scrotum, penis, testes and accessory organs(vas deferens, seminal vesicles, prostate gland and Cowper's gland).
- **Female Reproductive System:**
  - **Internal:** Vagina, cervix, uterus, fallopian tubes, and ovaries.
  - Ovaries produce secondary oocytes, which travel through the fallopian tubes, regulated by hormones.
- **Hormonal Control:** Hormones like **progesterone**, **oestrogen** (in females), and **testosterone** (in males) are controlled by the **hypothalamus** and **anterior pituitary gland**.

- **Puberty:** Marks the onset of sexual maturity.
  - **Age Range**:
    - Girls: 10 to 14 years.
    - Boys: 12 to 16 years.
  - Causes physical changes, differing between boys and girls.

Menstrual Cycle

- **Cycle:** Occurs approximately every 28 days, lasting 4-5 days.
- Triggered by a reduction in estrogen and progesterone.
- **Menarche:** First menstrual period.
- **Menopause:** Permanent cessation of menstrual cycles, diagnosed after 12 months without a period.

Nervous System

The nervous system **is an organised group of cells specialised for the conduction of electrochemical stimuli from sensory receptors through a network to the site at which a response occurs**. It serves as the body's command centre and can be divided into two main types:

Types of Nervous Systems

- **Diffuse Nervous System:** Found in lower invertebrates, this system lacks a brain, and neurons are spread throughout the body in a net-like arrangement.
- **Centralised Nervous System:** Seen in higher invertebrates and vertebrates, with a well-developed brain and spinal cord. The **Central Nervous System (CNS)** coordinates information and directs responses, while the **Peripheral Nervous System (PNS)** transmits impulses to and from the CNS.

Neurons

- **Neurons** are the fundamental units of the nervous system.
- Composed of three parts:
  - **Cell Body:** Contains cytoplasm, organelles, and granular structures called Nissl's granules.
  - **Dendrites:** Projections that receive signals from other neurons.
  - **Axon**: Transmits signals to other neurons or tissues.
- Neurons transmit information through **electrochemical signals** (chemical and electrical impulses).
- Communication between neurons occurs at **synapses**, which are junctions between two neurons. Synapses may have a small gap called the **synaptic cleft**.

Brain

- The **brain** is the primary organ of information processing and control in the body.
- It is divided into three major regions:
  - **Fore-brain:** Manages higher cognitive functions such as thinking, sensory perception, and voluntary motor activity.
  - **Mid-brain:** Responsible for motor movements, particularly eye movement, and processes auditory and visual information.
  - **Hind-brain**: Comprising the **medulla oblongata**, **pons**, and **cerebellum**, it regulates essential survival functions, including breathing, heart rate, and sleep cycles.
- The brain is protected by **meninges** and enclosed within the skull for added protection.

Musculoskeletal System

Muscles: Muscle tissue is mesodermal in origin, making up 40-50% of adult body weight. Muscles exhibit properties like **excitability, contractility, extensibility,** and **elasticity**. Specific minerals like calcium, Iron and sodium play a part in muscle contraction. **[UPSC 2013]**

Types of Muscles:

- **Skeletal Muscle:**
  - Attached to bones, responsible for skeletal movements.
  - Controlled by the peripheral CNS, hence **voluntary**.
  - Striated fibres with multiple nuclei; each fibre acts independently.
- **Smooth Muscle**:
  - Found in walls of internal organs like blood vessels, GI tract, bladder.
  - Controlled by the autonomic nervous system (**involuntary**).
  - Non-striated, spindle-shaped, with a single central nucleus.
- **Cardiac Muscle**:
  - Found in the heart walls.
  - Striated like skeletal muscle but controlled involuntarily.
  - Strong, rhythmic contractions with a single central nucleus.

Skeletal System

- **Human skeleton** serves as the framework of the body, consisting of bones, cartilage, ligaments, and tendons.
- **Two subdivisions:**
  - **Axial Skeleton:** Includes the vertebral column (spine) and parts of the skull.
  - **Appendicular Skeleton:** Includes pelvic and pectoral girdles, and bones of limbs.

Joints

- **Joints** are points of contact between bones or bones and cartilages, classified into**:**
  - **Fibrous Joints:** Immovable (e.g., skull bones forming the cranium).
  - **Cartilaginous Joints:** Limited movement (e.g., between vertebrae).
  - **Synovial Joints:** Permit considerable movement with a fluid-filled cavity (e.g., ball-and-socket, hinge, pivot, gliding, saddle joints).
- **Bone Count:** Infants are born with around 300 bones, which fuse to form the **206 bones** in adults.

BLOOD AND BLOOD GROUPS

Blood is a fluid connective tissue and the most crucial component of the circulatory system. In a healthy person, approximately 5 litres (12 pints) of blood circulates throughout their body.

Blood Composition

- **Plasma**
  - Forms about 55% of total blood(by volume).
  - Contains proteins (fibrinogen, globulins, albumins) and minerals (Na+, Ca++, Mg++, etc.).
  - It contains Factors for coagulation present in inactive form; plasma without clotting factors is serum.
- **Elements**
  - **Erythrocytes (Red Blood Cells):** Most abundant; formed in red bone marrow; contain haemoglobin for gas transport; lifespan is about 120 days.
  - **Leucocytes (White Blood Cells):** It forms about 1% of blood volume. Colourless, nucleated; divided into granulocytes (neutrophils, eosinophils, basophils) and agranulocytes (lymphocytes, monocytes); involved in **immune responses**.
  - **Platelets:** It is involved in blood clotting; reduced numbers can lead to clotting disorders.
- **Lymph (Tissue Fluid):**
  - As blood flows through capillaries, some water and small solutes move into tissue spaces, forming interstitial fluid.
  - Lymphatic system collects this fluid, returning it to major veins; lymph is colourless and contains specialised lymphocytes for immune responses.
  - Lymph also carries nutrients and hormones; fats are absorbed through lymph in lacteals of intestinal villi.

ABO Blood Group System

The basis of ABO grouping is of two antigens- Antigen A and Antigen B. The ABO grouping system is classified into four types based on the presence or absence of antigens on the red blood cells surface and plasma antibodies.

Table: ABO Blood Groups & Donor Compatibility

Blood Group	Antigen on RBCs	Antibodies in Plasma	Donor's Group
A	A	anti- B	A, O
B	B	anti- A	B, O
AB	A, B	nil	AB, A, B, O
O	nil	anti- A, B	O

Meaning of Antigen and Antibodies: Name of Blood Group is based on the Antigen, a particular blood group contains Antibodies which attack a particular antigen.

For eg: Anti-B antibodies attack B antigen, thus Blood Group A person cannot take blood from Blood Group B person as Blood Group B contains B antigen which would be attacked by Antibody anti-B on Blood Group A person. **Blood Group O** has no antigen thus can donate to any blood group and is known as **Universal Donor**.

Rh Blood Group System

- About two-thirds of the population contains the third antigen on the surface of their red blood cells known as *Rh factor* or *Rh antigen*; this decides whether the blood group is positive or negative.
- If the Rh factor is present, an individual is *rhesus positive* (Rh+ve); if an Rh factor is absent individual is *rhesus negative* (Rh-ve) as they produce Rh antibodies.

CLASSIFICATION OF ORGANISMS

There are **seven main taxonomic ranks in decreasing order as follows**: **Kingdom**, **phylum** or **division**, **class**, **order**, **family**, **genus**,and **species**.

Five Kingdom Classification

R.H. Whittaker proposed a Five Kingdom Classification in 1969. The kingdoms classified by him were named **Monera**, **Protista**, **Fungi**, **Plantae** and **Animalia**.

Table: Characteristics of the Five Kingdoms

Characteristic	Monera	Protista	Fungi	Plantae	Animalia
Cell type	Prokaryotic	Eukaryotic	Eukaryotic	Eukaryotic	Eukaryotic
Cell wall	Noncellulosic (Polysaccharide + amino acid)	Present in some	Present (without cellulose)	Present (cellulose)	Absent
Nuclear membrane	Absent	Present	Present	Present	Present
Body organisation	Cellular	Cellular	Multiceullar/ loose tissue	Tissue/ organ	Tissue /organ/ organ system
Mode of nutrition	Autotrophic (chemosynthetic and photosynthetic) and Heterotrophic (saprophytic/ parasitic)	Autotrophic (Photosynthetic) and Heterotrophic	Heterotrophic (Saprophytic/ Parasitic)	Autotrophic (Photosynthetic)	Hetero-trophic (Holozoic/ Saprophytic etc.)

1. Kingdom Monera

- Bacteria are the **sole members of the Kingdom Monera.**
- Some of the **bacteria are autotrophic** ,but vast majority of bacteria are **heterotrophs**.
- The **Mycoplasma** are **organisms that completely lack a cell wall**. They are the **smallest living cells known and can survive without oxygen**. Many **mycoplasma induce diseases in animals and plants**.

2. Kingdom Protista

- All **single-celled eukaryotes are placed under Protista**.
- Members of **Protista are primarily aquatic**.
- The **protist cell body contains a well-defined nucleus and other membrane-bound organelles.**
- **Examples:** Ameoba, paramecium, plasmodium (malarial parasite)

3. Kingdom Fungi

- Fungi are **multicellular**, **with a cell wall** (**made up of Chitin**), organelles **including a nucleus**, but no chloroplasts.
- They have **no mechanisms for locomotion**.
- **Mushroom** Belongs to this Phylum. They are **saprophytic**, **decomposers**, **parasitic** or **coprophilous** (**growing on dung**). **[UPSC 2023]**
- **Mycorrhizal fungi** play a crucial role in **plant nutrient uptake**, **water relations**, **ecosystem establishment**, **plant diversity**, **and productivity of plants.** The fundamental importance of **mycorrhizal biotechnology in the restoration and to improve revegetation of disturbed mined lands is well recognised.** **[UPSC 2013]**

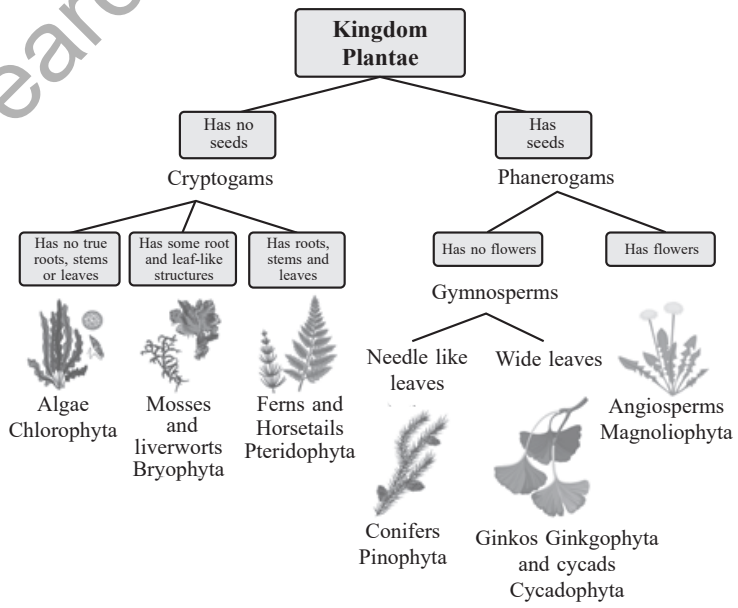
- **Mucormycosis** (also called **zygomycosis**) is a serious but rare fungal infection caused by a group of moulds called **mucormycetes**. It is also termed as **black fungus** due to the **necrosis of affected tissue of the patient's skin which turns it into black.**

4. Kingdom Plantae:

- It includes all eukaryotic chlorophyll-containing organisms commonly called plants.
- A few members are partially heterotrophic such as the insectivorous plants or parasites.
- Bladderwort and Venus fly trap are examples of insectivorous plants and Cuscuta is a parasite.

Classification of Plant Kingdom

- **Thallophytes(commonly called Algae)**
  - They are a group of simple, primitive, non-vascular plants in the plant kingdom.
  - They are primarily characterized by their undifferentiated body structure, called a thallus, which lacks true roots, stems, and leaves.
  - They are found mostly in aquatic and moist environments.
  - They are major carbon dioxide fixers; around 50% photosynthesis on earth is carried out by them.
  - **Common examples include:** Chlamydomonas, Spirogyra, Sargassum and Porphyra.
- **Bryophytes**
  - Bryophytes include the **various mosses** and **liverworts that are found commonly growing in moist, shaded areas in the hills**.
  - These are **also called amphibians of the plant kingdom because these plants can live in soil but are dependent on water for sexual reproduction**.
  - They lack **true roots, stems or leaves** (**may possess root-like, leaf-like or stem-like structures**).
- **Pteridophytes**
  - Pteridophytes are used for medicinal purposes and as soil- binders.
  - They are also frequently grown as ornamentals.
  - Evolutionarily, they are the first terrestrial plants to possess vascular tissues- xylem and phloem.

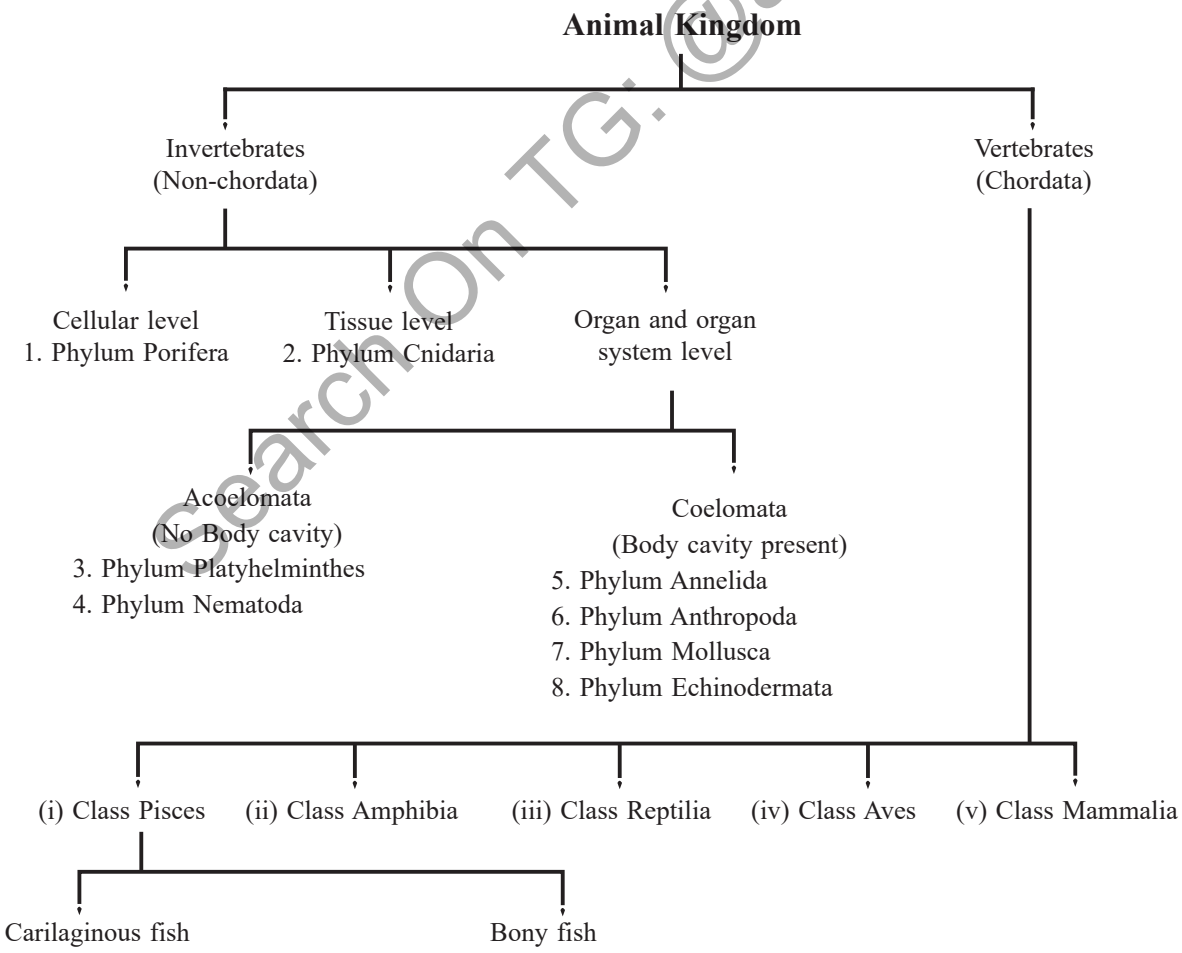


- **Gymnosperms**
  - The gymnosperms (**gymnos: naked**, **sperma: seeds**) are **plants in which the ovules are not enclosed by any ovary wall and remain exposed, both before and after fertilisation**.
  - The seeds **that develop post-fertilisation are not covered**, i.e., **are naked**.
  - Gymnosperms **include medium-sized trees** or **tall trees** and **shrubs.**
  - **Examples:** Cycas, Pinus, Ginkgo.
- **Angiosperms**
  - They are **also called Flowering plants**.
  - The **pollen grains** and **ovules are developed in specialised structures called flowers**.
  - The **male sex organ in a flower is the stamen.** The **female sex organ in a flower is the pistil**.
  - In **angiosperms**, the **seeds are enclosed in fruits**. The angiosperms **are an exceptionally large group of plants occurring in a wide range of habitats**.
  - **Examples:** Tomato, Mango, Hibiscus etc.

- When the bark of a tree is removed in a circular fashion all around near its base, it gradually dries up and dies because Roots are starved of energy **[UPSC 2011]**
- Lichens, which are capable of initiating ecological succession even on a bare rock, are actually a symbiotic association of Algae and and fungi **[UPSC 2014]**
- Fruits stored in a cold chamber exhibit longer storage life because rate of respiration is decreased **[UPSC 2013]**
- **Carbon Cycle:** carbon dioxide to the carbon cycle on the planet Earth added through Volcanic action, Respiration And Decay of organic matter. **[UPSC 2014]**

5. Animal Kingdom

- This kingdom is characterised by **heterotrophic eukaryotic organisms that are multicellular**, and **their cells lack cell walls.**
- They **directly or indirectly depend on plants for food**.
- Their mode of **nutrition is holozoic- by ingestion of food**.



Classification of Animals

Phylum	Characteristics	Examples
Porifera	Marine, asymmetrical, hermaphroditic, filter feeders	Sponges
Coelentrata (Cinidaria)	Aquatic, sessile/free-swimming, diploblastic	Coral reefs, Physalia (Portuguese man-of-war)
Platyhelminthes	Endoparasitic flatworms, bilaterally symmetrical	Taenia (tapeworm)
Aschelminthes	Roundworms, distinct sexes	Ascaris (roundworm)
Annelida	Segmented, aquatic/terrestrial	Pheretima (earthworm)
Arthropoda	Largest phylum, chitinous exoskeleton, open circulation	Apis (honey bee), Anopheles (mosquito)
Mollusca	Terrestrial/aquatic, calcareous shell	Pila (apple snail)
Echinodermata	Marine, calcareous endoskeleton, water vascular system	Asterias (starfish)
Chordata	Notochord, dorsal nerve cord, divided into three subphyla	

Hibernation [UPSC 2014]

Hibernation is a seasonal heterothermy characterized by low body-temperature, slow breathing and heart-rate, and low metabolic rate.

The phenomenon of hibernation can be observed in 1. Bats 2. Bears 3. Rodents

Aestivation

Aestivation is a state of dormancy that animals enter to survive in hot and dry conditions. Observed in snail, frog, salamander, desert tortoise etc.

3 Biotechnology

BIOTECHNOLOGY

It is the **application of the principles of engineering** and **biological science to create new products from raw materials of biological origin**, for example, **vaccines** or **food**. The two core fields that enabled the birth of modern biotechnology are:

- **Genetic Engineering:** It includes techniques to alter the chemistry of genetic material (DNA and RNA) to introduce these into host organisms and thus change the phenotype of the host organism.
- **Bioprocess Engineering**: Maintenance of sterile (**microbial contamination-free**) ambience in chemical engineering processes to enable growth of only the desired **microbe/eukaryotic cell in large quantities for the manufacture of biotechnological products like antibiotics, vaccines, enzymes,** etc.

BASICS OF GENETICS

Gene

- A gene is a segment of DNA that contains the necessary information to produce a functional product, typically a protein. Genes can vary in size and function, with humans estimated to have about 20,000-25,000 genes. Genes can be classified into:
  - **Structural Genes:** Code for proteins.
  - **Regulatory Genes:** Control the expression of other genes.
  - **Non-coding Genes:** Do not code for proteins but have regulatory functions.

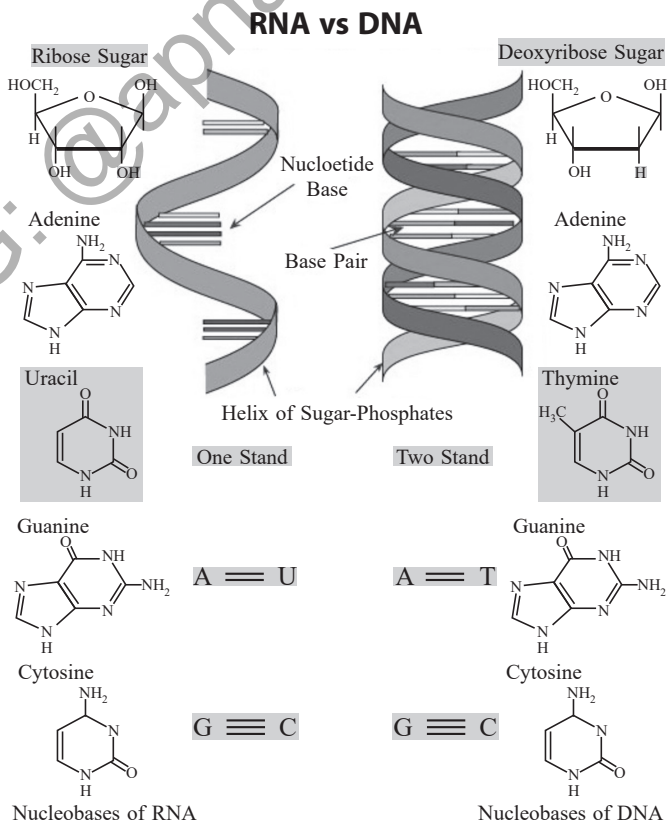
DNA

- Deoxyribonucleic Acid (DNA) is a molecule that contains the genetic instructions for the development, functioning, growth, and reproduction of all known organisms and many viruses.
- DNA is composed of two long strands that form a double helix, consisting of four nucleotide bases: **Adenine (A), Thymine (T), Cytosine (C) and Guanine (G)**.
- The sequence of these bases encodes genetic information. The specific pairing of the bases (A with T, and C with G) allows for the replication of DNA.

Chromosome

- **Chromosomes** are thread-like structures composed of DNA and proteins, found in the nucleus of most living cells. They carry genetic information in the form of genes, which determine the hereditary traits passed from one generation to the next.
- Each species has a characteristic number of chromosomes in its cells; for example, humans have 46 chromosomes, organized into 23 pairs.

RNA



- **RNA (Ribonucleic Acid)** is a single-stranded molecule involved in various biological roles, primarily related to the synthesis of proteins and the transmission of genetic information.
- It is similar to DNA but differs in several key aspects, such as **having ribose sugar instead of deoxyribose** and using the **nitrogenous base uracil (U) instead of thymine (T)**.
- RNA consists of four nitrogenous bases: Adenine(A), Cytosine(C), Uracil(U), and Guanine(G).

Protein Synthesis

- Flow of Genetic Information from DNA to Proteins.
- Central Dogma states that the genetic information flows from DNA to RNA to Protein.

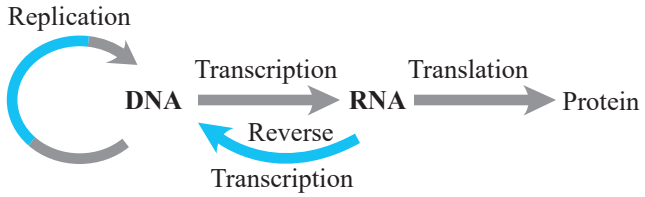


Fig: Flow of Genetic Information

- **DNA Replication:** DNA replication is the process by which DNA makes a copy of itself during cell division.
- **Transcription:** The process by which a cell makes an RNA copy of a piece of DNA. This RNA copy, called messenger RNA (mRNA), carries the genetic information needed to make proteins in a cell. As mRNA attaches to ribosome to start protein synthesis, tRNA brings amino acids to make a chain of amino acids which ultimately forms the protein.
- **Translation:** The process by which a cell makes proteins using the genetic information carried in messenger RNA (mRNA). The mRNA is made by copying DNA, and the information it carries tells the cell how to link amino acids together to form proteins. Translation takes place in the cytoplasm of a cell on ribosomes.

Dark DNA

- **Dark DNA** refers to genomic regions that are difficult to detect or interpret using standard sequencing methods, often due to high mutation rates or repetitive sequences.
- While traditionally considered **"junk DNA,"** recent research suggests that dark DNA may play roles in gene regulation, evolution, and species adaptation, though its precise functions remain under investigation.

Adenovirus and Retrovirus

Virus Type	Adenovirus	Retrovirus
Genome	DNA	RNA
Envelope	Non-enveloped	Enveloped
Mechanism of Infection	Enters through endocytosis; DNA replicates in the nucleus without integration into the host genome	RNA converted into DNA via reverse transcriptase; integrates into the host genome
Replication Site	Nucleus (no integration)	Integrates into the host genome
Key Enzymes	None (direct DNA replication)	Reverse transcriptase, Integrase
Acute/ Chronic Infection	Acute (short-term infection)	Chronic (long-term infection)
Examples	Human Adenovirus, Adenovirus vectors	HIV, HTLV, SARS-CoV-2 (Coronavirus)

GENOME SEQUENCING

- It is the process of determining the complete DNA sequence of an organism's genome. It involves identifying the exact order of the four nucleotide bases (adenine, thymine, cytosine, and guanine) across all chromosomes.
- Genome sequencing provides insights into genetic makeup, allowing researchers to study genes, understand hereditary traits, identify mutations linked to diseases, and drive advancements in personalized medicine and biotechnology.

Human Genome Project [UPSC 2011]

- In the 1980s, scientists began discussing the possibility of sequencing all **3.2 billion nucleotide pairs** in the human genome.
- These discussions led to the launch of the Human Genome Project in 1990. The initial goals of the Human Genome Project were:
  - To map all the human genes,
  - To construct a detailed physical map of the entire human genome, and
  - To determine the nucleotide sequence of all 24 human chromosomes by the year 2005.

Genome India Project

- The Genome India Project, initiated by the **Department of Biotechnology in 2020**, aims to sequence the genomes of 10,000 individuals across India.
- By analyzing this genetic data, the project seeks to understand disease patterns and support predictive diagnostics, personalized medicine, and targeted preventive care.
- Led by the **Centre for Brain Research at IISc, Bengaluru**, and involving 20 institutions, the project advances India's capabilities in next-generation healthcare and precision medicine.

Human Microbiome Initiative of Select Endogamous Population of India

- This project aims to comprehensively characterize human-associated microbes in diverse endogamous groups, including tribal populations with minimal modern lifestyle influence.
- The study examines how diet, lifestyle, geography, and age affect the gut microbiome using metagenomic approaches.
- It also explores potential links between **microbial enterotypes** and the **three distinct Ayurvedic Prakriti types**, enhancing understanding of the microbiome's role in health and disease.

Earth Bio-Genome Project

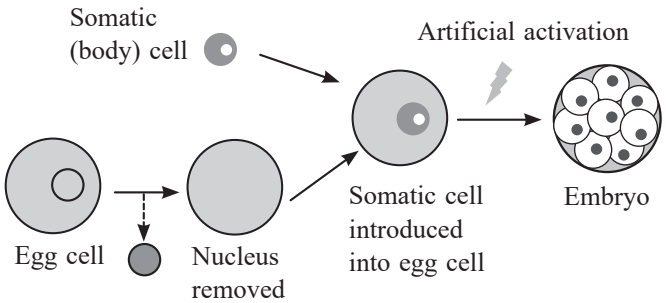
- The Earth Bio-Genome Project is a project aiming at analysing and sequencing genomes and building a new basis for biology to drive solutions for biodiversity preservation and human society sustainability.
- The Earth Bio-Genome Project (EBP) is a worldwide group of scientists who plan to sequence, classify, and characterise the genomes of all eukaryotic biodiversity on Earth over the course of ten years.
  - It's a global catalogue of life on the planet.
  - In three phases, it hopes to sequence 1.5 million species.
- The EBP project will assist in the creation of a precise genetic sequence as well as the discovery of evolutionary relationships between the species, orders, and families that will make up the Digital Library of Life.

[UPSC 2017]

Transcriptome refers to the protein-coding part of an organism's genome. It refers to the set of RNA molecules such as messenger RNA (mRNA), transfer RNA (tRNA), ribosomal RNA (rRNA), and other noncoding RNA molecules that are present in cells. **[UPSC 2016]**

Aerial metagenomics typically refers to the study of genetic material (such as DNA or RNA) collected from the air, usually in the form of airborne particles or aerosols. **[UPSC 2023]**

Somatic Cell Nuclear Transfer



In genetics and developmental biology, somatic cell nuclear transfer (SCNT) is a laboratory strategy for creating a viable embryo from a body cell and an egg cell.

Process of SCNT

- **Extraction of Somatic Cell:** A somatic cell is taken from the organism to be cloned. The cell contains the full DNA of the organism.
- **Enucleation of Egg Cell:** An egg cell is collected from a donor female, and its nucleus (which contains genetic material) is removed, leaving an enucleated egg.
- **Nuclear Transfer:** The nucleus from the somatic cell is then inserted into the enucleated egg. This step allows the egg to have the full DNA of the donor organism.
- **Activation and Development:** The reconstructed egg is stimulated (either electrically or chemically) to begin dividing and developing, just like a fertilized egg. It starts to divide into a blastocyst, a pre-embryonic stage.
- **Embryo Implantation:** The developing embryo is implanted into the uterus of a surrogate mother, where it continues to develop into a full organism.

Applications of SCNT

- **Cloning:** SCNT is most famously used for cloning organisms, such as the cloning of **Dolly the sheep** in 1996. This was the first mammal cloned from an adult somatic cell.
- **Therapeutic Cloning:** SCNT can be used to create stem cells for therapeutic purposes. These stem cells are genetically identical to the donor organism, making them useful for studying diseases, drug development, and regenerative medicine.
- **Conservation:** SCNT has been explored as a potential tool for cloning endangered species, helping preserve genetic diversity.

Ethical and Scientific Considerations

While SCNT holds promise in various fields such as medicine and conservation, it raises several ethical concerns, particularly regarding animal welfare and the implications of cloning humans. Additionally, SCNT is often inefficient, with a high rate of failure and abnormal development in the cloned organisms. **[UPSC 2017]**

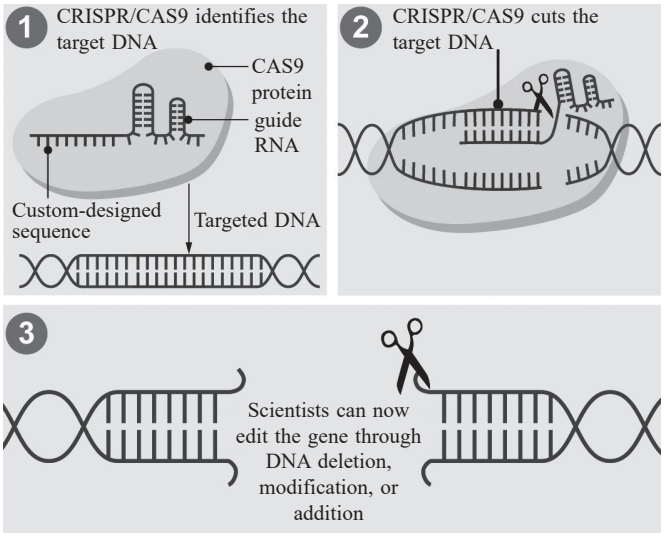
The INDIgen Project

- It was launched by the **CSIR**, aims to sequence the whole genomes of thousands of Indian individuals to create a comprehensive database reflecting India's diverse population.
- The project seeks to understand the genetic diversity of India and its impact on health, disease susceptibility, and drug response.
- It also supports the development of personalized medicine, predictive diagnostics, and precision healthcare for the Indian population.

GENOME EDITING

Genome editing, also known as genome engineering or gene editing, is a sort of genetic engineering that involves inserting, deleting, modifying, or replacing DNA in a living organism's genome.

Genome Editing Techniques [UPSC 2020]



1. **Clustered regularly interspaced short palindromic repeats (CRISPR)- CRISPR- associated protein 9 (Cas9)**: CRISPR is the DNA-targeting component of the system, and it is made up of an RNA molecule, or guide, that is engineered to attach to certain DNA bases via complementary base-pairing. CRISPR-associated protein 9 **(Cas9)** is the nuclease component that cuts the DNA.

   The CRISPR-Cas9 genetic scissors were discovered by Emmanuelle Charpentier and Jennifer A. Doudna, who won the Nobel Prize in Chemistry in 2020. **[UPSC 2019]**
2. **Transcription activator-like effector nucleases (TALENs)**: Transcription activator-like effector (TALE) domains make up the DNA-binding domain of TALENs.
3. **Zinc-finger nucleases (ZFNs):** ZFNs are fusions between a custom-designed Cys2-His2 zinc-finger protein and the cleavage domain of the FokI restriction endonuclease. FokI cleavage domain, which cuts DNA within a five- to seven-bp spacer sequence that separates two flanking zinc-finger binding sites.
4. **Homing endonucleases or mega-nucleases:** Homing endonucleases, also known as mega-nucleases.
   - These enzymes make extensive sequence-specific contacts with their DNA substrate.
   - However, unlike ZFNs and TALENs, the binding and cleavage domains in homing endonucleases are not modular.

RNA INTERFERENCE (RNAI) [UPSC 2019]

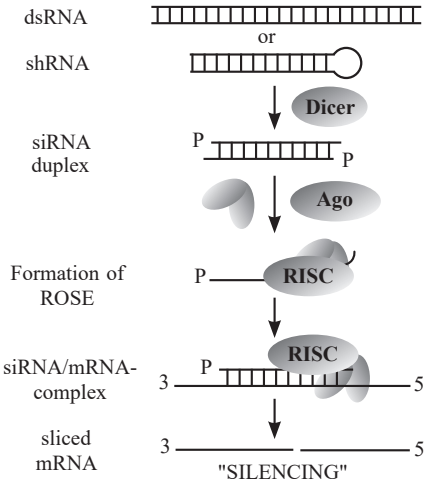
RNA interference (RNAi) is a natural process used by cells to regulate gene expression and defend against viruses. It works by silencing specific genes so that they do not produce proteins.

- **Triggering RNAi:**
  - **The process starts when double-stranded RNA (dsRNA)** enters the cell. This can happen naturally (from a virus) or artificially (scientists can introduce dsRNA to silence specific genes).
- **Dicing the RNA:**
  - An enzyme called Dicer cuts the dsRNA into **small pieces called small interfering RNA (siRNA)**. These are short RNA fragments, about 21-23 nucleotides long.
- **Forming the RISC Complex:**
  - The siRNA pieces are loaded into a protein complex called the **RNA-induced silencing complex (RISC)**. RISC removes one strand of the siRNA, keeping the strand that matches the target mRNA (messenger RNA).
- **Targeting the mRNA:**
  - The siRNA guides RISC to the target mRNA (the molecule that carries the instructions to make a protein). The siRNA binds to the mRNA because they have a matching sequence.
- **Silencing the Gene:**
  - Once bound, RISC cuts the mRNA into pieces, destroying it. Without the mRNA, the cell cannot make the protein encoded by the gene, effectively silencing it.

Applications

- **Research:** Scientists use RNAi to study what specific genes do by turning them off.
- **Medicine:** RNAi-based drugs are being developed to treat diseases like cancer, viral infections, and genetic disorders by silencing harmful genes.

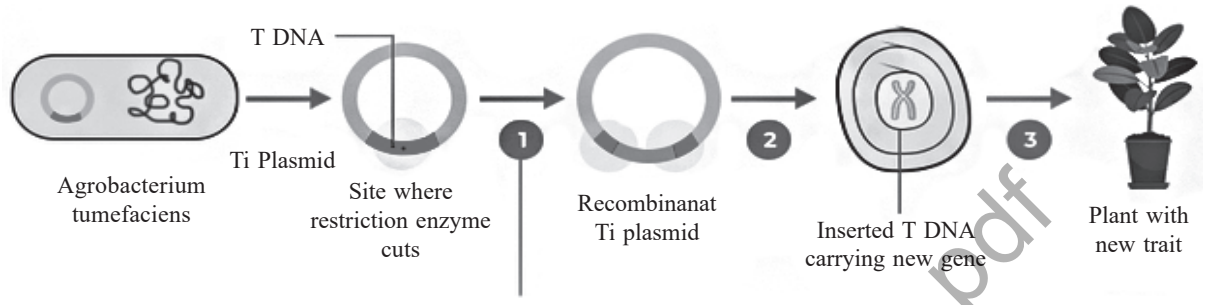
RNAi is like a "**mute button**" for genes, helping cells control which proteins are made.It is used as protection against unwanted invaders like viruses.



Production of Pest-resistant Plants using RNAi

- Several nematodes parasitise a wide variety of plants and animals, including human beings.
- A nematode, **Meloidogyne incognita**, infects the roots of **tobacco plants** and causes a great reduction in yield. A novel strategy was adopted to prevent this infestation which was based on the process of RNA interference (RNAi).
- Using **Agrobacterium vectors**, nematode-specific genes were introduced into the host plant.
- The consequence was that the parasite could not survive in a transgenic host expressing specific interfering RNA.

RECOMBINANT DNA TECHNOLOGY [UPSC 2013]



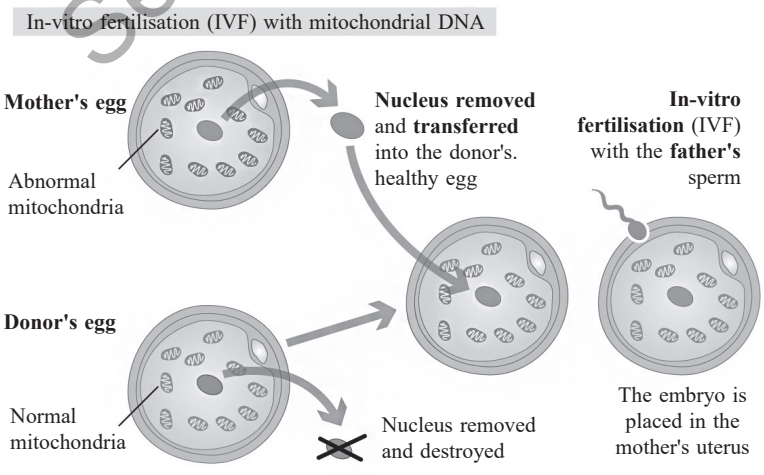
- This technology Combines DNA from different sources to modify genetic makeup.
- **Recombinant DNA:** A DNA molecule made **in vitro with segments from different sources**.

Steps:

- **Restriction Enzymes**:
  - Cut DNA at specific sequences to create fragments.
  - These fragments are combined with DNA from other organisms.
- **Cloning Vectors**:
  - Vectors like plasmids carry recombinant DNA into host cells.
  - Key elements in vectors:
    - **Origin of replication**: Ensures DNA replication in the host.
    - **Selectable markers:** Help identify successful recombinants.
    - **Cloning sites:** Allow insertion of foreign DNA.
- **Methods of DNA Insertion**:
  - **Micro-injection**: DNA injected into the nucleus of animal cells.
  - **Biolistics:** DNA-coated metal particles are shot into plant cells.
- **PCR (Polymerase Chain Reaction):** Amplifies the gene of interest to produce many copies.
- **Gene Expression:** Transformed cells express the desired gene and produce useful products (e.g., proteins, enzymes).
- **Applications**:
  - **Medicine:** Production of insulin and vaccines.
  - **Agriculture:** Genetically modified crops.
  - **Research:** Gene therapy, functional genomics.

THREE PARENT BABY/ MITOCHONDRIAL REPLACEMENT THERAPY [UPSC 2021]

The technique involves using DNA from three people in order to prevent serious inherited diseases



Mitochondria

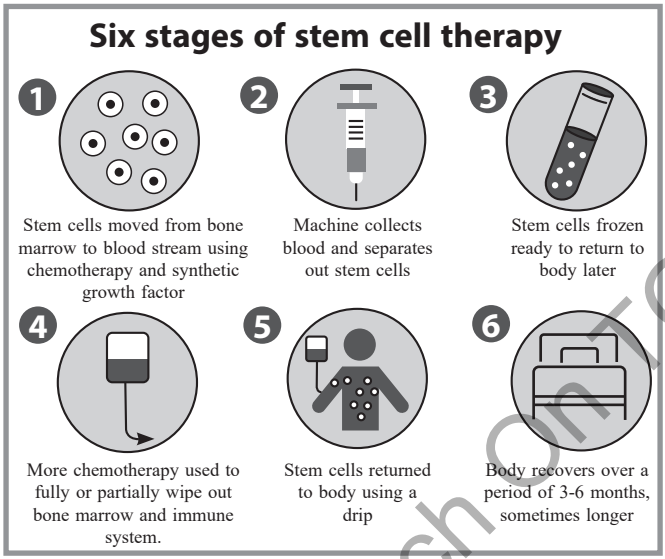
"Powerhouses" of the cell that have their own genome

Unknown Risks

Uncertainties remain over the interaction between the mother's nuclear DNA and the donor's mitochondrial DNA

- Involves conceiving a child from IVF (in vitro fertilization) using the genetic material of the parents and the mitochondrial material of a donor.
- Diseased mitochondria are replaced by healthy mitochondria in order to avoid transfer of mitochondrial diseases from the mother to the offspring. Done either before or after IVF of the egg.
- Also known as **Mitochondrial Replacement Therapy (MRT)** and Three-parent babies process. Latter name is used due to involvement of three persons.
- **Mechanism:** Embryo from the biological parents is combined with mitochondria from the donor's egg.
- **Most common techniques:** Maternal Spindle Transfer (MST) Technique and Pronuclear Transfer (PNT) technique (substitute to MST). **[UPSC 2020]**
- In both techniques, eggs or embryos are created using nuclear genetic material and healthy donated mitochondria.

STEM CELL THERAPY [UPSC 2012]



Stem cell therapy, also known as **regenerative medicine**, promotes the repair response of diseased, dysfunctional or injured tissue using stem cells or their derivatives.

- Researchers grow stem cells in a lab.
- These **stem cells are manipulated to specialise into specific types of cells, such as heart muscle cells, blood cells or nerve cells**.
- The specialised cells can then be implanted into a person.

The Main Sources are:

- Embryonic tissue,
- Fetal tissues, such as fetus, placenta (i.e., amnion and chorion), amniotic fluid and umbilical cord (wharton jelly, blood),
- Specific locations in the adult organism, Example: Fat, bone marrow, skeletal muscle, skin or blood.
- Differentiated somatic cells after they have been genetically reprogrammed.

BIOTECHNOLOGICAL APPLICATION IN AGRICULTURE

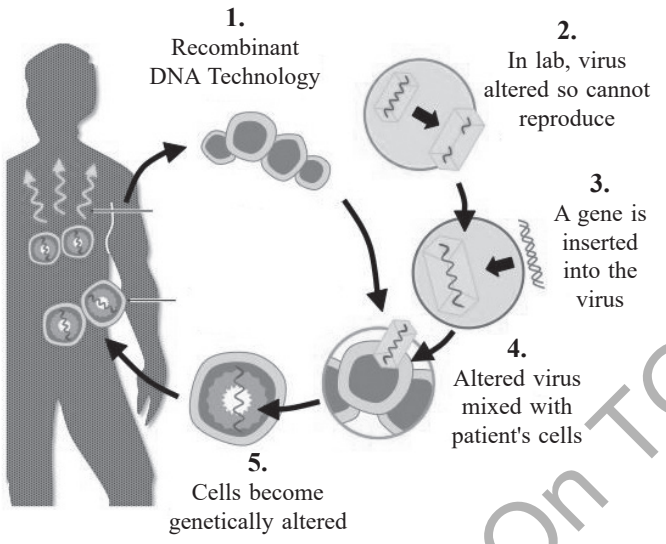
- **Genetically Modified (GM) Crops**: GM crops, like **Bt cotton** and **Golden Rice**, are engineered for improved traits. Bt cotton, containing *Bacillus thuringiensis* (Bt) toxin genes, offers resistance to bollworms, reducing pesticide use. **Bollgard I** (single-gene technology) is India's first biotech crop technology (Genetically modified crop) approved for commercialization in India in 2002, followed by **Bollgard II** – (double-gene technology) in mid-2006. **[UPSC 2021]**
  - **Golden Rice** is biofortified with vitamin A to combat malnutrition.
  - **Bt Brinjal** is a transgenic brinjal developed by introducing the **cry1Ac gene from the Bacillus thuringiensis** soil bacterium into Brinjal. This brinjal has been genetically modified to withstand insects like the Brinjal Fruit and Shoot Borer (Leucinodes orbonalis). **[UPSC 2012]**
  - Cytoplasmic male sterility and Gene silencing technique are used to create transgenic crops. **[UPSC 2014]**
- **Pest and Disease Resistance**: Biotech enables plants to resist pests and diseases. For example, crops engineered with **Cry proteins** from Bt bacteria protect against pests like cotton bollworms and corn borers.
- **Herbicide Resistance**: Crops like **Roundup Ready soybeans** are modified to withstand herbicides, allowing farmers to control weeds without harming crops.
- **Improved Nutritional Content**: Genetic modifications enhance the nutritional profile of crops, like **biofortified wheat and rice** with higher protein or iron content.
- **Tissue Culture and Micropropagation**: These methods help in the rapid propagation of plants, ensuring uniformity and disease-free planting material.
- **Biofertilizers and Biopesticides**: These eco-friendly options reduce chemical input by using microbial cultures that fix nitrogen or target pests naturally, promoting sustainable agriculture.Some species of Bacteria, Fungi and Flowering plants are employed biopesticides. **[UPSC 2012]**
- **Food Fortification**

  It is **the practice of adding vitamins and minerals to commonly consumed foods during processing to increase their nutritional value** and is a proven, safe and cost-effective strategy for improving diets and for the prevention and control of micronutrient deficiencies.
  - **Biofortification:** It is the process in which food crops with improved nutritional value are grown, and these projects mainly concentrate on **boosting iron**, **zinc**, **amino acids** and **provitamin A carotenoid** in different food crops.
  - Example: iron biofortification of rice, beans, maize and sweet potato; zinc biofortification of wheat, rice, beans, sweet potato and corn; and Vitamin A biofortification of sweet potatoes, corn and cassava.

Regulations of GMs in India

- **EPA,1986:** The Environment Protection Act of 1986 notified the rules governing the management of genetically modified organisms (GMOs) and their products in 1989, with guidelines provided later.
- **GEAC:** The Genetic Engineering Appraisal Committee (GEAC) functions in the **Ministry of Environment, Forest and Climate Change (MoEF&CC)**. As per Rules 1989, it is responsible for the appraisal of activities involving large-scale use of hazardous microorganisms and recombinants in research and industrial production from the environmental angle.

BIOTECHNOLOGICAL APPLICATION IN MEDICINE



- **Recombinant DNA Technology**: Enables the production of essential proteins like **insulin** and **human growth hormone**. Recombinant insulin, produced by inserting the insulin gene into bacteria, is widely used in diabetes management.
- **Gene Therapy**: Used to treat genetic disorders by correcting defective genes. For instance, **Adenosine Deaminase (ADA) Deficiency**, a form of severe combined immunodeficiency **(SCID)**, is treated by introducing functional ADA genes into patients.
- **Vaccines**: Biotechnologically produced vaccines, such as the **Hepatitis B vaccine**, are developed using recombinant DNA techniques, enhancing safety and effectiveness.
- **Monoclonal Antibodies**: These lab-made antibodies target specific cells or proteins, useful in treating diseases like **cancer** and **autoimmune disorders** (e.g., **Rituximab** for lymphoma).
- **Stem Cell Therapy**: Stem cells are used to regenerate damaged tissues. This has applications in treating **spinal cord injuries**, **Parkinson's disease**, and **heart diseases**.
- **Pharmacogenomics**: Studies how genes affect individual responses to drugs, paving the way for **personalized medicine**, which customizes treatments based on a patient's genetic profile.

BIOTECHNOLOGICAL APPLICATION IN ENVIRONMENT

Environmental biotechnology, specifically, refers to the use of procedures to safeguard and restore the environment's quality.

- **Biorock Technology:**

  Biorock is the name given to the substance formed by the electro-accumulation of minerals dissolved in seawater on steel structures that are lowered onto the sea bed and are connected to a power source, e.g., solar panels that float on the surface. It has been used for **Coral restoration.** **[UPSC 2022]**

Other Techniques	
Bioremediation	Bioremediation is the process of using microorganisms to remove or detoxify toxins from soils, water, or sediments that would otherwise be harmful to human health.
Phytoremediation	Phytoremediation is a bioremediation process that uses various types of plants to remove, transfer, stabilise, and/ or destroy contaminants in the soil and groundwater.
Phyto-degradation	In this process, plants actually metabolize and destroy contaminants with in plant tissues.
Phyto-volatilization	In this process, plants take up water containing organic contaminants and release the contaminants into the air through their leaves.
Biosensors	A biosensor is an analytical device that converts a biological response into a physical, chemical or electrical signal.

DNA BARCODING

- **DNA barcodes** consist of **a standardized short sequence of DNA (400-800 base pairs)** that in principle should be easily generated and characterized for all species on the planet. **A massive online digital library of barcodes will serve as a standard to which the DNA barcode sequence of an unidentified sample from the forest, garden, or market can be matched**.

- Applications of DNA barcoding **include the identification of new species, safety assessment of food, identification and assessment of cryptic species, detection of alien species, identification of endangered and threatened species** etc. **[UPSC 2022]**

GENE SILENCING/METHYLATION

- Gene silencing is the regulation of gene expression in a cell to prevent the expression of a certain gene.The predominant mechanism involves the methylation of DNA.
- When genes are silenced, their expression is reduced.
  - Ex: the researchers designed two small RNA molecules that **silence the fungal genes which produce aflatoxin in Groundnut.**

Applications of Gene Silencing

- Specific gene silencing using RNAi in cell culture.
- Cancer treatments
- RNA interference has been used for applications in biotechnology.
- Useful in epigenomic analysis and clinical application of molecular diagnosis.
- Neuro-degenerative disorders treatment.

DNA PROFILING OR DNA FINGERPRINTING

- **DNA Profiling** is a forensic technique used to obtain a unique DNA pattern (profile) from an individual or tissue sample. It assists in criminal investigations by comparing suspects' DNA profiles with evidence to determine involvement in crimes. Additionally, it is used for parentage testing, immigration eligibility, and genealogical and medical research.
- **Microsatellite DNA** refers to short, repetitive DNA segments (1-6+ base pairs) that vary among individuals. These non-coding sequences serve as polymorphic markers, valuable for studying inheritance patterns and creating DNA fingerprints in forensic analysis. **[UPSC 2023]**

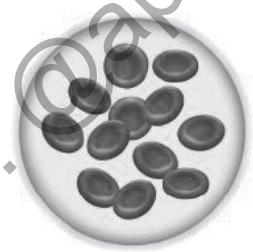
GENETIC DISORDERS

- A genetic disorder is a disease that is caused by a change, or mutation, in an individual's DNA sequence.
- The three main categories are:
  - **Single Gene Disorders**: Disorders caused by defects in one particular gene, often with simple and predictable inheritance patterns. Example: **Huntington's disease, Cystic fibrosis.**
  - **Chromosome Disorders**: Disorders resulting from changes in the number or structure of the chromosomes. Example: **Down's syndrome,** which results from an extra chromosome 21.
  - **Multifactorial Disorders** (Complex Diseases): Disorders caused by changes in multiple genes, often in a complex interaction with environmental & lifestyle factors such as diet or cigarette smoke. Example: **Cancer.**

Mutation

- Mutations are changes in the genetic sequence, and they are the main cause of diversity among organisms.
- A single mutation can have a large effect, but in many cases, evolutionary change is based on the accumulation of many mutations with small effects.
- Example: **Sickle cell anaemia** disease in humans caused due to single gene mutation

Sickle Cell Anaemia



Normal red blood cells

Sickle cell anemia

- It is an inherited blood disorder in affected individuals at birth, causing the production of abnormal haemoglobin.
- Normally, the haemoglobin protein, which resides inside red blood cells, attaches to oxygen in the lungs and carries it to all parts of the body.
- In **sickle cell disease, the haemoglobin is abnormal, causing the red blood cells to be rigid and shaped like a C or sickle,** the shape from which the disease takes its name.
- Sickle cells can get stuck and block blood flow, causing pain and infections.

Biometric Identification **[UPSC 2014]**

Fingerprint, Iris scanning, Retinal scanning and Voice recognition are used for biometric identification of person.

4 Health and Diseases

Definition of Health: According to the WHO, "Health is a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity." Health encompasses various dimensions, including physical, mental, social, emotional, and spiritual well-being.

BASIC CONCEPTS

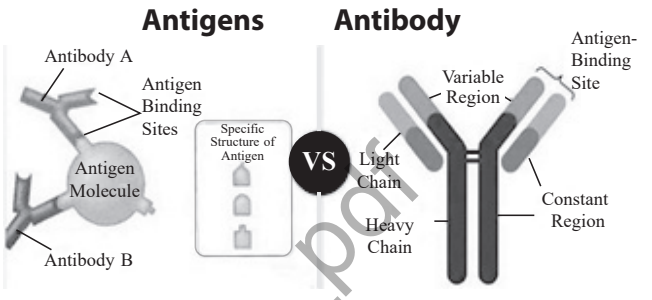
Pathogens

Pathogens are microorganisms causing diseases in plants and animals. Most are parasites that harm their hosts. The main categories include:

1. **Bacteria:**
   - Prokaryotic microorganisms that can produce toxins and elicit strong immune responses.
   - **Example:** Streptococcus bacteria can cause strep throat.
2. **Viruses:**
   - Obligate intracellular parasites that can only replicate inside a host cell.
   - **Example:** The influenza virus leads to seasonal flu outbreaks.
3. **Protozoans:**
   - Unicellular eukaryotes, often free-living or parasitic.
   - **Example:** Plasmodium, which causes malaria, is transmitted by mosquitoes.
4. **Helminths:**
   - Multicellular parasitic worms visible to the naked eye, living in hosts' bodies.
   - **Example:** Tapeworms inhabit the gastrointestinal tract.
5. **Fungi:**
   - Eukaryotic organisms that absorb organic matter from their environment.
   - **Example:** Candida species can cause opportunistic infections. **[UPSC 2021]**

Antigen and Antibody

Antigens trigger immune responses, while antibodies neutralise pathogens, forming the basis of adaptive immunity.



Feature	Antigen	Antibody
Also Called	Immunogens	Immunoglobulins
Molecular Type	Lipids, proteins, carbohydrates, nucleic acids	Proteins
Effect	Cause allergic reactions and illnesses	Protect against antigens
Specific Binding Site	Epitopes (regions on antigens)	Paratopes (variable regions on antibodies)
Origins	Originates outside the body	Originates within the body

IMMUNITY AND VACCINES

Immunity

Immunity is the body's defence mechanism against infections caused by foreign antigens from bacteria, viruses, fungi, toxins, and foreign substances. It can be categorised into several types:

1. **Humoral Immunity:**
   - Activated by B lymphocytes, which produce antibodies to neutralise pathogens and their toxins. These antibodies complement proteins that target specific diseases. **[UPSC 2022]**
2. **Cellular Immunity:**
   - Involves T lymphocytes that directly attack infected cells and help regulate the immune response through cytokines. **[UPSC 2022]**
3. **Types of Immunity:**
   - **Innate Immunity:**
     - The first line of defence, including physical barriers (skin, mucus) and reflexes (cough).

- **Acquired Immunity:**
  - Developed through exposure to infectious agents or vaccines, providing long-term protection.
  - Immunity can be acquired either actively or passively; thus enabling active and passive immunity respectively.
  - **Active Immunity:** It develops when the immune system produces its own antibodies in response to exposure to an antigen. It is usually longer lasting compared to passive immunity. Based on how it is acquired it cab be further classified into:
  - **Natural Active Immunity:** Acquired through natural exposure to a pathogen (ex- recovering from an infection like chickenpox).
  - **Artificial Active Immunity:** Acquired through vaccination, where a weakened or inactivated pathogen, or a part of it, is introduced to stimulate the immune system. ex- COVID vaccine.
  - **Passive Immunity:** Temporary immunity gained through the transfer of antibodies from another individual, such as maternal antibodies to a foetus or antiserum for short-term protection against diseases like hepatitis.

    Example: Covid Plasma Therapy
- **Herd Immunity:**
  - When a significant portion of a population is immune, reducing the spread of infectious diseases.
- **Immunoglobulins:**
  - Antibodies produced in response to antigens, classified into five major types (IgG, IgM, IgA, IgD, IgE), providing protection against pathogens.

4. **Immunotherapy:**
   - A treatment method that enhances the immune system to fight diseases, particularly cancer.
5. **Monoclonal Antibodies:**
   - Artificially generated antibodies targeting specific antigens to assist the immune response.

Vaccines

Vaccines are biological preparations that contain weakened, killed, or fragmentary microorganisms or their toxins. They are primarily used to prevent diseases and can be administered through various methods, including injections, oral, or nasal routes.

Types of Vaccines

1. **Weakened (Attenuated) Vaccines:**
   - Composed of live microorganisms that have been modified to reduce their virulence. Examples include vaccines for measles, mumps, rubella, and oral polio-OPV **(Sabin vaccine)**.
2. **Inactivated Vaccines:**
   - Contains killed or inactivated organisms. These vaccines often require higher doses for an effective immune response. Examples include vaccines for rabies and injectable polio- IPV **(Salk vaccine)**.
   - **Exmaple:** HPV, Hepatitis B
3. **Subunit Vaccines:**
   - Made from specific proteins of the infectious agents, including toxoids inactivated to stimulate immunity. Examples include vaccines for **tetanus and diphtheria.**
4. **Recombinant DNA Technology Vaccines:**
   - Use genetic material from pathogens to induce an immune response without causing disease. Examples include some modern vaccines developed using viral vectors.
5. **Conjugate Vaccines:**
   - Conjugate vaccines enhance immune responses by **linking weak antigens, such as bacterial polysaccharides, to strong protein antigens.** This combination helps stimulate a robust immune response, including activation of T-helper cells, making them especially effective in young children, whose immune systems may not respond well to polysaccharides alone.
   - These vaccines are critical for preventing infections caused by encapsulated bacteria, such as **Haemophilus influenzae type b (Hib), Streptococcus pneumoniae (in Pneumococcal Conjugate Vaccine)**, and **Neisseria meningitidis** (in Meningococcal Conjugate Vaccine). They provide long-lasting protection and have significantly reduced the burden of diseases like pneumonia and meningitis.
6. **Messenger RNA (mRNA) Vaccines:**
   - Deliver mRNA that instructs cells to produce antigens, triggering an immune response. An example is **GEMCOVAC-19,** India's first indigenous mRNA vaccine for COVID-19.

Mission Indradhanush

Launched in 2014 by the Government of India, **Mission Indradhanush** aims to enhance vaccination coverage for children and pregnant women, particularly in underserved areas. The program targets ten diseases, including:

- Tuberculosis,
- Polio
- Hepatitis B
- Diphtheria
- Pertussis
- Tetanus
- Measles
- Rubella
- Rota virus
- Haemophilus Influenzae type b
- Japanese Encephalitis (sub national) and
- Pneumococcal Pneumonia (sub national).

COMMUNICABLE DISEASES

- **Infectious diseases** are a **leading cause of death in children** and **young adults worldwide**. **Lower respiratory infections**, **diarrhoeal diseases**, and **tuberculosis** are among the **most common and deadliest types of infectious diseases**.
- Based on the causative agents, these diseases can be classified as:
  - Bacterial
  - Viral
  - Parasitic
  - Fungal

Bacterial Diseases

- Bacteria are **unicellular organisms** that **reproduce sexually** or **asexually** and **can exist in an environment with oxygen (aerobic)** or in **a situation lacking oxygen (anaerobic)**. Some may enter **a dormant state** and **form spores where they are protected from the environment** and **may remain viable for years**.

Table: Bacterial Diseases

Disease	Agent	Vector/Transmission	Treatment/Prevention
Tuberculosis	Mycobacterium tuberculosis **(usually attacks lungs but can affect any part of body)**	Air-Borne	Prevention: Bacille Calmette-Guérin (BCG) Vaccine
Diphtheria [UPSC 2014]	Corynebacterium diphtheriae	Person to person- usually through respiratory droplets	Diphtheria, tetanus, and pertussis (DTaP/DTP) vaccine
Cholera	Vibrio cholerae	Contaminated water or food	Dukoral Vaccine and Adequate Sanitation
Leprosy (Hansen's Disease)	Mycobacterium leprae	Droplets (from nose and mouth)	Multidrug therapy (MDT)
Whooping cough (Pertussis)	Bordetella pertussis	Air-borne	Diphtheria, tetanus, and pertussis (DTaP/DTP) vaccine
Tetanus	Clostridium tetani	Through spores in environment	Diphtheria, tetanus, and pertussis (DTaP/DTP) vaccine
Plague	Yersinia pestis	Flea bites, Direct Contact, Infectious Droplets	Sanitaion and rodent control
Gonorrhea	Neisseria gonorrhoeae	Sexually transmitted disease (STD)	Intramuscular ceftriaxone
Syphilis	Treponema pallidum	Sexually transmitted disease (STD)	Benzathine penicillin G
Typhoid (Enteric Fever)	Salmonella typhi	Contaminated drinking water and food	Oral Vaccine, Injectable Vaccine
Pneumococcal Disease [UPSC 2020]	Streptococcus pneumoniae	Direct Contact- Respiratory Secretions	Pneumococcal Conjugate Vaccines (PCV13, PCV15, and PCV20)
Streptococcal Pharyngitis	Streptococcus pyogenes	Direct contact, respiratory droplets	Penicillin, amoxicillin
Bacterial Meningitis	Various (e.g., *Neisseria meningitidis*, *Streptococcus pneumoniae*)	Respiratory droplets, direct contact	Antibiotics (e.g., ceftriaxone)
Leptospirosis	Leptospira spp.	Contact with contaminated water	Antibiotics (e.g., doxycycline)

Anthrax	Bacillus anthracis	Inhalation, ingestion, or skin contact	Antibiotics (e.g., ciprofloxacin)
Brucellosis	Brucella spp.	Ingestion of unpasteurized dairy, contact with infected animals	Antibiotics (e.g., doxycycline + rifampin)

Viral Diseases [UPSC 2021, 2016, 2013]

- A virus is a **nucleic acid molecule (RNA or DNA)** encapsulated in a protein coat or capsid. The virus is not a complete cell and can only replicate inside a living cell (bacteria, plants, fungi etc.). The capsid may have a protective lipid-containing envelope.
- The capsid and envelope facilitate attachment and penetration into host cells (e.g., **via attachment to receptors like ACE 2)** and often contain virulence factors. Inside the host cell, the nucleic acid molecule utilises cellular proteins and processes for virus replication.
- Virus can infect hosts such as Bacteria, Fungi, plants apart from human beings and animals. **[UPSC 2016]**
- Based on the type of nucleic acids, viruses can be classified as:
  - **DNA viruses** (e.g., Adenovirus) contain usually double-stranded DNA (dsDNA) and rarely single-stranded DNA (ssDNA). These viruses replicate using DNA-dependent DNA polymerase.
  - **RNA viruses** have typically ssRNA (single-stranded RNA) but may also contain dsRNA.
  - **Retrovirus** [e.g., Human Immunodeficiency Virus (HIV)] core contains several copies of reverse transcriptase bound to two identical single-stranded RNA molecules.

The key difference between **RNA Viruses** and **retroviruses** is that RNA viruses are **viruses that have single-stranded or double-stranded RNA as their genetic material,** while **retroviruses are viruses that have single-stranded RNA as their genetic material but use DNA intermediates in their life cycle.** **[UPSC 2021]**

Table: Viral Diseases

Disease	Agent	Vector/Transmission	Treatment/Prevention
Dengue	Dengue virus (RNA Virus)	Aedes aegypti or Aedes albopictus female mosquitoes	(Not Approved in India yet.)
Chikungunya [UPSC 2013]	Chikungunya virus (RNA Virus)	Aedes aegypti or Aedes albopictus female mosquitoes	(Not Approved in India yet.)
Poliomyelitis (Polio)	Polio virus (RNA Virus)	• Person to person: faecal-oral route. • Contaminated water/ food.	• Inactivated poliovirus vaccine (IPV) • Oral poliovirus vaccine (OPV)
AIDS [UPSC 2019, 2013]	Human Immunodeficiency Virus (HIV) (RNA Virus)	Exchange of body fluids **(excluding saliva)**	Anti Retroviral Therapy (ART) with: • Fostemsavir • Ibalizumab-uiyk • Lenacapavir • Lamivudine • Cabotegravir • Zidovudine etc.
Hepatitis- A, B, C, D, E, G [UPSC 2019, 2013]	Hepatitis- A, B, C, D, E, G Viruses [All are RNA viruses **except Hepatitis B- a DNA virus**]	• Hepatitis A and E- contaminated food or water • Hepatitis B, C, D, G- Parenteral contact with body fluids/blood	• HAV Vaccine • HBV Vaccine- also for Hepatitis D • **No Vaccines- Hepatitis C, E, G**

Chickenpox [UPSC 2014]	Varicella-Zoster Virus	Air-borne Direct Contact	Varivax, ProQuad (MMRV)
Ebola	• Zaire ebolavirus (**deadliest strain**) • Sudan ebolavirus • Taï Forest ebolavirus • Bundibugyo ebolavirus • **All are RNA Viruses**	Zoonosis & Body fluids	• Ervebo • Zabdeno+Mvabea
Nipah	Nipah virus (NiV) (RNA Virus)	Zoonosis, Direct contact and Food contaminated by body fluid of infected animals	No approved Vaccines
COVID-19	SARS-CoV-2 (many strains) (RNA Virus)	• Contact and droplet transmission • Air-borne • **Fomite transmission**	Covaxin, Covishield, Sputnik-V, **GEMCOVAC-OM (mRNA vaccine)**
Japanese Encephalitis	Japanese encephalitis virus [RNA Virus]	Culex tritaeniorhynchus mosquitoes	Inactivated Vero cell culture-derived Vaccine (IXIARO)
Zika Fever	Zika Virus (RNA Virus)	Aedes aegypti or Aedes albopictus female mosquitoes	No approved Vaccines
Influenza	Influenza virus	Airborne droplets, direct contact	Antiviral medications (e.g., oseltamivir), supportive care
Measles	Measles virus	Airborne droplets	Supportive care, vitamin A
Mumps	Mumps virus	Airborne droplets, direct contact	Supportive care
Rubella	Rubella virus	Airborne droplets	Supportive care
Herpes Simplex	Herpes simplex virus	Direct contact (oral and genital)	Antivirals (e.g., acyclovir)
Rabies	Rabies virus	Animal bites (usually from bats or dogs)	Post-exposure prophylaxis, supportive care

Smallpox

Smallpox is an acute contagious disease caused by the variola virus, a member of the orthopoxvirus family. Smallpox has been **eradicated in India.** The smallpox vaccine, created by **Edward Jenner in 1796**, was the first successful vaccine to be developed. **[UPSC 2014]**

Parasitic Diseases

- These are diseases caused by **protozoa**, **helminths**, and **arthropods** (**live within**, **on**, or **at the expense of a host**).
- Protozoa include unicellular organisms, such as the flagellates- **Giardia** and **Trichomonas**, and **amoebae- Entamoeba** (causing **enteric** and **gynaecological disorders**).
- Helminths are worms that infest humans. Arthropods include **lice**, **fleas**, **sandflies**, **blackflies**, and **ticks**, and **they serve as important disease vectors**.

Table: Parasitic Diseases

Disease	Agent	Vector/Transmission	Treatment/Prevention
Sleeping Sickness (Trypanosomiasis)	Trypanosoma brucei	Tsetse fly	Pentamidine
Chagas Disease	Trypanosoma cruzi	Triatomine bugs	No Vaccine
Ascariasis	Ascaris lumbricoides (Hookworm)	Soil-Transmitted Helminths (STH) [Worm Eggs- Faecal Route]	Albendazole and Mebendazole
Elephantiasis (Lymphatic filariasis)	Wuchereria bancrofti, Brugia malayi, Brugia timori	Mosquitoes (various)	Diethylcarbamazine (DEC)
Kala-azar (Leishmaniasis)	Leishmania species (protozoans)	Phlebotomine Sand flies	Miltefosine
Malaria	• Plasmodium parasites- P. falciparum, P. vivax, P. malariae, P. ovale and P. knowlesi. • **P. falciparum** is the **deadliest malaria parasite (common in Africa)** • **P. vivax** is dominant- **outside sub-saharan Africa.**	Female Anopheles mosquitoes	R21/Matrix-M and RTS, S against **P. Falciparum (not for other strains)**
Primary Amebic Meningoencephalitis (PAM)	Naegleria fowleri	Water containing Naegleria fowleri enters the nose (not by drinking)	Combination of Drugs
River Blindness (Onchocerciasis)	Onchocerca volvulus	Blackflies (Simulium)	Ivermectin
Giardiasis	Giardia lamblia	Fecal-oral route, contaminated water	Antiparasitic (e.g., metronidazole)
Loa loa filariasis	Loa loa	Deerfly bites	Antiparasitic (e.g., ivermectin)
Ascariasis	Ascaris lumbricoides	Fecal-oral route	Antiparasitic (e.g., albendazole)

Vector Borne Disease

- Vector-borne diseases are transmitted by organisms that carry infectious pathogens, significantly impacting global health. These diseases are prevalent in tropical and subtropical regions, often affecting impoverished populations. Environmental factors, such as climate change, can increase vector proliferation.
- **Statistics:** Over 700,000 people die annually from vector-borne diseases, accounting for about 17% of all infectious diseases.

Vectors	Diseases	Causative Organisms
Mosquitoes	Chikungunya, Dengue, Malaria	Chikungunya Virus, Dengue Virus, Plasmodium
Tse-tse Flies	African Trypanosomiasis	Trypanosoma Brucei
Ticks	Lyme Disease, Tick-borne Encephalitis	Borrelia Burgdorferi, Tick-borne Encephalitis Virus

Wolbachia Method [UPSC 2023]: Wolbachia are safe, naturally occurring bacteria, which have evolved to live inside the cells of many insect species. The World Mosquito Program (WMP) discovered that Wolbachia blocks viruses like dengue, chikungunya and Zika from growing in the bodies of Aedes aegypti mosquitoes. This means that if Wolbachia is established in a mosquito population, it results in decreasing incidence of dengue, Zika, and chikungunya.

Cornavirus (COVID-19)

- COVID-19, caused by the SARS-CoV-2 virus, is a respiratory viral disease. The name "Corona" refers to the crown-like spikes on the virus's surface. Other examples of coronaviruses include SARS, the common cold, and MERS.
- COVID-19 was a new strain of this virus called SARS Cov-2. **Angiotensin Converting Enzyme 2 (ACE2)** has been discovered to be the SARS-CoV-2 virus's receptor. The coronavirus can enter a variety of human cells through this particular protein and spread infection. **[UPSC 2021]**

Testing Methods for COVID-19

1. **RT-PCR (Reverse Transcription Polymerase Chain Reaction):**
   - A molecular technique used to detect viral RNA in samples. It involves reverse transcription to convert RNA into complementary DNA (cDNA) followed by amplification using polymerase chain reaction (PCR).
   - **Technology Aspect:** High sensitivity and specificity make it the gold standard for diagnosing COVID-19.
2. **RT-LAMP (Reverse Transcription Loop-Mediated Isothermal Amplification):**
   - A rapid method for nucleic acid amplification that operates at a constant temperature, eliminating the need for thermal cycling.
   - **Technology Aspect:** Faster and simpler than RT-PCR, enabling quicker results, which is crucial during outbreaks.
3. **TMA (Transcription Mediated Amplification):**
   - This technique amplifies RNA using enzymes, providing a sensitive and rapid diagnostic tool for detecting viral infections.
   - **Technology Aspect:** TMA offers high sensitivity and specificity with a shorter time-to-result compared to traditional methods.

COVID Vaccines in India

1. **COVAXIN:**
   - An inactivated virus vaccine, which uses killed virus particles to elicit an immune response.
   - **Biological Aspect:** Triggers the body's immune response without causing disease.
2. **Covishield:**
   - A viral vector vaccine using a modified adenovirus to deliver the spike protein of SARS-CoV-2.
   - **Biological Aspect**: The immune system recognizes the spike protein and mounts a response, preparing the body for future infection.
3. **ZyCoV-D:**
   - The first DNA plasmid vaccine in India, which introduces a small, circular piece of DNA that codes for the spike protein.
   - **Biological Aspect**: This DNA is taken up by cells, leading to the production of the spike protein and triggering an immune response.
4. **Sputnik V:**
   - Another viral vector vaccine that uses two different adenoviruses for its two doses, enhancing immune response.
   - **Biological Aspect**: By using two distinct vectors, it minimizes the risk of pre-existing immunity against the vector reducing efficacy.
5. **Biological E's COVID-19 Vaccine (Corbevax):**
   - Protein Sub-unit COVID 19 Vaccine.
   - **Covovax:** SARS-CoV-2 rS Protein (COVID-19) Nanoparticle Vaccine developed by Serum Institute of India, based on the Novavax vaccine technology.

Fungal Diseases

- **Mycoses:** Infections caused by molds and yeasts (types of fungi).
- **Common Fungal Infections:**
  - **Mucormycosis (Black Fungus):**
    - Caused by molds from the Mucorales order.
    - Affects sinuses, brain, and lungs, primarily in immunocompromised individuals.
  - **Pneumocystis Pneumonia (PCP):**
    - Caused by *Pneumocystis jirovecii*.
    - Affects the lungs, common in HIV/AIDS patients.
  - **Aspergillosis:**
    - Caused by *Aspergillus* species.
    - Primarily impacts the lungs and respiratory system.
  - **Dermatophytic Infections (Tinea):**
    - Caused by fungi invading hair, skin, or nails.
    - Common across various living organisms.
- **Fungal Infections in HIV:**
  - Major contributors include Cryptococcus, Candida, Aspergillus, and Mucor, causing significant morbidity.

NON-COMMUNICABLE DISEASES (NCD)

The **World Health Organization (WHO)** identifies four major types of non-communicable diseases:

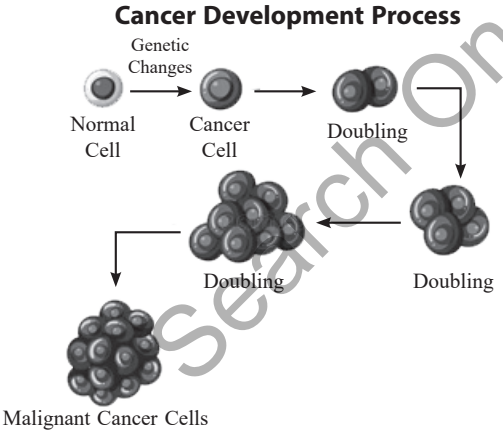
1. Cancer
2. **Cardiovascular Diseases (CVDs)** (e.g., heart attack, stroke)
3. **Chronic Respiratory Diseases (CRDs)** (e.g., asthma, Chronic Obstructive Pulmonary Disease - COPD)
4. Diabetes Mellitus

Epidemiology

- **77%** of NCD deaths occur in low- and middle-income countries.
- **CVDs** account for the highest proportion of NCD deaths, followed by cancers, chronic respiratory diseases, and diabetes.
- **Risk Factors:** Major contributors to NCD mortality include tobacco use, physical inactivity, harmful alcohol consumption, unhealthy diets, and air pollution.

Cancer

- **Cancer** occurs when cells divide uncontrollably, forming **tumors**. Tumors can be:
  - **Benign:** Non-cancerous, localized, and do not spread.
  - **Malignant:** Cancerous and can invade surrounding tissues or metastasize (spread) to other parts of the body.



Common Cancers in India

- **Cervical Cancer:** Originates in the cervix and progresses slowly, causing about **75,000 deaths/year** in India. The **Human Papillomavirus (HPV)** vaccine is an effective preventive tool. An immunization campaign targeting HPV is planned in India.
- **Breast Cancer:** Prevalent among women, characterized by the uncontrolled growth of breast cells.
- **Oral Cancer:** Affects both men and women, often linked to tobacco use and poor oral hygiene.

Causes of Cancer: Transformation of normal cells into cancerous neoplastic cells is induced by agents called **carcinogens**, which can be:

- **Physical Carcinogens:** UV and ionizing radiation.
- **Chemical Carcinogens:** Asbestos, tobacco smoke components, alcohol.
- **Biological Carcinogens:** Oncogenic viruses (e.g., HPV, hepatitis B), bacteria, and parasites.

Cardiovascular Diseases (CVDs)

- **CVDs** encompass a range of conditions affecting the heart and blood vessels, causing damage to arteries in organs such as the brain, heart, kidneys, and eyes.

Common Types of CVDs

- **Heart Attack (Myocardial Infarction):** Occurs when the blood supply to the heart is obstructed, **typically by fatty deposits (atherosclerosis)** in the coronary arteries. Symptoms include severe chest pain lasting over 30 minutes, radiating to the left arm, shoulder, or jaw, and not relieved by painkillers.
- **Stroke:** A condition where blood supply to the brain is interrupted or a blood vessel in the brain bursts. This deprives brain tissue of oxygen and can cause permanent damage.
- **Types of Stroke**
  - **Ischemic Stroke:** Caused by blood clots blocking blood vessels in the brain.
  - **Hemorrhagic Stroke:** Occurs when a blood vessel leaks or ruptures, increasing pressure on brain cells.

Risk Factors: High blood pressure, high cholesterol, diabetes, and a family history of CVDs contribute significantly. Stroke is the second leading cause of death worldwide and the third leading cause of disability.

Chronic Respiratory Diseases (CRDs)

- **CRDs** affect the airways and lung structures. Common CRDs include:
  - **Chronic Obstructive Pulmonary Disease (COPD):** Characterized by persistent respiratory symptoms and airflow limitation.
  - **Asthma:** A chronic inflammatory disease of the airways, causing wheezing, breathlessness, and chest tightness.

Management: Although CRDs are incurable, treatments (e.g., bronchodilators, steroids) help alleviate symptoms and improve quality of life.

Risk Factors: Tobacco smoke, air pollution, occupational chemicals, and childhood respiratory infections contribute to CRDs.

Diabetes Mellitus

Diabetes is a chronic condition arising from insufficient insulin production or ineffective use of insulin by the body, leading to elevated blood glucose levels.

Types of Diabetes

1. **Type 1 Diabetes (T1DM):** The pancreas produces little to no insulin, necessitating daily insulin administration. Causes include genetic predisposition and environmental factors.
2. **Type 2 Diabetes (T2DM):** The most prevalent form; characterized by insulin resistance and/or inadequate insulin production. Often preventable through lifestyle modifications.

NEGLECTED TROPICAL DISEASES (NTDS)

- **NTDs** encompass a diverse group of communicable diseases prevalent in tropical and subtropical regions. They disproportionately affect marginalized populations living in poverty.

Examples of NTDs

- **Noma (Cancrum Oris):** A severe gangrenous disease of the mouth and face, primarily affecting malnourished children aged 2-6 years.
- Other NTDs include **dengue**, **chikungunya**, **rabies**, **leishmaniasis**, **leprosy**, and **lymphatic filariasis**.

Initiatives: The **London Declaration on Neglected Tropical Diseases 2012** and the **Kigali Declaration on Neglected Tropical Diseases 2022**

LIFESTYLE DISEASES

- **Lifestyle diseases** are linked to unhealthy behaviors often associated with modern living, including poor diet, lack of physical activity, and substance abuse.

Common Lifestyle Diseases

- **Asthma:** Triggered by environmental factors such as pollution, exacerbated by a sedentary lifestyle. Requires a balanced approach to management.
- **Tobacco-Induced Diseases:** Includes **COPD**, lung cancer, and heart diseases, stemming from both smoking and passive smoking. Tobacco cessation is crucial for prevention.
- **Obesity:** Results from excessive calorie intake and physical inactivity. A significant risk factor for CVDs and diabetes. Management involves a balanced diet and regular exercise.
- **Hypertension (High Blood Pressure):** Often due to stress, high salt intake, and obesity. It is a critical risk factor for heart diseases and stroke. Lifestyle changes can help manage blood pressure.
- **Mental Health Disorders:** Increasingly prevalent due to modern lifestyle pressures, with social isolation and work-related stress being major contributors. Physical activity and social engagement are vital for mental health maintenance.

RARE DISEASES

Rare diseases affect a small percentage of the population, with about **72-96 Million** people in India affected. Approximately **450 rare diseases** are documented in India.

Common Rare Diseases Include:

- Autoimmune diseases, Gaucher's disease, hemophilia, sickle cell anemia, thalassemia, and certain types of muscular dystrophies.

Government Initiatives: The **National Policy for Treatment of Rare Diseases, 2021** classifies rare diseases into three groups based on treatment needs, offering financial assistance and establishing specialized treatment centers.

NUTRITIONAL DISEASES

Nutritional inadequacy indicates insufficient nutrient intake, while **nutritional deficiency** signifies critically low levels of nutrients that impair bodily functions.

Types of Nutritional Diseases:

- **Macronutrient Deficiency:**
  - **Protein-Energy Malnutrition (PEM):** Prevalent in developing countries, characterized by insufficient protein and energy intake.
    - **Marasmus:** Severe undernutrition leading to extreme weight loss and emaciation.
    - **Kwashiorkor:** Resulting from severe protein deficiency, often in children weaned from breast milk, leading to symptoms like a swollen belly (edema).
- **Ketosis:** Arises from long-term carbohydrate insufficiency, characterized by elevated ketone bodies, often marked by a sweet odor on the breath.
- **Essential Fatty Acid Deficiency:** A low **omega-3 index** is associated with an increased risk of mortality from coronary heart disease. **Omega-3 and omega-6 fatty acids** are crucial for cardiovascular health.

Micronutrient Deficiency

Micronutrient	Deficiency Disease/Symptoms
Vitamin A	Xerophthalmia, Bitot spots, night blindness, keratomalacia, and permanent blindness
Vitamin B1	Beriberi (wet beriberi affects cardio-vascular system; dry beriberi affects CNS, causing impaired motor function and numbness)
Vitamin B3	Pellagra (dermatitis, dementia, diarrhea)
Vitamin B6	Anaemia, peripheral neuropathy, sebo-rrheic dermatitis, glossitis, depression, seizures
Vitamin B12	Megaloblastic anaemia, fatigue, weakness

Vitamin B9	Megaloblastic anaemia, pancytopenia, glossitis, oral ulcers
Vitamin C	Scurvy (gum disease), behavioural and mood changes
Vitamin D [UPSC-2014]	Hypocalcemia, hypophosphatemia, rickets (children), osteomalacia (adults)
Vitamin E [UPSC-2014]	Ataxia, myopathy, pigmented retinopathy, vision loss
Vitamin K [UPSC-2014]	Coagulation disorder, hemorrhagic disease of newborns
Calcium	Cataracts, dental changes, osteoporosis, rickets, brain alterations
Iron	Microcytic hypochromic anaemia (small red blood cells, low hemoglobin)
Iodine	Goiter (thyroid enlargement)
Zinc	Skin lesions, infection susceptibility, night blindness, low sperm count, slow wound healing
Magnesium	Linked with colorectal cancer, osteoporosis, hypertension, metabolic syndrome, diabetes
Selenium	Keshan disease (cardiomyopathy), Kashin-Bek disease (arthritis), thyroid issues, immune problems
Fluoride	Dental caries, bone problems
Biotin	Metabolic acidosis, developmental delay, seizures, hair loss, dermatitis

Food Fortification

It is the practice of adding vitamins and minerals to commonly consumed foods during processing to increase their nutritional value and is a proven, safe and cost-effective strategy for improving diets and for the prevention and control of micronutrient deficiencies.

Probiotics are foods/supplements that contain live microorganisms (Bacteria, Yeast) intended to maintain or improve the 'good' bacteria (normal microflora) in the body. **[UPSC 2022]**

DRUGS AND MEDICINES

Definition

- **Drugs:** Chemical substances that alter physiological functions in living organisms. They can be **natural** (from plants, animals, or minerals) or **synthetic** (manufactured in labs).
- **Medicines:** Therapeutically active drugs used for the diagnosis, treatment, or prevention of diseases.

Mechanism of Action

- Drugs target specific macromolecules (e.g., proteins, receptors) to generate biological responses, often affecting the **nervous system**. They can be toxic at high doses (lethal doses).

Regulatory Framework in India

Drugs and Cosmetics Act, 1940

- Regulates the **import, manufacture, distribution, and sale** of drugs and cosmetics in India.

Key Regulatory Authorities

- Central Drugs Standard Control Organization (CDSCO)
- State Drug Control Authorities
- Drug Controller General of India (DCGI)

Drug Price Control Order (DPCO) Act

- Established under the **Essential Commodities Act, 1955**, this act empowers the **National Pharmaceutical Pricing Authority (NPPA)** to regulate the prices of essential medicines.

Products Covered Under DPCO

1. **Essential Medicines:** Listed in the **National List of Essential Medicines (NLEM)** for treating critical conditions (e.g., diabetes, hypertension).
2. **Life-saving Drugs:** Treat life-threatening diseases (e.g., cancer, HIV/AIDS).
3. **Generic Medicines:** Non-branded versions of drugs, providing cost-effective alternatives.
4. **Medical Devices:** Includes cardiac stents, orthopedic implants, etc.
5. **Bulk Drugs:** Active Pharmaceutical Ingredients (APIs) for drug manufacturing.

FATS

Overview of Lipids

- **Lipids** are generally water-insoluble organic compounds essential for various biological functions. They include fats, oils, waxes, and steroids.
- **Fatty Acids:** The building blocks of fats, characterized by a carboxyl group (–COOH) attached to a hydrocarbon chain (R group). Fatty acids can be classified into:
  - **Saturated Fatty Acids:** Contain only single bonds (C–C) between carbon atoms.
  - **Unsaturated Fatty Acids:** Contain one or more double bonds (C=C) within the carbon chain.

Saturated Fats

- Composed solely of single bonds between carbon atoms, resulting in the maximum number of hydrogen atoms bonded to each carbon.
- **Characteristics:**
  - Typically solid at room temperature (e.g., butter, lard).
  - More stable and less prone to rancidity compared to unsaturated fats.
  - Mostly found in animal fats but also present in some plant oils (e.g., coconut oil).

Unsaturated Fats

- Contain at least one double bond in their structure, resulting in fewer hydrogen atoms.
- **Characteristics:**
  - Generally liquid at room temperature (e.g., olive oil, fish oil).
  - More vulnerable to rancidity due to oxidation.
  - Healthier compared to saturated fats, offering benefits like improved heart health.

Cholesterol

- **Cholesterol** is a fat-like, waxy substance synthesized mainly in the liver. It is essential for:
  - Formation of cell membranes.
  - Synthesis of hormones (e.g., estrogen, testosterone).
  - Production of vitamin D and bile acids that aid in digestion.

Types of Cholesterol

1. **Low-Density Lipoproteins (LDL):** Known as "bad" cholesterol, high levels can lead to plaque buildup in arteries, increasing the risk of heart disease.
2. **High-Density Lipoproteins (HDL):** Known as "good" cholesterol, it helps remove LDL cholesterol from the bloodstream, protecting against heart disease.

Trans Fats

- **Trans fats**, or trans-fatty acids (TFAs), are a type of unsaturated fat that can be found in both natural and industrial forms.
- **Health Risks:** Linked to increased risk of cardiovascular diseases by raising LDL cholesterol and lowering HDL cholesterol.

Types of Trans Fats

1. **Naturally Occurring Trans Fats:** Found in small amounts in some animal products (e.g., meat, dairy) due to microbial fermentation in ruminants.
2. **Artificial Trans Fats:** Created through hydrogenation, a process that converts liquid oils into solid fats, commonly found in partially hydrogenated oils (PHOs).

Sources of Trans Fats

- **Natural Sources:** Ruminant animals (cattle, sheep), dairy products, and some meats.
- **Industrial Sources:** Used in processed foods, baked goods, margarine, and fast food.

Global Initiatives to Eliminate Trans Fats

- **REPLACE Campaign:** Launched by WHO in 2018 to eliminate industrially produced trans fats globally by 2023.
- **Denmark:** First country to ban trans fats in 2003.
- **United States:** FDA banned artificial trans fats in 2015.

Indian Initiatives Against Trans Fats

1. **FSSAI Initiative-Trans Fat Free Logo:** A voluntary labeling initiative promoting trans-fat-free products.
2. **Heart-Attack Rewind Campaign:** Launched in 2018 to reduce bad cholesterol from the food supply, targeting a reduction of trans fat consumption below 2%.
3. **RUCO (Repurpose Used Cooking Oil) Initiative:** Promotes the safe disposal and recycling of used cooking oil into biodiesel, addressing health risks and promoting sustainability.

Draft Food Safety and Standards Regulations, 2019

- Proposed regulations by FSSAI aim to reduce trans fats in food products to less than 2% by 2022.
- Mandatory labeling of trans fats on food packaging to help consumers identify products with high trans fat levels.

Eat Right Movement

- **Eat Right India** is an initiative by the Government of India and FSSAI, promoting safe, healthy, and sustainable food practices.

FOOD ADULTERATION

- **Food Adulteration** refers to the intentional or unintentional addition of substances that degrade food quality and safety, considered a criminal offense if it violates food safety standards.

Type of Adulteration	Example	Impurity
Intentional Adulteration	Rice	Plastic rice (synthetic starch grains)
	Chili Powder	Brick powder or artificial color (red lead oxide)
	Coffee Powder	Chicory powder (to increase weight)
Incidental Adulteration	Fruits and Vegetables	Pesticide residues or insecticides
	Flour	Rodent droppings or insects
	Honey	Sugar syrup or glucose (to increase sweetness)
Metallic Adulteration	Rice	Lead or mercury (from contaminated water)
	Black Salt	Iron filings

ANTIMICROBIAL RESISTANCE (AMR)

Definition: Occurs when microbes (bacteria, viruses, fungi, parasites) no longer respond to antimicrobial medicines (antibiotics, antivirals, antifungals, antiparasitics).

How does Antibiotic Resistance Occur?

1. High number of bacteria. A few of them are resistant to antibiotics.
2. Antibiotics kill bacteria causing the illness, as well as good bacteria protecting the body from infection.
3. The resistant bacteria now have preferred conditions to grow and take over.
4. Bacteria can even transfer their drug-resistance to other bacteria, causing more problems.

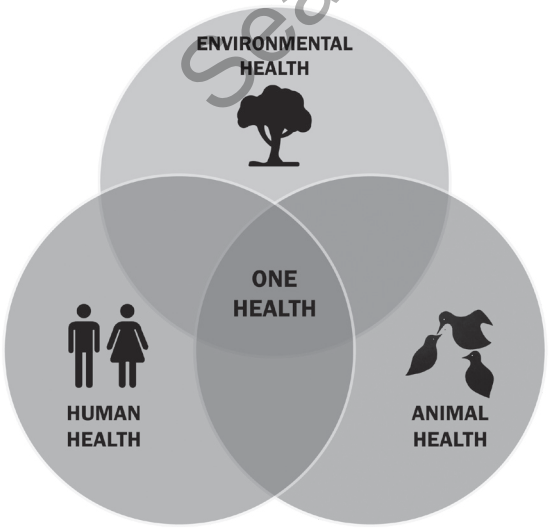
- **Causes:** Natural process influenced by genetic changes in pathogens, accelerated by human misuse and overuse of antimicrobials. **[UPSC 2019]**
- **Consequences:** Resistance makes infections difficult or impossible to treat.
- **Role of Vaccines:** Help prevent diseases and reduce antibiotic misuse.

BIOFILM **[UPSC-2022]**

Biofilms can form on medical implants within human tissues. Biofilms can form on food and food processing surfaces.Biofilms can exhibit antibiotic resistance

One Health Approach

- **Definition:** A holistic strategy recognizing the inter-connection between human, animal, and environmental health.
- **Issues Addressed**: Ecosystem degradation, zoonotic diseases, and AMR.
- **Global Collaboration**: One Health Joint Plan of Action (2022-26) involves FAO, UNEP, WHO, and the World Organisation for Animal Health to tackle health threats.



- **India's Initiative**: National One Health Mission by the Office of the Principal Scientific Advisor aims to coordinate One Health efforts, including:
  - **Animal Pandemic Preparedness Initiative (APPI)**
  - **Animal Health System Support for One Health (AHSSOH)**, funded by the World Bank.

Traditional Medicine System

- **Definition**: Encompasses knowledge and practices based on indigenous beliefs to maintain health and treat illnesses.
- **Major Systems in India**: Ayurveda, Yoga, Naturopathy, Unani, Siddha, Sowa Rigpa, and Homeopathy (AYUSH).
- **Government Support**: The Ministry of AYUSH promotes research and integration into mainstream healthcare.
- **Traditional Knowledge Digital Library (TKDL)**: Preserves knowledge related to Indian medicine systems.
- **WHO Endorsement**: Recognizes the role of traditional medicine in achieving Universal Health Coverage (UHC).
- **Ayurveda**, originating in India during the ancient Vedic period, is based on the balance of **three doshas—Vata (air), Pitta (fire), and Kapha (water)**—and focuses on body-mind harmony, preventive health, and rejuvenation through natural remedies.
- **Yoga**, also originating in India, emphasizes the union of mind, body, and spirit through physical postures **(Asanas)**, breathing exercises **(Pranayama)**, and meditation **(Dhyana)**.
- **Naturopathy** is based on the healing power of nature and uses elements such as diet therapy, fasting, and hydrotherapy for holistic health.
- The **Unani** system, which originated in Greece and was introduced to India by Arabs, is built around the theory of **four humors** (blood, phlegm, yellow bile, and black bile), aiming to balance these humors for maintaining health.
- **Siddha**, a traditional system practiced primarily in South India, is based on the **Pancha Boothas** (five elements) and **three humors** (Vata, Pitta, Kapha), using herbs, minerals, and diet to maintain bodily balance.

- **Sowa Rigpa**, also known as the **Amchi** system, is a traditional Tibetan medicine influenced by **Ayurveda**. It is based on similar principles, such as the **five elements** and the balance of humors, and is largely derived from the **Ashtanga Hridaya**, a key Ayurvedic text. This system has been enriched in Tibet and is practiced in regions like **China**, the **Himalayan regions of India, Mongolia, Nepal, Russia**, and **Bhutan**. It incorporates holistic healing practices, including herbal remedies, dietary adjustments, and spiritual healing.
- **Homeopathy**, developed in the 18th century by Samuel Hahnemann in Germany, is based on the principle of "**like cures like**" and uses highly diluted substances to treat diseases, providing individualized treatments for holistic health. These traditional medicine systems play a vital role in global healthcare, integrating ancient knowledge with modern wellness practices.

Global Centre for Traditional Medicine (GCTM)

- **Location**: Jamnagar, Gujarat, India.
- **Purpose**: First global knowledge centre for traditional medicine.
- **Financial Commitment**: India has committed approximately US$ 250 million to support its establishment and operations.

ASSISTED REPRODUCTIVE TECHNOLOGY (ART) AND SURROGACY

ART refers to medical techniques used to address infertility, defined by the WHO as the inability to conceive after one year without contraception. It includes procedures like in vitro fertilization (IVF), artificial insemination, and surrogacy. Common ART methods are:

1. **In Vitro Fertilization (IVF):** Fertilization occurs outside the body.
2. **Gamete Intrafallopian Transfer (GIFT):** Transfer of eggs and sperm into the fallopian tubes for fertilization.
3. **Zygote Intrafallopian Transfer (ZIFT):** Fertilization occurs outside, and the embryo is placed in the fallopian tube.
4. **Intracytoplasmic Sperm Injection (ICSI):** A single sperm is injected into a mature egg, used for male infertility or failed IVF attempts.
5. **Artificial Insemination:** Deliberate introduction of sperm into the female's cervix or uterus, including:
   - Intrauterine insemination
   - Intracervical insemination
   - Intratubal insemination

Surrogacy

Surrogacy involves a woman (surrogate) agreeing to carry a child for another person or couple.

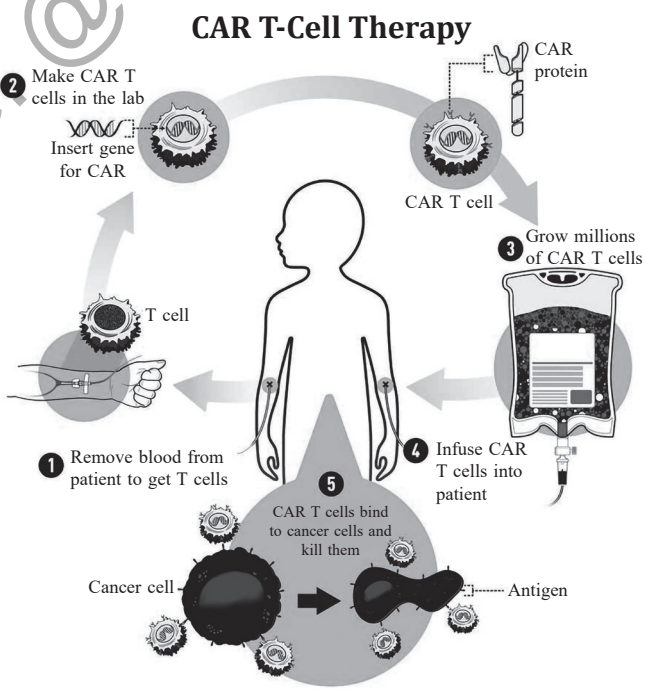
- **Altruistic Surrogacy:** No monetary compensation other than medical expenses.
- **Commercial Surrogacy:** Monetary compensation beyond medical costs.

Surrogacy (Regulation) Bill, 2019

- Bans commercial surrogacy; allows altruistic surrogacy.
- **Eligibility:** Indian couples, married for 5 years, with specific age limits, and no surviving children (with exceptions).
- **Surrogate criteria:** Must be a close relative, married, aged 25-35, and allowed to attempt surrogacy only once.
- Regulatory Framework: **National and State Surrogacy Boards e**stablished.
- **Offences and Penalties:** Includes penalties with a jail term of 10 years and a fine of up to Rs 10 lakhs for commercial surrogacy.

CAR-T CELL THERAPY

CAR-T cell therapy is a type of cellular immunotherapy that genetically **alters T cells** in a laboratory **to enhance their ability to locate and destroy cancer cells.** T cells are immune cells that attack pathogens (viruses, bacteria, fungi, and parasites) as well as harmful cells like cancer cells.



The Central Drugs Standard Control Organisation (CDSCO) has approved **NexCar19**, an indigenous CAR-T cell therapy developed by ImmunoACT, a company incubated at IIT Bombay. The CDSCO functions as the Central Drug Authority, overseeing drug import regulations, new drug approvals, and clinical trials under the Drugs and Cosmetics Act of 1940.

5 Information and Communication Technology, Computer and Emerging Technologies

ELECTROMAGNETIC WAVES

Electromagnetic Waves are a form of energy that travels through space at the speed of light. They are composed of oscillating electric and magnetic fields that are perpendicular to each other and to the direction of propagation.

Characteristics of Electromagnetic Waves

Electromagnetic waves possess several fundamental properties that shape their behaviour and interactions:

- **Transverse Nature:** Oscillations of electric and magnetic fields occur perpendicular to the direction of wave propagation.
- **Wavelength and Frequency:** Each wave is characterised by its wavelength (distance between peaks) and frequency (oscillations per second), which are inversely related.
- **Constant Speed:** In a vacuum, all electromagnetic waves travel at the speed of light.
- **Energy Relationship:** Wave energy is directly proportional to its frequency
- **Medium Independence:** Unlike mechanical waves, electromagnetic waves do not require a medium to propagate.
- **Wave Phenomena:** These waves exhibit reflection, refraction, diffraction, and polarisation, similar to water waves.
- **Matter Interaction:** Electromagnetic waves interact with matter through absorption, transmission, and scattering.
- **Wave-Particle Duality:** Electromagnetic radiation exhibits both wave-like and particle-like properties, behaving as photons in certain contexts.

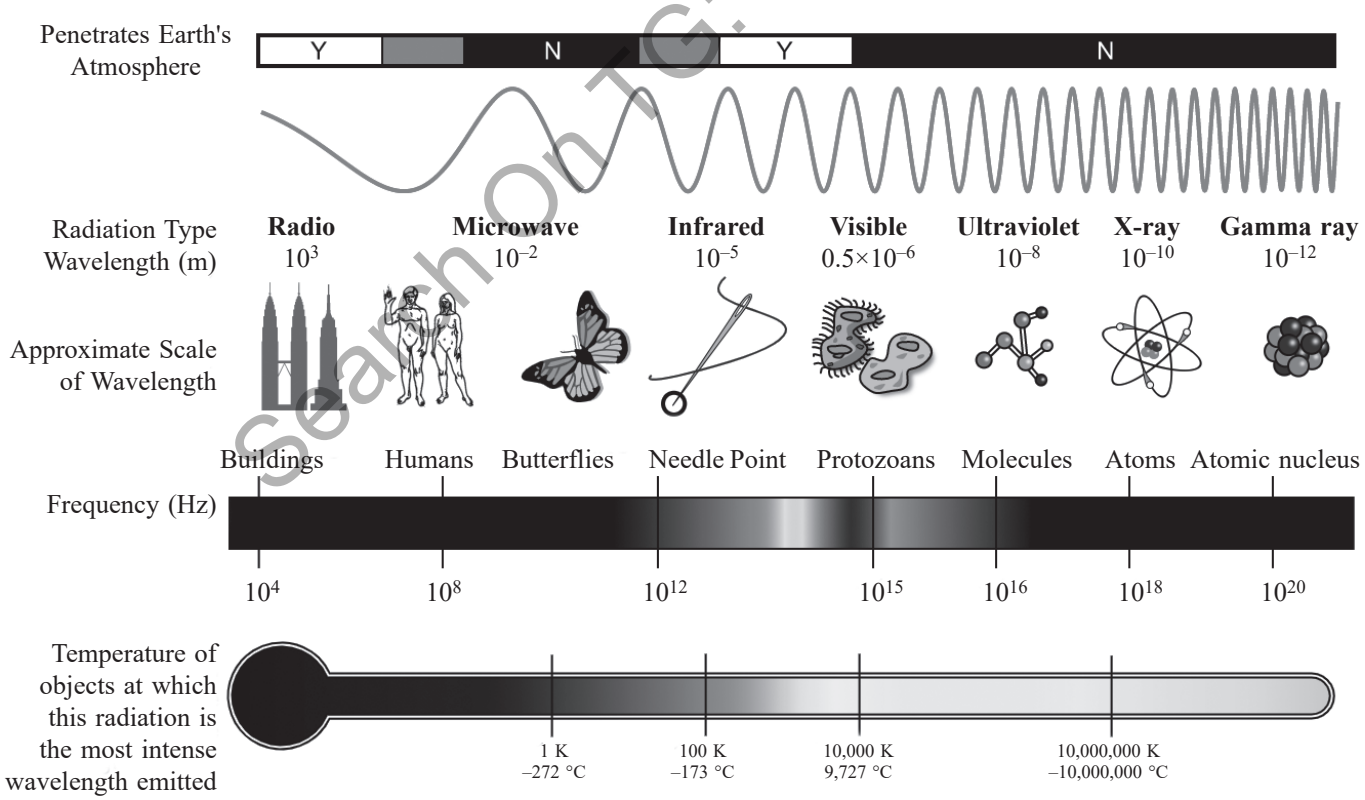


Fig: Electromagnetic Spectrum

Electromagnetic Spectrum

The electromagnetic spectrum is a broad range of all types of electromagnetic waves, arranged in order of increasing frequency and decreasing wavelength. It includes:

Type	Penetration in Earth's Atmosphere	Applications
Radio Waves	Penetrate Earth's atmosphere	AM/FM radio, television broadcasts, satellite communication, radar.
Microwaves	Penetrate Earth's atmosphere	Cellular phones, satellite communication, radar, microwave ovens.
Infrared	Partially absorbed by the atmosphere, especially by water vapor and carbon dioxide.	Remote sensing, thermal imaging, night vision, infrared astronomy.
Visible Light	Partially absorbed by Earth's atmosphere	Human vision, photography, optical telescopes.
Ultraviolet	Most of the UV radiation is absorbed by the ozone layer, protecting us from harmful effects.	Medical treatments, sterilization, tanning beds.
X-rays	Absorbed by Earth's atmosphere	Medical imaging (X-rays), industrial applications (radiography).
Gamma Rays	Absorbed by Earth's atmosphere	Medical treatments (radiation therapy), nuclear physics research.

DIFFERENT TYPES OF COMPUTER NETWORKS

Personal Area Network (PAN)

A PAN is the smallest and most personal type of network. Used for communication among devices like smartphones, tablets, laptops etc within a range of about 10 meters.

Local Area Network (LAN) [UPSC 2022]

It is a network that is limited to a small geographic area, such as a single building, a campus, or a group of nearby buildings. E.g., An office network where computers are connected to a shared printer and server.

Metropolitan Area Network (MAN)

It has a larger geographic scope than a LAN but is smaller than a WAN. It typically covers a city or a large campus, connecting multiple buildings within a city or a large campus area.

Wide Area Network (WAN)

It covers a broad area, often spanning across cities, countries, or even continents. It connects multiple LANs and MANs, allowing for the exchange of data over long distances. **[UPSC 2022]**

Virtual Private Network (VPN)

It is a technology that allows secure and encrypted communication over an untrusted network, such as the internet.

WIRELESS COMMUNICATION TECHNOLOGIES

- **Bluetooth:** Short-range wireless technology for connecting devices, commonly used for data transfer between devices like smartphones, headphones, and speakers.
  - Can penetrate thin walls and obstacles, but is easily blocked by solid objects like walls or metal.
- **Wi-Fi Direct:** Allows devices to connect to each other directly without the need for a traditional Wi-Fi network.
  - It's useful for peer-to-peer communication between devices.
  - **Penetration:** Similar to standard Wi-Fi, can penetrate thin walls but is blocked by solid objects.
- **Cordless Phone:** Typically uses Digital Enhanced Cordless Telecommunications (DECT) technology for short-range wireless communication between a phone and its base station.
  - **Penetration:** Can penetrate walls and other obstacles, but signal strength can be affected by distance and interference.
- **Hotspot:** A physical location where people can access the internet, typically using Wi-Fi, through a wireless local area network (WLAN) with a router connected to an internet service provider.
  - **Penetration:** Similar to standard Wi-Fi.
- **Wi-Fi:** Wireless local area networking technology that allows devices to connect to the internet and communicate with each other within a certain range of a Wi-Fi router or access point.
  - Penetration: Similar to Bluetooth, can penetrate thin walls but is blocked by solid objects. **[UPSC 2016]**

- **WiMAX (Worldwide Interoperability for Microwave Access):** A wireless communication standard that provides high-speed, long-range broadband connections.
  - It's designed for wireless metropolitan area networks (WMANs).
  - **Penetration:** Can penetrate walls and other obstacles, but signal strength can be affected by distance and terrain.
- **Li-Fi:** A wireless communication technology that uses light to transmit data. **[UPSC 2016]**
  - It is a form of **Visible Light Communication (VLC)** and can provide high-speed, bi-directional communication.
  - It is **more energy efficient than Wifi** and can provide fast communication and connection in spaces such as office, home etc. where light is not intercepted by an obstacle.
  - VLC uses electromagnetic spectrum **wavelengths 375 to 780 nm.** VLC can transmit large amounts of data faster than Bluetooth. VLC has **no electromagnetic interference.** **[UPSC 2020]**
  - **Penetration:** Limited by the range of visible light, easily blocked by opaque objects.
- **Zigbee:** It is a low-power, low-data-rate wireless communication protocol commonly used for short-range communication between devices in applications like home automation, industrial control, and sensor networks.
- **Infrared (IR):** It involves the use of infrared light for wireless data transfer.
  - It's commonly found in TV remote controls and some short-range communication applications.
- **NFC (Near Field Communication):** It is a short-range wireless communication technology that enables data exchange between devices when they are in close proximity (typically within a few centimetres).
  - It's often used for contactless payments, file sharing, and access control.
  - **Example:** cardless payments through Samsung Pay, Google Pay. **[UPSC 2015]**
- **RFID (Radio-Frequency Identification):** It uses radio waves to identify and track objects.
  - It is used in logistics, inventory management, and access control systems.
  - An RFID system consists of a tag, which contains a microchip and an antenna, and a reader, which emits radio signals and receives the tag's response.
  - RFID tags can store various kinds of data, such as serial numbers, product information, or personal identification.
  - **Example: FASTag.** **[UPSC 2022]**

BARCODE & QR CODE

Barcode: A barcode is a method of encoding data in a visual format that can be read by machines. **It stores information in either one-dimensional (1D) or two-dimensional (2D) representations.** Typically composed of a series of bars and spaces, a barcode represents numbers and characters in a way that computers can easily interpret.

QR Code: QR Code stands for Quick Response Code. This technology allows for the storage of information in a **format that can be quickly scanned and understood by devices.** QR codes are especially prevalent in today's fast-moving environment, commonly used for mobile payment systems and other applications requiring swift data retrieval.

Barcodes have limited storage capacity and can typically hold 20-25 characters of numeric data. In contrast, **QR codes have a much larger capacity** and can store up to 7,089 numeric characters or 4,296 alphanumeric characters.

REMOTE SENSING

Remote sensing is the technique of using electromagnetic energy to analyse the physical characteristics of distant objects. It encompasses photography, geophysical surveying, and advanced methods utilising various parts of the electromagnetic spectrum.

Types of Remote Sensors

Remote sensors collect data by detecting reflected energy from the Earth's surface. These sensors can be mounted on satellites or aircraft and are categorised as passive or active:

- **Passive Sensors:** These sensors measure natural energy reflected or emitted from the Earth's surface, primarily sunlight.
- **Active Sensors:** Active sensors emit their own energy, such as a laser beam, and measure the reflected signal to gather information.

Applications of Remote Sensing

- **Agriculture:** Crop identification, forecasting, damage assessment, soil and moisture mapping
- **Oceanography:** Monitoring ocean circulation, currents, temperature, and sea ice
- **Hazard Assessment:** Tracking hurricanes, earthquakes, erosion, and flooding
- **Natural Resource Management:** Land use, wetland mapping, wildlife habitat identification
- **Weather Forecasting:** Analysing weather patterns, precipitation, temperature
- **Environmental Monitoring:** Greenhouse gas sources, canopy chlorophyll, ecosystem health
- **Satellite Remote Sensing:** Land surface temperature, greenhouse gas analysis
- **Aircraft Sensors:** Enhancing satellite data for emission hotspots

LiDAR

LiDAR (Light Detection and Ranging) uses pulsed laser light to measure distances to Earth's surface, providing detailed 3D terrain data.

Key Components & Types: LiDAR includes a scanner, laser, and GPS receiver. Airborne platforms (aeroplanes, helicopters) gather large area data.

Types:

- **Topographic LiDAR:** Maps land with near-infrared lasers.
- **Bathymetric LiDAR:** Uses green light to measure underwater elevations.

How it Works:

LiDAR measures the time for light to reach the ground and return, converting it into elevation data.

Applications:

- Accurate shoreline maps
- Digital elevation models for GIS
- Emergency response assistance

CELLULAR WIRELESS COMMUNICATION TECHNOLOGIES

Mobile phones communicate through ground-based cellular networks. Mobile communication involves transmitting voice or data using wireless radio transmission.

Evolution of Wireless Telecom Technology: From 1G to 6G

Generation	Key Features	Latency	Wave Spectrum
1G	Analog system, poor voice quality, limited roaming	Higher latency	Low frequency (30 MHz - 1 GHz)
2G	Improved voice quality, SMS/MMS, roaming enabled	200 to 400 ms	900 MHz and 1800 MHz
3G	Mobile TV, online radio, video calling	100 to 300 ms	1.8 GHz - 2.5 GHz
4G	LTE system, VoLTE, VoWiFi for better calls	20 to 40 ms	600Mhz - 2.7 GHz
5G	High throughput, ideal for IoT	Low latency (As low as 1 ms)	30 GHz - 300 GHz (millimeter-wave)
6G	Data rates over 100 Gbps, AI integration, massive connectivity	Potentially < 1 ms	Above 100 GHz (terahertz bands)

Latency: In mobile networks, **latency** refers to the time delay in data transmission between a device and the network, measured in milliseconds. Lower latency improves user experiences in applications like video calls and online gaming, while 5G aims for latencies as low as 1 ms for enhanced real-time performance.

LTE (Long Term Evolution) and VoLTE

LTE is a wireless broadband standard that enhances mobile network capacity and speed over 3G.

Key Features:

- **High Data Rates**: Download speeds up to 300 Mbps, upload up to 75 Mbps.
- **Reduced Latency**: Ranges from 20 to 40 milliseconds, improving real-time communication.
- **All-IP Architecture**: Integrates voice, video, and data services on an IP network.
- **Applications**: Supports HD video, online gaming, and real-time communications.

VoLTE (Voice over LTE) [UPSC 2019]

VoLTE enabled voice calls over the LTE network, improving voice quality and call setup times.

Key Features:

- **HD Voice Quality**: Offers clearer voice with wideband audio.
- **Simultaneous Data & Voice**: Allows data use during calls without interruptions.
- **Faster Call Setup**: Reduces call setup to about 2 seconds.
- **Applications**: Ideal for video conferencing and emergency services.

Standalone and Non-Standalone 5G Networks

5G networks can be deployed in two primary modes: standalone and non-standalone.

- **Standalone (SA) 5G:**
  - Operates with dedicated equipment, independent of the existing 4G network.
  - Offers the full range of 5G capabilities, including network slicing for enhanced flexibility and efficient spectrum utilization.
- **Non-Standalone (NSA) 5G:**
  - Relies on the 4G core network for support.
  - Provides a faster and more cost-effective rollout compared to SA 5G, as it leverages existing infrastructure.
  - Allows operators to maximize the utilization of their existing network investments.

Voice over Internet Protocol (VoIP)

It utilizes IP-enabled devices and broadband connectivity to **convert voice into digital packets,** which are then transmitted over a packet-switched network.

Advantages of VoIP: Cost-effective, Integrate with other communication tools like video conferencing and email, Call forwarding, voicemail, call recording, call waiting.

VoWiFi: Voice Calls over Wi-Fi

- Wi-Fi Calling makes use of high speed Internet connection, available via broadband, to make and receive high definition (HD) voice calls. Users don't have to pay extra for these calls as it is using a Wi-Fi network.
- Wi-Fi Calling is aimed especially for areas where cellular networks are not strong.
- This is **not much different from a voice call using WhatsApp or any other over-the-top messaging platform,** but here the call is from one number to another, and not using an app.

Benefits: seamless switching between LTE and Wi-Fi networks, ensuring uninterrupted calls, extending voice coverage to areas with poor cellular reception; improved call quality; reduced cellular data usage, potentially leading to cost savings.

Internet of Things (IoT) [UPSC 2018]

IoT is a network of interconnected devices with unique identifiers, enabling **machine-to-machine (M2M) communication without human intervention.**

- These devices, equipped with sensors, software, and communication technologies, collect, transmit, and act upon data from their environments.

Applications of IoT: Smart Infrastructure like Power grids, transportation, safety and surveillance systems; Remote Management of Healthcare and agriculture; Smart Homes and cities.

Role of 5G and Edge Computing in IoT

- **Enhanced Connectivity:** 5G provides the high-speed, low-latency connectivity required for IoT devices to transmit and receive data efficiently.
- **Reduced Latency:** Edge computing enables real-time data processing and analysis, reducing latency and improving response times for IoT applications.
- **Increased Capacity:** 5G and edge computing together can handle the massive amount of data generated by IoT devices, ensuring seamless operation.
- **Improved Reliability:** Edge computing can provide redundancy and fault tolerance, ensuring that IoT applications continue to function even in the event of network disruptions.
- **Enhanced Security:** Edge computing can help improve data security by processing sensitive data closer to the source, reducing the risk of data breaches.
- **New Applications:** 5G and edge computing enable new IoT applications, such as autonomous vehicles, smart cities, and industrial automation.

Platform Sharing in Cellular Communication

Platform sharing in cellular communication refers to the collaborative arrangement where multiple Mobile Network Operators (MNOs) share infrastructure components, such as base stations, towers, and backhaul networks.

- This practice offers several benefits, including cost reduction, improved network efficiency, and accelerated deployment of new technologies.

Key Aspects of Platform Sharing:

- **Infrastructure Sharing:** MNOs can share various infrastructure components, including:
  - **Base stations:** The physical structures that transmit and receive radio signals.
  - **Towers:** The structures that support base stations.
  - **Backhaul networks:** The high-speed networks that connect base stations to the core network.
- **Sharing Models:** Different sharing models can be adopted, such as:
  - **Active Sharing:** MNOs jointly operate and manage shared infrastructure.
  - **Passive Sharing:** One MNO owns and manages the infrastructure, while others lease access.
  - **Hybrid Sharing:** A combination of active and passive sharing.
- **Benefits of Platform Sharing:**
  - **Cost Reduction:** Sharing infrastructure can significantly reduce capital and operational expenses for MNOs.
  - **Improved Network Efficiency:** By optimising resource utilisation, platform sharing can enhance network performance and coverage.
  - **Accelerated Deployment:** Sharing infrastructure can expedite the rollout of new technologies, such as 5G, by leveraging existing infrastructure.
  - **Reduced Environmental Impact:** Sharing infrastructure can help reduce the environmental footprint of cellular networks by minimizing the number of towers and base stations.

Key Technologies for Platform Sharing

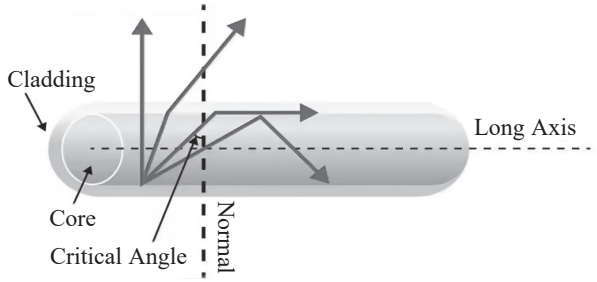
- **Network Slicing:** This technology allows MNOs to create virtual networks within a shared physical infrastructure, providing tailored services to different customer segments.
- **Shared Spectrum:** By sharing spectrum resources, MNOs can optimize their network capacity and reduce costs.
- **O-RAN (Open Radio Access Network):** O-RAN is an open, modular architecture that enables interoperability and flexibility in network deployment. It can facilitate platform sharing by decoupling hardware and software components.

FIBER OPTICS AND INTERNET

Fiber Optics

Optical fiber is a technology that uses light pulses to transmit data through long, thin strands of glass or plastic. Unlike traditional metal wires, optical fibers offer superior signal transmission with minimal attenuation.

Fiber Optic Internal Reflection



The Principle of Total Internal Reflection (TIR)

- Optical fibers operate based on the principle of total internal reflection.
- In TIR, light gets reflected on moving from denser to rarer medium if angle of incidence is greater than critical angle.
- This phenomenon occurs when light rays traveling within a medium (like glass) strike the boundary with another medium (like air) at an angle greater than the critical angle.
- The light rays are then reflected back into the original medium, allowing them to travel along the fiber without significant loss.

Advantages of Optical Fiber

- **High Bandwidth:** Can transmit vast amounts of data at high speeds, making them ideal for applications like internet, telecommunications, and video streaming.
- **Low Attenuation:** Have minimal signal loss over long distances, ensuring high-quality data transmission.
- **Immunity to Interference:** Not susceptible to electromagnetic interference, ensuring reliable and secure communication.

  Applications of Optical Fiber: Long-distance communication, Internet connectivity Local area networks (LANs), Sensors and monitoring

SURFACE WEB, DEEP WEB, AND DARK WEB

The internet can be broadly divided into three layers: the Surface Web, Deep Web, and Dark Web.

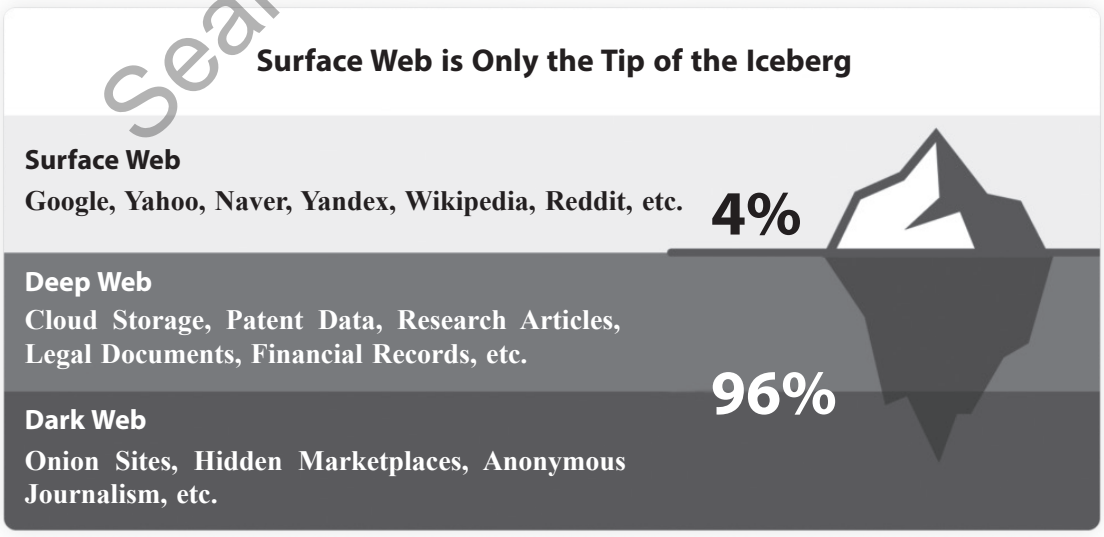
Surface Web

The surface web is the portion of the internet that is readily accessible to users using standard search engines like Google and Yahoo. However, it only represents a small fraction of the total internet content, **estimated to be around 4%.**

Deep Web

The deep web encompasses a vast portion of the internet, comprising **approximately 96%** of websites that are not publicly accessible. These websites are typically protected by passwords or paywalls, restricting access to authorized individuals.

- Examples include online banking portals, personal databases, social media accounts, scientific and academic databases, and legal documents.
- This hidden realm of the internet contains a wealth of information that is not readily available to the general public.



Dark Web

The **darknet is a subset of the deep web,** characterized by its deliberate anonymity and inaccessibility through standard search engines. Unlike the deep web, which can be accessed with specialized tools, the darknet requires specific browsers and networks to access its content.

Key Features of the Darknet

- **Anonymity:** The darknet prioritizes anonymity, using encryption and routing techniques to hide user identities and protect their online activities.
- **Accessibility:** Requires specialized browsers like Tor, Freenet, I2P, and Tails to access.
- **Content:** Hosts a wide range of content, including legal and illegal activities, such as marketplaces, forums, and whistleblowing platforms.

The Tor Network

Developed by the U.S. Naval Research Laboratory, Tor (The Onion Router) is the most widely used browser for accessing the darknet. It employs a layered routing system to obscure user identities and traffic patterns, making it difficult to track online activities.

White Space Internet

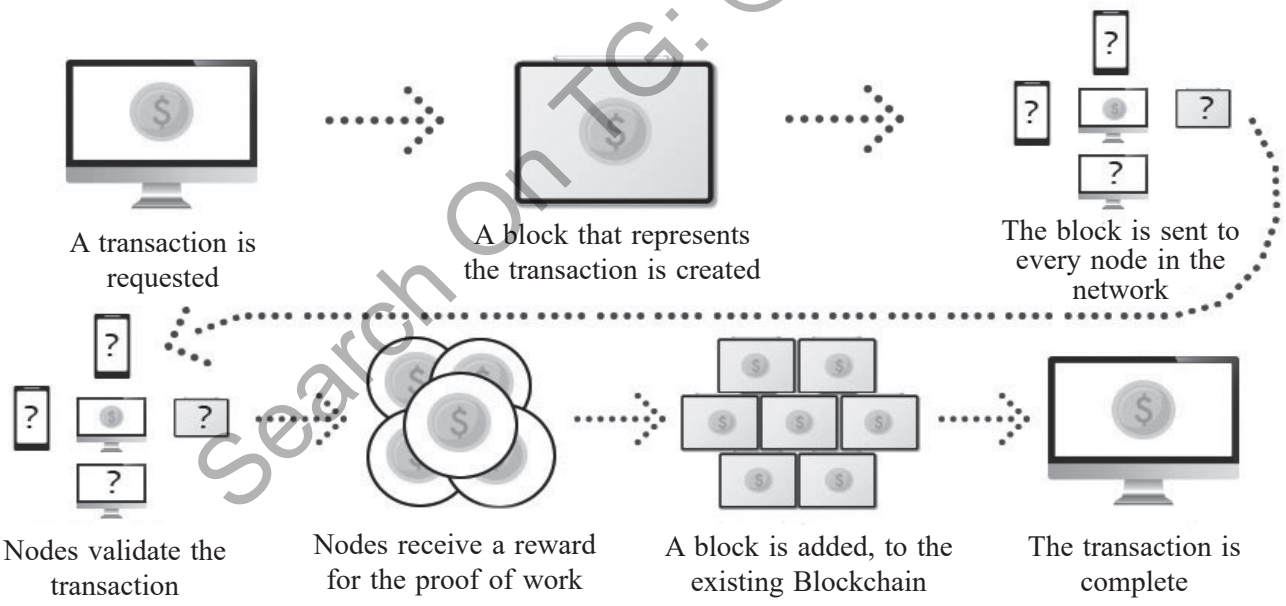
White Space Internet is a type of wireless broadband technology that **utilizes the unused frequency bands between television channels.** These "white spaces" are available for radio communication applications in certain geographical areas and times.

Features of White Space Internet: utilizes the unused frequency bands between television channels; Long-Range Coverage; can penetrate obstacles like buildings, foliage, and hills; Cost-Effective; easily deployed and reconfigured.

BLOCKCHAIN TECHNOLOGY [UPSC-2020]

Blockchain, a type of **Distributed Ledger Technology (DLT),** is a decentralised digital infrastructure that enables secure and transparent storage and transfer of information. Originally developed for Bitcoin, it has found applications in various sectors, including finance, supply chains, and voting.

How Blockchain Works?



Key Features of Blockchain:

- **Decentralization:** No central authority controls the network, making it resistant to censorship and manipulation.
- **Immutability:** Transactions are recorded as blocks and added to a chain, making them irreversible.
- **Transparency:** All transactions are visible to the public, ensuring transparency and accountability.
- **Security:** Blockchain uses cryptographic techniques to secure data and prevent tampering.
- **Energy Intensive:** Each block in the blockchain is added by solving complex calculations by the peers which needs high computational capacities and thus high energy consumption.

Evolution of Blockchain:

- **Origin:** Inspired by Ralph Merkle's hash tree data structures, **Satoshi Nakamoto** introduced blockchain for Bitcoin in 2008.
- **Ethereum:** Ethereum expanded blockchain capabilities with smart contracts, enabling more complex applications.
- **Growth:** Blockchain is now rapidly evolving and finding new applications across various industries.

Applications:

- **Financial Services:** Cryptocurrencies **(**Bitcoin and Ethereum), Payments and Trading (Singapore Exchange Limited), **Central Bank Digital Currency (CBDC)-** also known **e-Rupee** is based on blockchain technology.
- **Healthcare:** Medical Records, Drug Supply Chain
- **Copyright Management:** Protecting and managing copyright data, as demonstrated by Sony Music Entertainment.
- **Blockchain-as-a-Service (BaaS) - Cloud-Based Blockchain Solutions:** Third-party providers offer BaaS to simplify blockchain application development.

Non-Fungible Tokens (NFTs) [UPSC 2022]

Fungible refers to something that is interchangeable with another item of the same kind. For example, in the case of money or cryptocurrency, one unit is identical to another unit of the same value and can be exchanged without any difference. In contrast, non-fungible items, like NFTs, are unique and cannot be exchanged on a one-to-one basis with something else, as each has its own individual value.

NFTs are unique digital assets that represent ownership of real or virtual items. They are created on blockchains, such as **Ethereum,** and are assigned unique identification codes and metadata. **Unlike fungible tokens like money, each NFT is distinct and cannot be exchanged for another.**

NFTs can represent a wide range of items, including:

- **Digital art:** Paintings, photographs, music, videos
- **Real-world items:** Real estate, collectibles, physical goods
- **Intellectual property:** Patents, copyrights, trademarks
- **Identities:** Personal or corporate identities

NFTs **can be traded and exchanged for other NFTs, cryptocurrencies, or fiat currency, depending on their perceived value.** Transactions are recorded on blockchains, providing a transparent and secure record of ownership.

NFTs gained significant popularity in 2021 as artists recognized their potential for monetizing their work.

Evolution of Web (Web 1.0, 2.0, 3.0, and 5.0)

- **Web 1.0**: Often referred to as the "read-only web," was the first stage of the World Wide Web. It existed roughly from the mid-1990s to the early 2000s.
- **Web 2.0**: Refers to the second generation of the World Wide Web, characterized by a shift from static web pages to dynamic and interactive content. The term was popularized around the early 2000s.
- **Web 3.0**: It is the idea of a new internet that gives **users more control over their data** and privacy, using decentralization, blockchain, and tokenomics. It aims to offer a personalized and interactive experience but is still in development and not fully implemented.**[UPSC 2022] Examples :** Siri, Alexa, Google Assistant, and Ethereum.
- **Web 4.0**: This is the future stage of the web, expected to emerge by 2025. It is also called the **symbiotic web**, as it envisions a seamless integration of the web with the physical world, human biology, and consciousness.
- **Web 5.0**: This is the ultimate stage of the web, expected to emerge by 2030. It is also called the **emotional web,** as it anticipates a web that can understand and respond to the emotions, values, and preferences of the users.

Cryptocurrency

Cryptocurrency is a digital or virtual currency that utilizes cryptography for security. Unlike traditional currencies, cryptocurrencies are decentralized, meaning they are not controlled by a central authority like a government or bank.

- Popular examples of cryptocurrencies include Bitcoin, Ethereum, and Litecoin.
- These digital assets are often traded on decentralised exchanges and can be used for various purposes, such as purchasing goods and services, investing, or sending and receiving money.

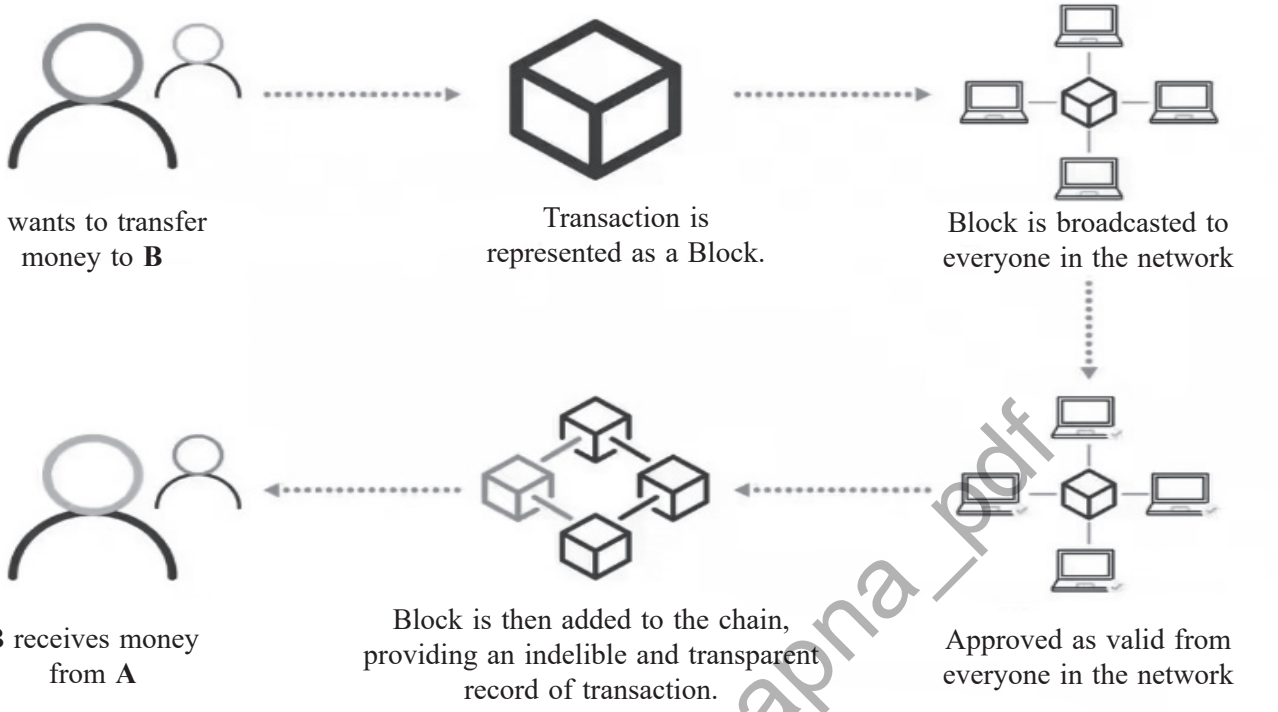
Legal Status of Cryptocurrency

The legal status of cryptocurrency varies significantly across countries. While some have embraced it, others have adopted a more cautious approach.

Cryptocurrency in India

- **RBI Warnings:** The Reserve Bank of India (RBI) has issued warnings against the use of cryptocurrencies, citing potential risks to investors.
  - RBI has introduced **Central Bank Digital Currency (CBDC) which is not a Cryptocurrency** as it's value is fixed by Central bank unlike cryptocurrencies which have different mechanism of value setting. CBDC however is also based on blockchain technology like cryptocurrency.
- **Supreme Court Ruling:** In 2018, the Supreme Court overturned an RBI ban on financial institutions dealing with cryptocurrencies.
- **Taxation and Regulation:** The government has introduced a **30% tax on cryptocurrency transactions** and established a panel to explore blockchain technology and a potential Central Bank Digital Currency (CBDC).

How Cryptocurrency transaction works



Global Landscape

- **Legal Tender:** El Salvador and the Central African Republic are the only countries where Bitcoin is legal tender.
- **Recognition and Regulation:** Many countries have taken steps to recognize and regulate certain cryptocurrencies.
- **Restrictions:** Some countries, like China and Russia, have imposed restrictions on cryptocurrency use.

Cryptocurrency vs NFT: Cryptocurrencies are fungible, meaning they are interchangeable and primarily used as a medium of exchange and a store of value. Their value is derived from market demand and supply, and they are traded on cryptocurrency exchanges (e.g., Bitcoin, Ethereum).

In contrast, NFTs (Non-Fungible Tokens) are unique and represent ownership of digital assets. Their value is subjective, based on the asset and market sentiment, and they are traded on NFT marketplaces (e.g., CryptoPunks, Bored Ape Yacht Club).

Consensus Mechanism in Cryptocurrency

Proof of Work (PoW) and **Proof of Stake (PoS)** are two primary consensus mechanisms used in blockchain technology to validate transactions and secure the network. They differ significantly in their approaches and implications.

Proof of Work (PoW)

- **Consensus Mechanism:** Miners compete to solve complex cryptographic puzzles. The first miner to solve the puzzle adds the next block to the blockchain.
- **Reward:** Miners receive newly minted cryptocurrency as a reward for their computational effort.
- **Security:** The computational power required to attack the network makes it highly secure.
- **Energy Consumption:** PoW is energy-intensive due to the computational resources needed for mining.
- **Examples:** Bitcoin, Ethereum (before the Merge)

Proof of Stake (PoS)

- **Consensus Mechanism:** Validators are selected based on the amount of cryptocurrency they stake in the network. The selected validator adds the next block to the blockchain.
- **Reward:** Validators earn transaction fees or newly minted cryptocurrency as a reward.
- **Security:** The economic incentive to act honestly prevents malicious behavior, as validators risk losing their stake if they misbehave.
- **Energy Efficiency:** PoS is significantly more energy-efficient than PoW.
- **Examples:** Ethereum (after the Merge), Cardano, Solana

Other Consensus Mechanisms

Delegated Proof of Stake (DPoS): In this system (used by networks like EOS and Tron), participants delegate their tokens to trusted validators who are then responsible for validating blocks. Those validators earn the minted cryptocurrency, which is often shared with delegators.

Minting Through Smart Contracts: Certain decentralized applications (DeFi(Decentralise Finance) projects for instance) mint new tokens based on rules encoded in smart contracts. These can be rewards for staking tokens or participating in specific network activities.

CBDC vs. e-RUPI

Central Bank Digital Currency (CBDC) and **e-RUPI** are both digital payment solutions, but they serve different purposes and operate under distinct mechanisms.

CBDC

- **Issuer:** Issued and regulated by a central bank, such as the Reserve Bank of India (RBI).
- **Purpose:** Intended to replace physical currency and provide a digital alternative for transactions.
- **Scope:** Covers a wide range of transactions, from daily purchases to large-scale payments.
- **Technology:** Can be based on various technologies, including blockchain.
- **Accessibility:** Accessible to the general public through banks and other financial institutions.

e-RUPI

- **Issuer:** Issued by the National Payments Corporation of India **(NPCI)** in collaboration with government departments.
- **Purpose:** Designed as a pre-paid, one-time payment instrument for specific goods or services.
- **Scope:** Primarily used for government welfare schemes and employee benefits.
- **Technology:** Based on **QR codes and UPI** (Unified Payments Interface).
- **Accessibility:** Available only to specific beneficiaries as designated by the issuing authority.

Blockchain Technology in India: Government Initiatives

- **Regulatory Sandbox:** The Reserve Bank of India (RBI) has established a regulatory sandbox to facilitate innovation in blockchain-based cryptocurrency and exchange solutions.
- **National Blockchain Strategy (2021):** The government has proposed a national strategy to promote blockchain adoption, including the development of state-specific applications and a reliable digital platform for e-governance services.
- **State-Level Initiatives:** States like Telangana, Tamil Nadu, and Maharashtra have invested in blockchain centres of excellence and startup incubators to foster blockchain innovation.
- **Digital India:** The Union Government has recognized blockchain as a key emerging technology under the Digital India initiative.
- **Centre of Excellence:** The **National Informatics Centre** has established a Centre of Excellence for Blockchain Technology to promote a unified, interoperable blockchain ecosystem across the country.

ENCRYPTION

Encryption is the process of scrambling data to make it unreadable to unauthorized parties. It involves using a cryptographic key, a set of mathematical values shared by the sender and recipient.

Types of Encryption

- **Symmetric Encryption:** Uses a single, shared key for both encryption and decryption.
- **Asymmetric Encryption (Public Key Encryption):** Uses two separate keys: a public key for encryption and a private key for decryption.

End-to-End Encryption

End-to-end encryption is a security measure that ensures data shared between two devices remains confidential.

- It prevents third parties, such as cloud service providers, internet service providers, and cybercriminals, from accessing or intercepting the data during transmission.
- **Examples:** Messaging apps like WhatsApp, Signal, and Telegram; Email services that support end-to-end encryption; Virtual private networks (VPNs) that use end-to-end encryption to secure internet traffic

How it Works:

- **Cryptographic Keys:** Unique cryptographic keys are generated and stored on the sender's and recipient's devices.
- **Encryption:** The data is encrypted using a complex algorithm, transforming it into an unreadable format.
- **Decryption:** Only the devices with the corresponding decryption keys can decode the encrypted data.

Quantum Key Distribution (QKD)

QKD, a type of quantum cryptography, provides a highly secure method for distributing and sharing secret keys used in cryptographic protocols.

- Unlike traditional cryptosystems that rely on complex mathematical algorithms, QKD leverages the laws of physics for security.

- **Benefits of QKD:** Unconditional Security, Long-Distance Transmission, Enhanced Privacy.
- **Applications:** Government and Military, Financial Institutions, Research and Development.

How QKD Works:

- **Quantum Bits (Qubits):** Encryption keys are transmitted as qubits through optical fibers. **[UPSC 2022]**
- **Total Internal Reflection:** Optical fibers enable efficient and long-distance data transmission.
- **Authentication:** Legitimate users must authenticate their interactions to ensure secure key distribution.
- **Secure Key Generation:** QKD allows two parties to generate a shared, random secret key.
- **Detection of Eavesdropping:** Any attempt to intercept the transmission will disturb the qubits, alerting the legitimate users.

BIG DATA AND COMPUTING

Big Data

Big data refers to a vast amount of structured, semi-structured, or unstructured data that is so voluminous that traditional data processing methods become inadequate.

- It encompasses not only the sheer quantity of data but also the challenges of collecting, storing, and analyzing it effectively.

Data Engineering and Data Science

Data Engineering

Data engineering involves designing, building, and maintaining data infrastructure to support data science and analytics initiatives. Data engineers extract, transform, and load (ETL) data from various sources, ensuring data quality and consistency. They work closely with data scientists to understand data requirements and build efficient data pipelines.

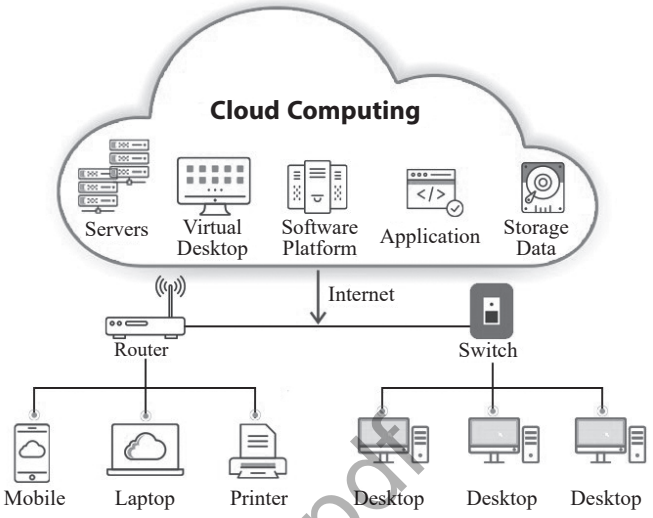
Data Science

Data science is the interdisciplinary field of extracting insights and knowledge from data using statistical and machine learning techniques. Data scientists collect, clean, analyze, and interpret data to solve problems and make informed decisions.

Cloud Computing

Cloud computing is a technology model that enables access to computing resources, such as storage and processing power, over the internet. Instead of relying on a local server, users can access these resources through web-based tools and applications. This on-demand access offers flexibility, scalability, and cost-effectiveness.

CLOUD COMPUTING ARCHITECTURE



How it Works:

Cloud computing involves storing and managing data on remote servers accessible via the internet. This centralised approach offers several key benefits:

- **Resource Pooling:** Dynamically allocates physical and virtual resources based on user demand.
- **On-Demand Access:** Provides scalable services that are available as needed, often with a pay-as-you-go pricing model.
- **Data Management:** Users can easily retrieve, manage, and interact with their data and applications hosted on the cloud.
- **Virtualization:** Creates and manages scalable virtual machines and environments using virtualization technology.
- **Automated Management:** Automates system maintenance tasks, including backup, updates, and security.
- **Accessibility:** Enables access from any device with internet connectivity, facilitating remote work and data sharing.

Cloud-Based Services

Cloud-based services offer flexible, scalable solutions through different service models, primarily structured around a subscription model. The three main service models are:

1. **Infrastructure as a Service (IaaS)**
   - **Definition:** Provides virtualized computing resources (servers, networks, storage).
   - **Applications:** Web hosting, big data analysis, e-commerce platforms.
   - **Examples:** Amazon EC2, MeghRaj Initiative.
   - **Access:** Clients provision resources via a web interface; service providers manage the hardware.

2. **Platform as a Service (PaaS)**
   - **Definition:** Manages application deployment without the need for hardware or OS management.
   - **Applications:** Application development, business analytics, disaster recovery.
   - **Examples:** Microsoft Azure App Service, AWS Elastic Beanstalk.
   - **Access:** Clients deploy apps through a dashboard; providers handle platform infrastructure.
3. **Software as a Service (SaaS)**
   - **Definition:** Offers complete software solutions with no maintenance required.
   - **Applications:** CRM, email, content management systems.
   - **Examples:** Microsoft Office 365, Google Workspace, DigiLocker.
   - **Access:** Clients use a web browser/app for access; providers maintain the software.

Subscription Model

- **Structure:** Clients pay recurring fees for access to services, with various tiers available (e.g., personal, business, enterprise).
- **Example:** Microsoft Office 365, where clients choose subscription levels based on their needs.

Dashboards and Access

- **Client Dashboards:** Clients can customize their dashboards to monitor usage and performance metrics.
- **Service Provider Dashboards:** Providers use dashboards to manage resources and service performance.
- **Editing Permissions:** Clients can edit their dashboards but cannot change underlying systems. Service providers can modify overall service settings.

Login IDs

- **Client Login IDs:** Unique IDs for secure access, allowing management of user roles.
- **Service Provider Login IDs:** Higher-level access for managing the service and providing support.

MeghRaj

It is a cloud computing initiative of the Government of India. It is a set of discrete cloud computing environments spread across multiple locations, built on existing or new (augmented) infrastructure, following a set of common protocols, guidelines and standards issued by the Government of India.

Edge Computing

Edge computing refers to the practice of processing data closer to its source, rather than relying on centralized cloud servers. This reduces latency and improves response times by eliminating the need to transmit data over long distances.

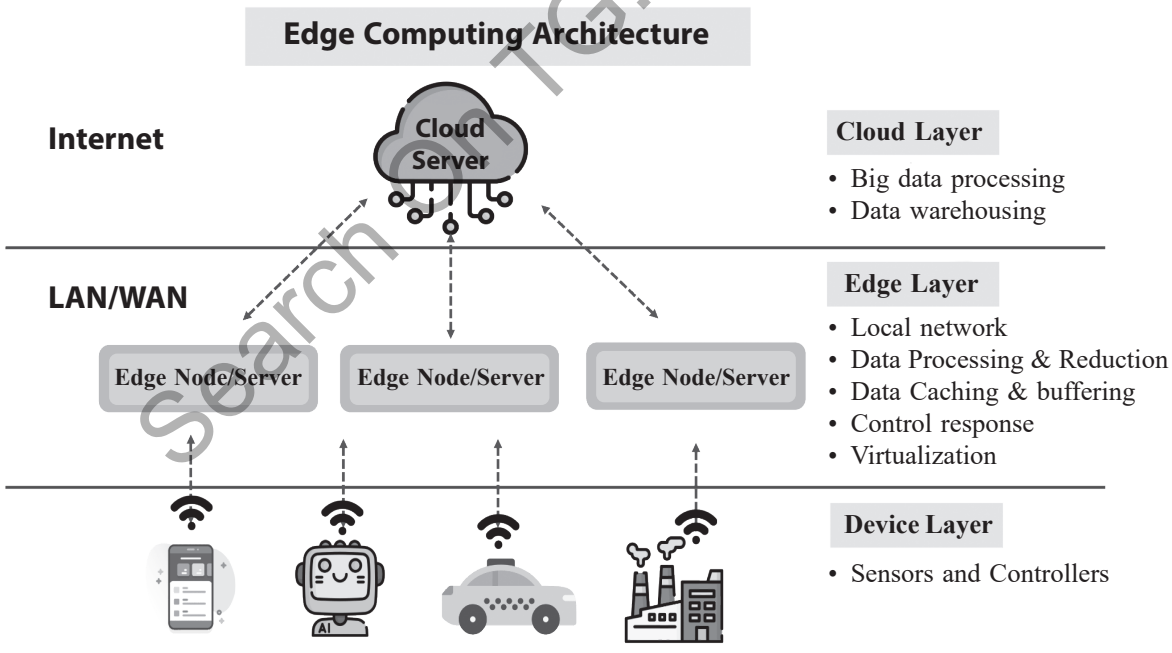


Figure: Edge computing architecture overview

Key Features of Edge Computing

- **Decentralized Processing:** Data is processed at the edge of the network, near the source of data generation (e.g., IoT devices, smartphones).
- **Reduced Latency:** By processing data locally, edge computing minimizes delays and ensures faster responses.
- **Real-Time Analysis:** Data can be analyzed in real-time, enabling timely decision-making and actions.

Applications of Edge Computing

- **Internet of Things (IoT):** Processing data from IoT devices for real-time applications.
- **Autonomous Vehicles:** Processing sensor data for self-driving capabilities.
- **Virtual Reality:** Rendering graphics and processing data locally for immersive experiences.
- **Augmented Reality:** Processing data from cameras and sensors for real-time overlays.

Cloud Vs. Edge Computing

Feature	Cloud Computing	Edge Computing
Data Processing	Non-time-sensitive	Real-time, high-speed
Internet Connectivity	Requires reliable internet	Limited or no internet needed
Use Cases	Dynamic workloads, large datasets	Highly sensitive data, real-time analysis
Cost	Costly for large datasets	Cost-effective for large datasets
Data Storage	Places data in cloud storage	Processes data locally

Supercomputers

Supercomputers are high-performance computing systems designed to handle complex computational tasks. They utilize multiple processors to divide and conquer problems, accelerating processing speeds. The performance of supercomputers is measured in **Floating-point Operations Per Second (FLOPS).**

Leading Supercomputers of World

The landscape of supercomputing is constantly evolving, with new and powerful machines emerging regularly. As of now, the following supercomputers occupy the top positions:

- **EI Captain:** Became the world's fastest supercomputer in Nov 2024 attaining speed of 1.742 exaFLOPS, beating the Frontier.
- **Frontier** is now the second fastest supercomputer in the world reaching maximum speed of 1.1 **exaFLOPS.**
- **Sunway TaihuLight (China), Tianhe-2 (China), Dell Frontera (USA), Piz Daint (Switzerland), and AI Bridging Cloud Infrastructure (ABCI) (Japan).** These are other notable supercomputers on the list.

The United States currently leads in terms of the number of supercomputers in the top 10, followed by China.

Supercomputers in India

India's supercomputing journey was spurred by the U.S. **denial of a Cray X-MP supercomputer in 1987.** This led to the establishment of domestic capabilities in supercomputer development.

- **C-DAC:** The Centre for Development of Advanced Computing has been a pioneer in supercomputing, developing the PARAM series.
- **BARC and ANURAG:** These organizations have also contributed to supercomputing development in India, creating the Anupam and PACE series, respectively.
- **PARAM Series:** C-DAC's PARAM series has been a cornerstone of Indian supercomputing, with notable achievements like the PARAM 8000 and PARAM 10000.
- **AIRAWAT:** India's fastest supercomputer as of June 2023, ranked 75th globally.
- **PARAM Siddhi – AI:** Another high-performance supercomputer focused on AI applications.

Quantum Computing [UPSC 2022]

Quantum computing is a revolutionary field that harnesses the principles of quantum mechanics to perform calculations far beyond the capabilities of classical computers. Unlike classical computers, which use bits (0s or 1s), quantum computers utilize qubits.

Qubits

A qubit, the fundamental unit of quantum information, is a quantum-mechanical system capable of existing in multiple states simultaneously.

Quantum Principles

Quantum computing relies on several fundamental principles that differentiate it from classical computing.

- **Superposition:** Unlike classical bits, quantum bits (qubits) can exist in multiple states simultaneously, a concept known as superposition. This enables quantum computers to process information in parallel, potentially solving complex problems much faster than classical computers.
- **Entanglement:** Quantum particles can become entangled, meaning their states are interconnected regardless of distance. This phenomenon allows for unique correlations and is essential for certain quantum algorithms.
- **Interference:** Quantum particles exhibit wave-like behavior, leading to interference effects that can be harnessed for computational tasks.
- **Tunneling:** Quantum particles can pass through barriers that would be impenetrable according to classical physics, a phenomenon known as tunneling. This principle is crucial for the operation of quantum computer hardware like **quantum dots.**

Qubit

A qubit, the fundamental unit of quantum information, is a quantum-mechanical system capable of existing in multiple states simultaneously.

- This phenomenon, known as superposition, distinguishes qubits from the bits used in traditional computers.
- Unlike bits, which can only represent 0 or 1, qubits can represent both 0 and 1 or any combination of the two states.
- This unique property enables quantum computers to perform complex calculations and solve problems that are intractable for classical computers.

Quantum Supremacy

Quantum supremacy refers to the ability of a quantum computer to perform certain calculations significantly faster than a classical computer.

- The term "Quantum Supremacy" was coined by John Preskill in 2011. In 2019, Google made headlines by achieving quantum supremacy with its 53-qubit quantum processor, **Sycamore.**
- The Sycamore successfully solved a sampling **problem in approximately 200 seconds,** a task that would have taken the **world's fastest classical supercomputer over 10,000 years** to complete.

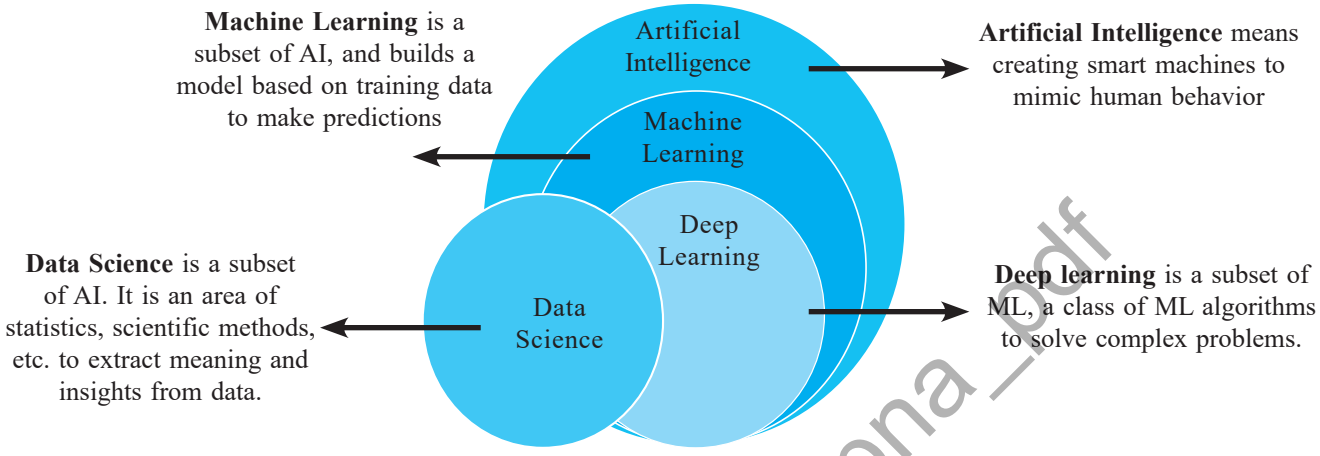
Difference between Classical and Quantum Computing

Parameter	Classical Computing	Quantum Computing
Basic Unit	Uses bits that are either 0 or 1.	Uses qubits that can be 0, 1, or both at the same time (superposition).
Parallelism	Works on tasks one after the other (sequentially).	Can work on many tasks at once because of superposition.
Hardware	Built with regular silicon chips that work at normal temperatures.	Uses special quantum processors that need to be kept very cold (cryogenic).
Programming	Follows a clear, step-by-step set of instructions.	Sets up conditions to find solutions using probabilities, not just direct steps.
Speed	Speed is limited by the number of transistors in the chip.	Can potentially solve certain problems much faster than classical computers.
Accuracy	Gives precise, reliable results.	Results can be uncertain and may require corrections (quantum error correction).

Artificial Intelligence and Machine Learning

AI is the ability of a computer, or a robot **controlled by a computer to do tasks that are usually done by humans** because they require human intelligence and discernment.

- Although there is **no AI that can perform the wide variety of tasks an ordinary human can do**, some AI can match humans in specific tasks.
- Alan Turing proposed "**Turing Test**" to evaluate machine intelligence.
- John McCarthy coined the term "Artificial Intelligence".



Components of Artificial Intelligence: Artificial Intelligence (AI) encompasses several core technologies that enable intelligent systems. These include:

- **Machine Learning:** Algorithms that allow systems to learn from data and improve their performance over time without explicit programming. **Example:** Spam filtering in email clients.
- **Deep Learning:** A subset of machine learning that utilizes artificial neural networks with multiple layers for complex tasks. **Example:** Facial recognition systems
- **Natural Language Processing (NLP):** Algorithms that enable computers to understand, interpret, and generate human language. **Example:** Virtual assistants like Siri or Alexa.
- **Computer Vision:** Algorithms that allow computers to analyze and understand visual information from images or videos. Example: Self-driving cars.
- **Neural Networks:** A type of machine learning model inspired by the human brain, consisting of interconnected nodes that process information and learn patterns. **Example:** Recommendation systems on streaming platforms.

Applications of Artificial Intelligence

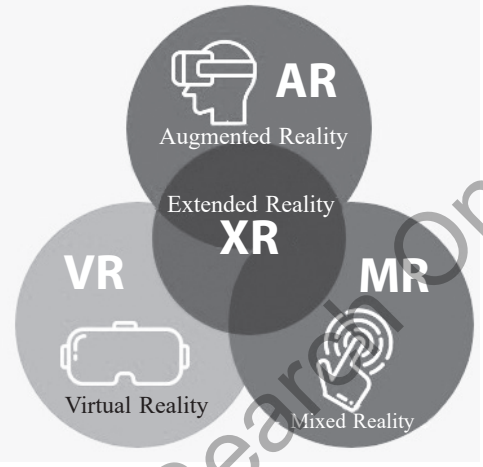
1. **GPT (Generative Pre-trained Transformer): an application of Generative AI**
   - A type of large language model capable of generating human-quality text, translating languages, writing different kinds of creative content, and answering your questions in an informative way.
   - **Example:** OpenAI's ChatGPT is a well-known GPT model that can engage in conversations, write different kinds of creative content, and translate languages.
2. **Healthcare**
   - **Disease diagnosis:** AI algorithms can analyze medical images, patient data, and genetic information to assist in diagnosing diseases more accurately and efficiently.
   - **Drug discovery:** AI can accelerate drug discovery by identifying potential drug candidates and simulating their interactions with biological targets.
   - **Personalized medicine:** AI can help tailor treatment plans to individual patients based on their genetic makeup and medical history.
3. **Other Sectors**

- **Finance:** AI is used for fraud detection, algorithmic trading, and customer service.
- **Manufacturing:** AI-powered robots and automation systems can improve efficiency and productivity in manufacturing processes.
- **Agriculture:** AI can optimize crop yields, monitor soil conditions, and predict weather patterns.
- **Customer service:** AI-powered chatbots can provide 24/7 customer support and answer queries efficiently.
- **Transportation:** AI is used for autonomous vehicles, traffic management, and logistics optimization.

Application	Example
Chatbots	ChatGPT by OpenAI, Copilot by Microsoft Bing
Smart Assistants	Siri, Alexa, Cortana
Recommendation Algorithms	Google's search algorithm, Netflix's personalized content recommendations
Face Recognition	FaceID on iPhones, Security cameras
Navigation Apps	Google Maps, Waze
Social Media Algorithms	Instagram, Facebook, Twitter's curated feeds
Ridesharing Apps	Uber, Ola

EXTENDED REALITY

Extended Reality (XR) is a broad term that encompasses technologies that enhance or replace our perception of the real world. It includes three primary types: Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR).



1. Augmented Reality (AR) **[UPSC 2019]**

- **Definition:** AR overlays digital information, such as images, videos, or 3D models, onto the real world.
- **Experience:** Users interact with the real world, enhanced by digital elements.
- **Example:** Pokémon Go, where virtual creatures are superimposed on real-world environments.

2. Virtual Reality (VR) **[UPSC 2019]**

- **Definition:** VR creates a fully immersive, computer-generated environment that replaces the real world.
- **Experience:** Users are completely immersed in a simulated reality.
- **Example:** VR gaming headsets that transport users to virtual worlds.

3. Mixed Reality (MR)

- **Definition:** MR blends the real and virtual worlds, allowing users to interact with both physical and digital objects.
- **Experience:** A combination of AR and VR, where digital elements seamlessly integrate with the real world.
- **Example: Microsoft HoloLens,** which allows users to interact with holograms superimposed on their real-world surroundings.

Metaverse **[UPSC 2024]**

The metaverse is a digital realm where individuals can interact with each other and virtual objects in a shared online space.

- Inspired by Neal Stephenson's 1992 novel "Snowcrash," the term envisions a future where people use virtual avatars to participate in a cyberspace world.

Key Elements of the Metaverse:

- **Virtual Reality (VR):** Immersive experiences that replace the real world.
- **Augmented Reality (AR):** Overlays digital information onto the real world.
- **Online Games:** Virtual worlds for gaming and social interactions.
- **Social Media:** Platforms for connecting and interacting with others.

The metaverse aims to create a seamless and immersive experience, blurring the lines between the physical and digital worlds. Companies like Meta (formerly Facebook), Microsoft, and Roblox are investing heavily in this technology, recognizing its potential to drive growth in the technology industry.

ELECTRONICS

Semiconductors

Semiconductors are materials that have electrical conductivity between that of conductors (like metals) and insulators (like glass). Their unique property lies in their ability to control the flow of electric current, making them essential components in various electronic devices.

Working:

1. **Doping:** The process of intentionally adding impurities (dopants) to a pure semiconductor material to alter its electrical properties.
   - **N-type semiconductors:** Doped with elements with more valence electrons (e.g., phosphorus) to create an excess of free electrons.
   - **P-type semiconductors:** Doped with elements with fewer valence electrons (e.g., boron) to create "holes" (absence of electrons).

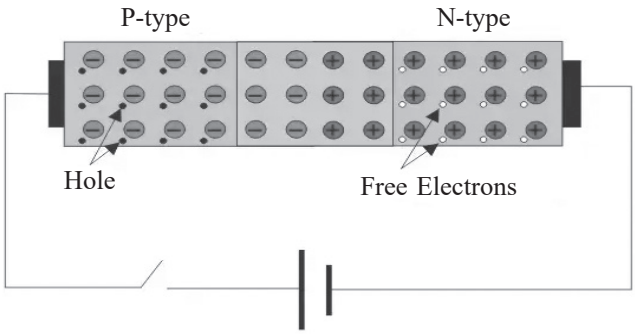


Fig. Forward Junction Pn Diode

2. **Junctions:** When P-type and N-type semiconductors are joined, a p-n junction is formed. This junction is the basis for many semiconductor devices.
3. **Current Flow:** The application of a voltage across a p-n junction causes current to flow in one direction only, this is called forward **bias**. This principle is a crucial component in diodes, transistors, and other electronic devices.
4. **Difference from Conductors:** In Conductors current can flow in both directions and conductors already have excess electrons to allow current flow unlike semiconductors which need doping with certain elements.

Transistor

A transistor is a semiconductor device with three terminals: emitter, base, and collector. Transistors are the fundamental building blocks of modern electronic circuits from smartphones to smart TVs.

Diode

A diode is a two-terminal semiconductor device that allows current to flow in only one direction. It is often used as a rectifier to convert Alternating Current (AC) into Direct Current (DC). Diodes can also be used as switches, voltage regulators, and Light-Emitting Diodes (LEDs).

Amplifier

An amplifier is a circuit that increases the amplitude of an electrical signal. Transistors are commonly used to build amplifiers, as they can control and amplify the flow of current. Amplifiers are essential components in various electronic devices, such as audio systems, radios, and televisions.

Wireless Charging

Wireless charging eliminates the need for cables by transferring power from a charger to a device using electromagnetic induction.

Working

- **Electromagnetic Induction:** A rapidly changing magnetic field in the charger induces an electric current in the device's receiving coil.
- **Compatibility:** Both the charger and device must support wireless charging.

Types of Wireless Charging

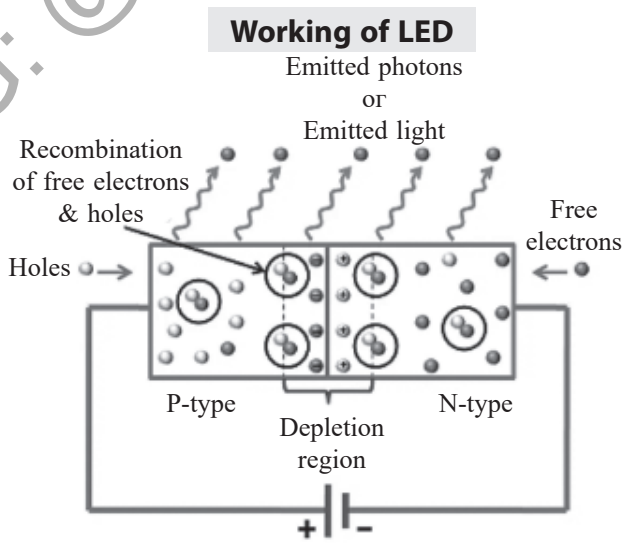
- **Tightly-Coupled Inductive Charging:** Requires close proximity between the charger and device, often using copper coils.
- **Radio Frequency (RF)-Based Charging:** Enables charging at a distance of several feet.
- **Loosely-coupled resonance charging:** Promises charging at even greater distances.

LED (Light-Emitting Diode)

Definition: A semiconductor device that emits light when a current is passed through it.

Working: LEDs consist of a p-n junction, where electrons recombine with holes, emitting light.

Applications: Lighting, displays, indicators, and signage.



OLED (Organic Light-Emitting Diode) [UPSC 2017]

Definition: A type of LED that uses organic materials to emit light.

Working: OLEDs emit light when an electric current is applied to a thin layer of organic material.

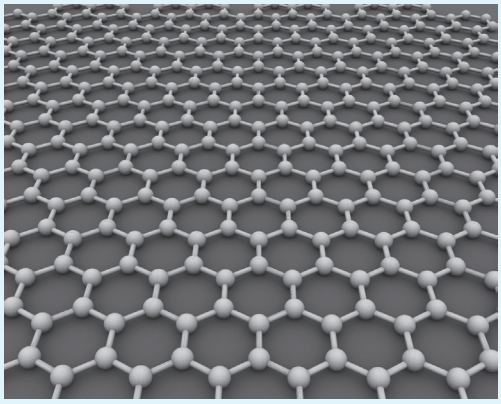
Applications: Displays in smartphones, televisions, and other electronic devices.

Advantages: Deeper blacks, wider viewing angles, and thinner designs compared to traditional LCDs.

Graphene [UPSC 2012]

Graphene, a single layer of carbon atoms in a honeycomb lattice, is the thinnest, strongest, and most conductive material known due to its structure and free-moving electrons.

It combines mechanical strength, thermal and electrical conductivity, flexibility, and lightweight properties. Applications include flexible electronics, batteries, biosensors, water filtration, and composites, with potential in quantum computing and sustainable energy.



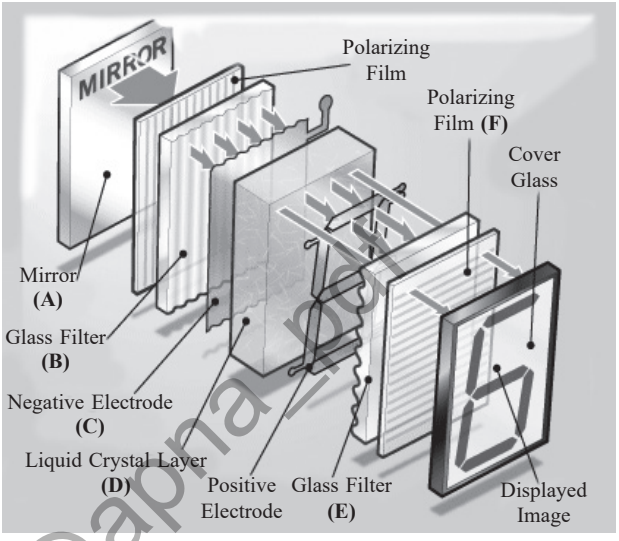
AMOLED (Active-Matrix Organic Light-Emitting Diode)

- **Definition:** An advanced type of OLED that uses a Thin-Film Transistor (TFT) array to control each pixel individually.
- **Working:**
  - **Pixel Structure:** Each pixel in an AMOLED display is composed of multiple organic light-emitting diodes (OLEDs).
  - **Individual Control:** Unlike LCD displays, where pixels are backlit and controlled by a liquid crystal layer, AMOLED displays **allow each pixel to be turned on or off independently.**
  - **Precise Image Control:** This individual control enables AMOLED displays to achieve deeper blacks and more vibrant colors, as pixels that are not being used can be completely turned off, resulting in a higher contrast ratio.
- **Applications:** High-end smartphones, tablets, and televisions.
- **Advantages:** Superior picture quality, higher contrast ratios, and lower power consumption compared to traditional OLEDs.

LCD (Liquid Crystal Displays)

LCD displays, or Liquid Crystal Displays, are commonly found in TVs, computer monitors, and other electronic devices. They work by using liquid crystals to control the amount of light that passes through a screen.

How LCDs Work:



1. **Backlight:** A backlight illuminates the display from behind.
2. **Polarizers:** Two polarizers are placed on opposite sides of the liquid crystal layer.
3. **Liquid Crystals:** These are tiny molecules that can twist and turn when an electric current is applied.
4. **Colour Filters:** A layer of colour filters (red, green, and blue) is placed behind the liquid crystals.

Controlling Light:

- **Off State:** When no voltage is applied to the liquid crystals, they remain twisted. This allows light to pass through both polarizers, creating a bright pixel.
- **On State:** When a voltage is applied, the liquid crystals untwist. This prevents light from passing through the second polarizer, creating a dark pixel.

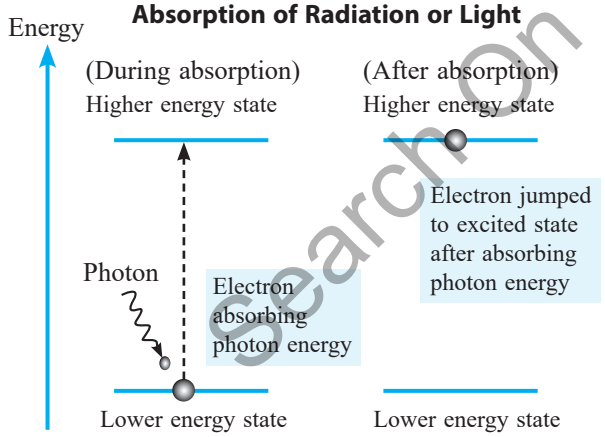
Creating Images: By controlling the voltage applied to different groups of liquid crystals, the amount of light passing through can be varied. This allows for the creation of different shades of gray and colors, forming images on the screen.

Comparison of LED and LCD **[UPSC 2019]**

Feature	LED (Light Emitting Diode)	LCD (Liquid Crystal Display)
Backlighting	Uses Light-Emitting Diodes (LEDs) for illumination.	Uses Cold Cathode Fluorescent Lamps (CCFLs) for backlighting.
Energy Efficiency	More energy-efficient, consuming less power.	Less energy-efficient, consuming more power.
Brightness and Contrast	Higher brightness and better contrast.	Generally lower brightness and contrast.
Viewing Angle	Wider viewing angle, maintaining quality from various positions.	Narrower viewing angle, with color fading at the sides.
Response Time	Faster response time for quicker image changes.	Slower response time, which can lead to motion blur.
Thickness	Thinner and lighter design.	Thicker and bulkier design.
Lifespan	Longer lifespan due to the durability of LEDs.	Shorter lifespan compared to LED technology.
Color Accuracy	Better color accuracy for more vibrant images.	Slightly less color accuracy than LED technology.
Cost	Generally more expensive due to advanced technology.	Generally less expensive and more budget-friendly.

LASER

LASER stands for Light Amplification by Stimulated Emission of Radiation. It is a technology that produces a highly focused and coherent beam of light.



Key Principles:

- **Stimulated Emission:** Atoms or molecules are excited by external energy, causing them to emit photons with the same energy, phase, and direction.
- **Amplification:** The emitted photons stimulate other atoms to emit photons, leading to a chain reaction and amplification of the light beam.
- **Coherence:** Laser light is highly coherent, meaning the photons are in phase with each other, producing a highly focused beam.

Applications: Communication (Optical fiber communications, barcode scanners); Medicine (Surgery, eye treatments); Industry (Cutting, welding, drilling); Entertainment (holography); spectroscopy.

3D printing **[UPSC 2018]**

3D printing, or additive manufacturing, creates three-dimensional objects by building layers of material based on a digital model. It works on the **principle of layer-by-layer deposition,** where materials like plastics, metals, or resins are precisely placed using techniques such as fused deposition modeling (FDM), stereolithography (SLA), or selective laser sintering (SLS). The science behind it involves translating a digital CAD (Computer-Aided Design) file into machine instructions that control the printer's movement and material deposition. Applications span medicine (custom prosthetics, organ models), aerospace (lightweight components), manufacturing (rapid prototyping), construction (3D-printed buildings), and art (custom designs). Its ability to create complex, customizable shapes efficiently is transforming industries globally.

6 Universe and Space Technology

ORIGIN OF UNIVERSE: BIG BANG THEORY

It is believed that the universe was born about 13.8 billion years ago in an event called the Big Bang. It is the most prevailing cosmological model for the birth of the universe.

Big Bang Theory

- It states that at some moment, all of space was contained in a (Known as singularity) of very high-density and high-temperature state from which the universe has been expanding in all directions ever since.
- After the initial expansion, the universe cooled sufficiently to allow the formation of subatomic particles and, later simple atoms.
- The majority of atoms produced by the Big Bang were hydrogen and helium along with trace amounts of lithium and beryllium.
- Giant clouds of these primordial elements (hydrogen and helium) later coalesced through gravity to form stars and galaxies.

Dark Energy and Dark Matter

Component of Universe	Percentage (%)
Dark Energy	68%
Dark Matter	27%
Ordinary Matter	5%
Total	100%

- **Dark Energy:** A mysterious force driving the accelerated expansion of the universe.
- **Dark Matter:** Non-luminous matter that does not emit or interact with electromagnetic radiation, detectable through its gravitational effects.
- **Ordinary Matter:** Includes stars, planets, gas, dust, and all known forms of visible matter

OBSERVING SPACE THROUGH TELESCOPES

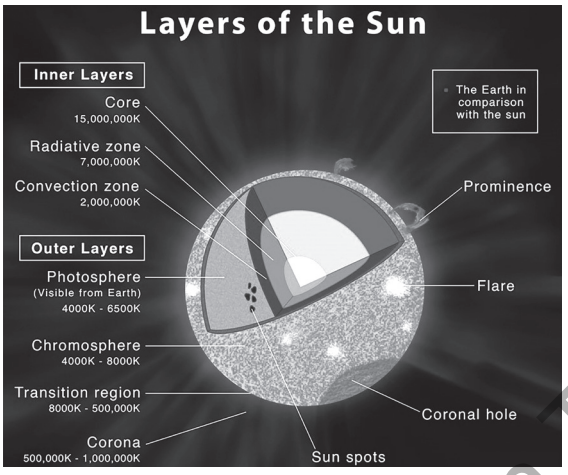
Name of Telescope	Description
Hubble Space Telescope	• The first major optical telescope launched into space in 1990. • Hubble observes **visible, ultraviolet, and infrared wavelengths** and has provided insights into the universe's size, galaxy and black hole evolution, star lifecycles, and dark energy.
James Webb Space Telescope	• Launched in 2021, JWST is NASA'S **primary infrared observatory** designed to study the early universe, galaxy formation, star and planetary system evolution, and the atmospheres of exoplanets. • NASA, the European Space Agency (ESA), and the Canadian Space Agency (CSA) are working together on this project.
Event Horizon Telescope (EHT)	• A collaboration of eight radio telescopes used to observe black holes and other astronomical objects. • Captured the first-ever image of a black hole in 2019.
ARIES Telescope	• A collaboration between India, Russia, and Belgium, this telescope is located at 2,500 meters in Devasthal, India. • It uses advanced technology for remote control and studies astronomical debris, magnetic fields, planets, and stars.
AstroSat (India)	• Launched in 2015, AstroSat is India's first dedicated astronomy satellite. • Unlike **Hubble (visible light) or Chandra (X-ray),** AstroSat observes across the electromagnetic spectrum, studying high-energy processes in binary star systems, neutron stars, and star-forming regions. **[UPSC 2016]**

Thirty Meter Telescope	• An under-construction project at Mauna Kea in Hawaii, involving **India, the US, Canada, China,** and **Japan,** aiming to be one of the world's largest optical telescopes with a 30-meter mirror. • It will provide significantly 12 times sharper images than Hubble and advance research in astrophysics.
SARAS Telescope (India)	• A radio telescope used to detect faint radio signals from the early universe, providing insights into the formation of the first stars and galaxies.

SUN CYCLE, SOLAR ECLIPSE AND GEOTAIL

The Sun is a massive, electrically charged ball of heated gas. When this charged gas travels, it creates a strong magnetic field. The magnetic field of the Sun passes through a cycle known as the solar cycle.

- The Sun's magnetic field totally turns approximately every 11 years. The north and south poles of the Sun will transfer locations as a result of this.



Changes in the Sun's magnetic field impact its surface activity. **Sunspots**, cooler regions with strong magnetic fields, are a key indicator of this activity. The solar cycle progresses through distinct phases:

- **Solar Minimum:** The cycle begins with minimal sunspot activity.
- **Solar Maximum:** Sunspot activity reaches its peak.
- **Solar Decline:** Sunspot activity decreases, eventually returning to the solar minimum.

Solar activity during the solar maximum can have effects like:

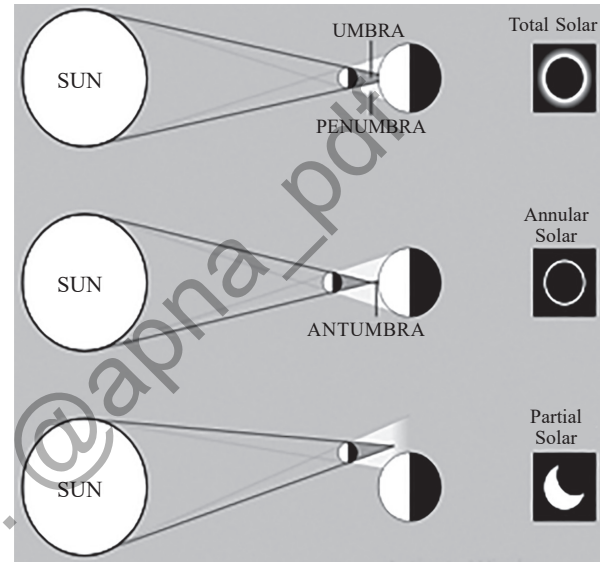
- **Auroras:** Eruptions can cause beautiful auroras, also known as the northern and southern lights.
- **Disruptions:** Strong solar flares can disrupt radio communications and even damage power grids on Earth. Orbits of the satellites could be disturbed. Shortwave radio communication of the aircraft flying over polar regions could be interrupted. **[UPSC 2022]**

Solar Eclipse

When the moon passes between the sun and the earth, a solar eclipse occurs. The moon stops the sun's light from reaching the earth when this happens. The planet is then bathed in the moon's shadow.

- **There are three Types of Solar Eclipses**: annular solar eclipse, total solar eclipses, partial solar eclipses.

Solar Eclipses

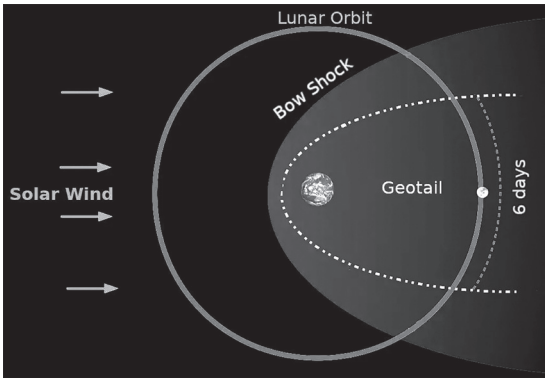


- **Total Solar Eclipse:** Occurs when the Moon completely blocks the Sun, creating a temporary night-like darkness. Only the Sun's corona is visible during totality.
- **Annular Solar Eclipse:** Occurs when the Moon is at or near its farthest point from Earth, appearing smaller than the Sun. This results in a ring of sunlight around the Moon's silhouette.
- **Partial Solar Eclipse:** Occurs when the Sun, Moon, and Earth are not perfectly aligned, causing only part of the Sun to be obscured. People outside the area covered by the Moon's inner shadow will see a partial eclipse.

Geotail

The geotail is a region in space formed by the interaction between the Earth's magnetic field and the solar wind, a continuous stream of charged particles emitted by the Sun.

- The Earth's magnetic field acts as a barrier, deflecting the solar wind plasma.
- This interaction creates a magnetic envelope around Earth, compressed on the Sun-facing side and extended into a long tail i.e. geotail on the opposite side extending beyond the moon's orbit.
- Approximately, once every 29 days, Moon traverses the geotail for about 6 days centered around full moon.



GRAVITY

Gravity is the force by which a planet or other body draws objects toward its center. The force of gravity keeps all of the planets in orbit around the sun.

- Objects with more mass have more gravity. Gravity also gets weaker with distance. So, the closer objects are to each other, the stronger their gravitational pull is.

Variation of Gravity on Earth

- Gravity isn't the same everywhere on Earth. Gravity is slightly stronger over places with more mass underground than over places with less mass.
- **GRACE Mission:** NASA uses two spacecraft to measure these variations in Earth's gravity. These spacecraft are part of the Gravity Recovery and Climate Experiment (GRACE) mission.

Einstein's Theory of General Relativity [UPSC 2018]

General relativity, formulated by Albert Einstein in 1915, is a revolutionary theory that fundamentally changed our understanding of gravity and the universe.

- Unlike Newton's theory of gravity, which describes it as a force acting between objects, Einstein's theory proposes that gravity is a curvature of spacetime caused by the presence of mass and energy.
- **Key Principles:**
  - **Equivalence Principle:** The effects of gravity and acceleration are indistinguishable.
  - **Curvature of Spacetime:** Massive objects warp the fabric of spacetime, influencing the motion of other objects.
  - **Gravitational Waves:** Disturbances in spacetime caused by accelerating massive objects, predicted by general relativity and detected in 2015.

Implications

- **Black Holes:** General relativity predicts the existence of black holes, regions of spacetime where gravity is so strong that nothing, not even light, can escape.
- **Gravitational Lensing:** The bending of light by massive objects, as predicted by general relativity, has been observed through gravitational lensing.
- **Cosmology:** General relativity provides the foundation for our understanding of the universe on a large scale, including the expansion of the universe and the formation of galaxies.

Applications

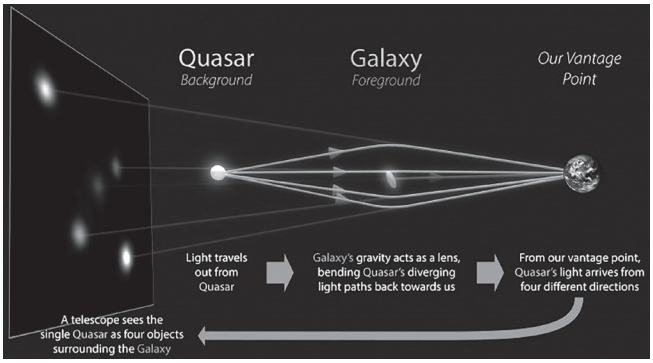
- **GPS Systems:** The accuracy of GPS systems relies on correcting for the effects of general relativity, as the clocks on GPS satellites experience time dilation due to their relative motion and gravitational potential.
- **Astronomy:** General relativity is essential for understanding the behavior of astronomical objects, such as binary stars, neutron stars, and black holes

Gravitational Waves [UPSC 2019]

- Gravitational waves were first proposed by Albert Einstein, 100 years ago as part of the Theory of Relativity.
- In 2016, scientists at Laser Interferometer Gravitational-wave Observatory (LIGO) first detected the gravitational waves.
- The **evolved Laser Interferometer Space Antenna (eLISA)** is a mission aiming at exploring the Gravitational Universe from space for the first time. The experiment will employ a **trio of spacecraft flying in formation in the shape of an equilateral triangle** that has sides one million kilometers long, with lasers shining between the craft. **[UPSC 2020]**
- GWs are ripples in space-time that move at the speed of light and are created by some of the Universe's most furious and intense processes.
- They hold information about their cataclysmic origins, as well as crucial insights regarding gravity's nature.
- They form when
  - Things move at extremely high speeds,
  - When a star explodes asymmetrically (known as a supernova),
  - When two large stars orbit one other, and
  - When two black holes orbit each other and join.

Gravitational Lensing

Gravitational lensing occurs when a massive celestial body, like a galaxy cluster, bends the path of light passing near it.



- This phenomenon, predicted by Einstein's theory of relativity, acts as a cosmic lens, magnifying distant objects that would otherwise be too faint to observe.
- The curvature of spacetime caused by the massive object distorts the light's path, creating distorted images such as rings or halos around the lens.

LIGO- India – InDIGO

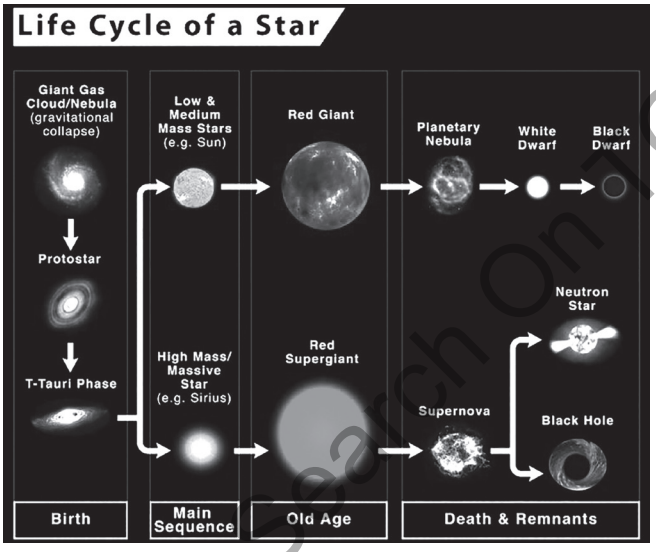
- LIGO-India project is an Indian Initiative in Gravitational
- wave observations (InDIGO), expected to be completed by 2025.
- It aims to move one advanced LIGO detector from Hanford to Maharashtra (Hingoli district), India.
- The project is piloted by the Dept. of Atomic Energy (DAE) and Dept. of Science and Tech (DST).

STARS AND PLANET: LIFE CYCLE OF A STAR

- **Stars** are celestial bodies primarily composed of hydrogen and helium. Through nuclear fusion, they generate light and heat. These luminous spheres of plasma are the fundamental building blocks of galaxies.

Life Cycle of Stars

The stellar evolution infers the process and life cycle of the star from its formation to decay and ultimately death of a star.



Stellar Nebula: The journey of a star begins in a stellar nebula, a vast cloud of gas and dust primarily composed of hydrogen and helium.

Protostar Formation: As the density and temperature within the nebula rise, nuclear fusion reactions ignite at its core, marking the birth of a protostar.

- This dense, hot core continues to gather surrounding gas and dust, eventually evolving into a fully developed star.

T-Tauri Star: Before reaching its stable main sequence stage, a young star passes through the T-Tauri phase. T Tauri stars are characterized by irregular brightness variations and strong stellar winds.

- This transitional phase bridges the gap between protostars and mature stars.

Main Sequence Stars

The majority of a star's life is spent in a stable phase on the main sequence. Our Sun is currently a main sequence star.

- **Hydrostatic Equilibrium:** During the main sequence, a star's core is in hydrostatic equilibrium. This means that the outward thermal pressure from nuclear fusion reactions balances the inward pull of gravity, maintaining the star's stability.
- **Nuclear Fusion:** The energy that supports a main sequence star against gravitational collapse comes from nuclear fusion in its core. Hydrogen atoms combine to form helium, releasing a tremendous amount of energy in the process.
- **End of the Main Sequence:** Once hydrogen fusion in the core ceases, the star loses its stability and evolves off the main sequence. The path it takes depends on its mass.
- **Lifespan:** The lifespan of a main sequence star is directly related to its mass. More massive stars burn through their fuel at a faster rate, resulting in shorter lifespans. Conversely, low-mass stars like red dwarfs can shine for tens of billions of years.
- **Red Dwarfs:** Red dwarfs are the smallest and least luminous main sequence stars, typically less than 10% of the Sun's mass. They emit minimal energy and have surface temperatures between 3000-4000K. Despite their small size, red dwarfs are abundant and have extremely long lifespans.

Death of Star

When a **star exhausts the hydrogen** in its core, it undergoes changes leading to its eventual fate.

Red Giants and Supergiants: When a main sequence star, less massive than eight times the Sun, depletes its core hydrogen, it undergoes significant changes.

- The core contracts, increasing temperature and pressure, igniting helium fusion.
- Simultaneously, hydrogen fusion shifts to the outer layers, causing the star to expand into a red giant. Our Sun is destined to become a red giant in the distant future. **[UPSC 2024]**

Planetary Nebulae: Red giants become unstable, pulsating and periodically expelling portions of their outer atmosphere.

- Eventually, these outer layers are completely blown away, forming an expanding cloud of dust and gas known as a planetary nebula.

White Dwarfs: Average-sized stars like our Sun, near the end of their lives, shed their outer layers, revealing their hot, dense cores. These cores become white dwarfs.

- White dwarfs are incredibly hot, resembling glowing cinders despite being stellar remnants. They are supported by electron degeneracy pressure, preventing complete gravitational collapse.

Chandrasekhar Limit

The Chandrasekhar Limit, named after Subrahmanyan Chandrasekhar, sets the maximum mass for a white dwarf at 1.4 solar masses. Stars exceeding this limit are destined to become neutron stars or black holes.

Nova Explosions: White dwarfs in binary star systems can accrete matter from their companion stars.

If enough hydrogen accumulates on the white dwarf's surface, nuclear fusion can ignite, leading to a nova explosion. This sudden brightening is caused by the fusion of the accreted hydrogen.

Supernova Explosions: Massive stars with more than eight solar masses are destined to undergo supernovae. These cataclysmic events occur when the star's core collapses after exhausting its nuclear fuel.

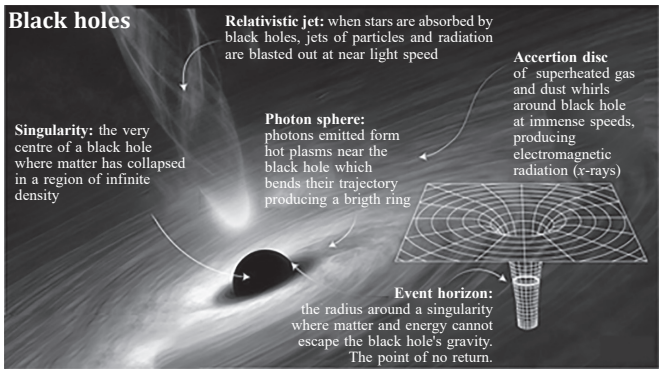
- The collapse triggers a series of nuclear reactions, culminating in the formation of an iron core.
- Iron fusion is energetically unfavorable, leading to the core's collapse and the subsequent rebound, creating a powerful shock wave that blasts the star's outer layers into space.

Neutron Stars: If the core of a supernova has a mass between 1.4 and 3 solar masses, it collapses further, forming a neutron star. These incredibly dense objects are composed primarily of neutrons, packed together tightly by immense gravity.

- Neutron stars often exist in binary systems, where their strong gravitational fields can accrete material from companion stars. This accretion process can lead to the emission of X-rays.
- **Pulsars:** The rapidly rotating magnetic fields of neutron stars can produce beams of radiation that are observed as pulsars.
- **Magnetars:** A subset of neutron stars known as magnetars have exceptionally strong magnetic fields, billions of times stronger than Earth's. These powerful fields can produce intense bursts of X-rays and gamma rays.

Black Holes: When a massive star's core collapses to a mass greater than three times that of the Sun, it transforms into a black hole. These incredibly dense objects have such intense gravity that nothing, not even light, can escape their grasp.

- **Black holes are divided into three types:** Stellar black holes (also known as unicorns), Supermassive black holes, and Intermediate-mass black holes.



KEY TERMS

Planet

The most recent definition of a planet was adopted by the International Astronomical Union in 2006. It says a planet must do three things:

- It must orbit a star (in our cosmic neighborhood, the Sun).
- It must be big enough to have enough gravity to force it into a spherical shape.
- It must be big enough that its gravity cleared away any other objects of a similar size near its orbit around the Sun.

Dwarf Planet (UPSC 2024)

- As per the **International Astronomical Union (IAU):** A dwarf planet is a celestial body that circles the sun, has enough mass to assume a roughly round shape, has not cleared the neighborhood surrounding its orbit, and is not a moon.
- Ceres, Pluto, Eris, Makemake, and Haumea are the first five dwarf planets discovered.

Pluto was reclassified as a "dwarf planet" by the International Astronomical Union (IAU) in 2006 due to its inability to clear its orbit of other debri.

Kuiper Belt

- The Kuiper Belt is a ring of icy rocks & dust bodies just outside of Neptune's orbit, known as Kuiper belt objects or trans-neptunians.
- Pluto is the largest known Kuiper Belt Object instead of the 9th planet of our Solar system. There are bits of rock and ice, comets, and dwarf planets.

Asteroid Belt

- Asteroids are remnants of planetary formation mainly composed of refractory rocky and metallic minerals and some ice, that circle the sun in a zone lying between Mars and Jupiter.
- The circular chain of asteroids is called the asteroid belt or main asteroid belt.

Ploonets

- A celestial object, which are orphaned moons that have escaped the bonds of their planetary parents.
- The researchers explain that the angular momentum between the planet and its moon results in the moon escaping the gravitational pull of its parent planet.

Goldilocks Zone

- The 'Goldilocks Zone,' or habitable zone – 'the region around the star where a planet could sustain liquid water on its surface'. **[UPSC 2014]**
- Our Earth is in the Sun's Goldilocks zone.

Astronomical Distance

- For measuring these extremely large distances, we use two astronomical units, the light year and the parsec.
- A light year is defined as the distance travelled by light in one year. Astronomical distances are measured in light-years because Speed of light is always the same. **[UPSC 2021]**

Asteroids

- Big chunks of rocks float through space and orbit the sun, mostly found in the main asteroid belt i.e., between Mars and Jupiter.
- The biggest one is Ceres (940 km wide), twice as big as the Grand Canyon. **[UPSC 2011]**

Meteoroid

- Smaller rock pieces that break off from an asteroid, float through interplanetary space.
- Can be as small as grain of sand or as large as a meter across.

Meteor

- When a meteoroid enters the earth's atmosphere, it begins to burn up and falls to the ground.
- This burning trail is known as meteor or falling stars/ shooting star.

Meteorite

- If a meteoroid rock doesn't completely burn up as it falls to Earth- the rock left behind is called a meteorite.

Comets

- Comets are frozen leftovers from the formation of the solar system composed of dust, rock and ices, ranging from few miles to tens of miles wide.
- Orbits closer to the sun, they heat up and spew gases and dust into a glowing head visible in the atmosphere.
- Comets have highly elliptical orbits, unlike planets which have near-circular orbits. **[UPSC 2011]**

Van Allen Radiation Belts

- It is a zone of energetic charged particles, most of which originate from the solar wind.
- The particles are captured by and held around a planet by that planet's magnetic field.
- These are intense over the Equator and are absent over the poles.
- One of the consequences of the belts is the aurora borealis and aurora australis.

Space Debris

Space junk, also known as space debris, refers to any man-made objects left in orbit around Earth.

- This includes large items like defunct satellites and smaller debris such as paint flecks or fragments from rocket launches.
- The majority of space junk is found in Low Earth Orbit (LEO), within 2,000 kilometers of the Earth's surface.
- **Kessler Syndrome:** The runaway effect of debris from one collision causing another, generating more debris and further collisions is called the Kessler Syndrome.

Space Debris Removal Initiatives

International Initiative	Indian Initiative
• Committee on Peaceful Uses of Outer Space (COPUOS) (1958)	• ISRO System for Safe & Sustainable Operations Management (IS4OM) (2022)
• Clean Space Initiative (ESA, 2012)	• Project Netra (Network for Space Object Tracking and Analysis)
• Liability Convention of 1972	• ISRO SSA (Space Situational Awareness) Control Centre (2020)
• Outer Space Treaty (1967)	

ORBITS

An orbit is the curved path that an object in space (such as a star, planet, moon, asteroid or spacecraft) takes around another object due to gravity.

Types of Orbit based on Altitude

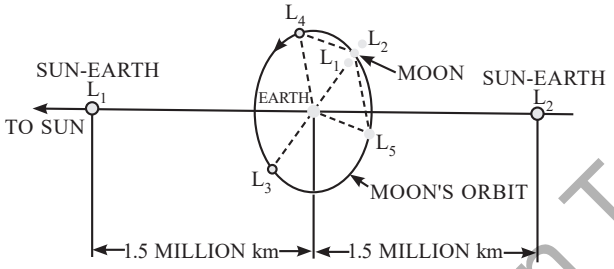
Orbit Name	Altitude (km)	Orbital Period	Applications
High Earth Orbit (HEO)	>35,786	24 hours (geosynchronous)	Communication satellites (GSAT series), weather monitoring
Medium Earth Orbit (MEO)	2,000 - 35,780	12 hours	Global Positioning Systems (GPS, GLONASS, Galileo)
Low Earth Orbit (LEO)	160 - 2,000	90 minutes	Satellite imaging, Earth observation, communication satellites (constellations), International Space Station (ISS)

Types of Orbit based on Functionality

Orbit Type	Description	Altitude (km)	Orbital Period	Applications
Geosynchronous Orbit (GEO)	A high Earth orbit where the satellite appears stationary above a fixed point on Earth.	35,786	24 hours	Weather monitoring, communication, navigation. e..g. INSAT and GSAT series
Polar Orbit	A low Earth orbit passing over Earth's poles.	200-1,000	15 - 16 orbits per day	Earth observation, remote sensing. e.g. Cartosat series of ISRO
Sun-Synchronous Orbit (SSO)	A polar orbit where the satellite passes over the same point on Earth at the same local time.	600-800	~14 orbits per day	Climate change studies, weather prediction, resource management
Transfer Orbits	Intermediate orbits used to move satellites between other orbits.	Varies		Used to transition between different orbits

Lagrange point

- A Lagrange point is a position in space where the gravitational forces of two large celestial bodies (such as the Earth and the Moon or the Earth and the Sun) and the centrifugal force of an object placed there balance each other, allowing the object to remain in a stable or semi-stable position relative to the two bodies.



  - These points, named after the mathematician Joseph-Louis Lagrange, offer stable positions for spacecraft to maintain their relative position to the Earth and Sun.

Lagrange Point	Location	Purpose
L1	Between Earth and Sun	Observing the Sun (e.g., Aditya-L1 mission)
L2	Behind Earth, opposite the Sun	Observing the larger universe (e.g., James Webb Space Telescope)
L3, L4, and L5	Equilateral triangles with Earth and Sun	Potential for future missions and observations

Halo Orbit: Halo orbits are three-dimensional, periodic orbits around Lagrange points in a two-body system like Earth-Sun or Earth-Moon.

- It is commonly linked with L1, L2, and L3 Lagrange points, where the gravitational forces of two large bodies and centrifugal force balance each other.

SATELLITE

Satellites are celestial bodies that orbit larger bodies, such as planets. They can be natural, like Earth's moon, or artificial, launched into space for specific purposes. Artificial satellites are placed in various orbits using rockets and equipped with instruments for a wide range of applications. An artificial satellite orbiting around the Earth does not fall down. This is so because the attraction of Earth Provides the necessary acceleration for its motion. **[UPSC 2011]**

- **Functions of Satellites:** Earth Observation, Communication, Navigation.
- **Application:** For the measurement/ estimation of Chlorophyll content in the vegetation of a specific location, Greenhouse gas emissions from rice paddies of a specific location and Land surface temperatures of a specific location, etc. **[UPSC 2019]**

Type of Satellite	Purpose	Examples
Earth Observation Satellites (EOS)	Long-term observation of Earth's atmosphere, biosphere, lithosphere, and oceans, Weather forecasting, climate monitoring, disaster warning	Cartosat, Oceansat, Resourcesat, EOS-04
Navigation Satellites	Geospatial services, navigation, and positioning	GPS, GLONASS, Galileo, BeiDou, NavIC
Communication Satellites	Telecommunication, broadcasting, internet services	INSAT, Starlink, OneWeb, GSAT31

IRNSS-NavIC **[UPSC 2018]**

- The Navigation with Indian Constellation (NavIC) satellite system is an autonomous regional navigation satellite system that provides location data in the Indian area and 1500 kilometers surrounding the Indian landmass.
- IRNSS would offer two types of services Standard Positioning Services, which would be available to all users, and Restricted Services, which would only be available to permitted users.
- There are seven satellites in all. **Three** will be geostationary above the Indian Ocean and **four** will be geosynchronous.

SPACE ORGANISATIONS IN INDIA

Organization	Description
Indian Space Research Organization (ISRO)	• Government of India's nodal agency for space research, under the Department of Space (DOS). • Founded in 1969, headquartered in Bengaluru, Karnataka. • Developed and launched India's own launch vehicles, PSLV and GSLV.
Indian National Space Promotion and Authorization Centre (IN-SPACe)	• Government body established in 2020 to promote private sector participation in space activities. • Facilitates partnerships between ISRO and private companies. • Regulates and encourages Indian industry and startups in satellite construction, rocket development, and commercial launch services.
New Space India Limited (NSIL)	• ISRO's commercial arm, wholly owned by the Government of India. • Collaborates with IN-SPACe to enable industry consortiums to undertake some of ISRO's responsibilities. • Provides commercial services such as satellite launch, ground station services, and data analysis.
Antrix Corporation	• ISRO's commercial arm, founded in 1992. • Promotes and commercializes space products, services, and technology transfer.

Space Startups in India

New Startup Name	Established	Focus
Dhruva Space Private Limited	2012	Satellite manufacturing and related services
Bellatrix Aerospace	2015	Satellite propulsion systems and technologies
Aadyah Aerospace	2016	Satellite design, manufacturing, launch vehicles, and propulsion
Agnikul Cosmos	2017	Developing a small satellite launch vehicle
Manastu Space	2017	Green technology for space, including alternative fuels, refueling stations, and deorbiting solutions
Skyroot Aerospace	2018	Developing satellite launch vehicles and associated technologies
Satellize	2018	Satellite communication and related services
Pixxel	2019	Building a constellation of Earth observation satellites

TYPES OF LAUNCH VEHICLES BY ISRO

A launch vehicle is a **rocket-powered vehicle** that transports a spacecraft **beyond the Earth's atmosphere**, either into orbit around the Earth or to another destination in outer space.

Launch Vehicles of India

Launch Vehicle	Stages	Payload Capacity	Orbits	Description
Small Satellite Launch Vehicle (SSLV)	3 (solid, solid, liquid)	10-500 kg	Low Earth Orbit (LEO)	India's smallest launch vehicle, designed for launching small satellites. Successfully launched its first mission in 2022.
Polar Satellite Launch Vehicle (PSLV)	4 (solid, liquid, liquid, solid)	1,750 kg (LEO), 1,425 kg (GTO)	Sun-Synchronous Polar Orbit, Geosynchronous/ Geostationary Orbit	India's workhorse launch vehicle, successfully launched numerous satellites including Chandrayaan-1 and several communication and remote sensing satellites.

Geosynchronous Satellite Launch Vehicle (GSLV) Mark II	3 (solid, liquid, cryogenic)	2,250 kg (GTO), 6 tonnes (LEO)	Geosynchronous Transfer Orbit, Low Earth Orbit	Capable of launching heavy satellites into geostationary orbit, using a cryogenic upper stage. Successfully launched communication satellites.
Geosynchronous Satellite Launch Vehicle Mk-III (LVM3)	3 (liquid, solid, cryogenic)	4 tonnes (GTO), 8 tonnes (LEO)	Geosynchronous Transfer Orbit, Low Earth Orbit	India's most powerful launch vehicle, capable of launching heavy satellites and supporting human spaceflight missions. Successfully Chandrayaan-2 Chandrayaan-3 and Gaganyaan.

ROCKET TECHNOLOGY

Sounding Rockets

Sounding rockets are single- or two-stage solid-propellant rockets designed to carry scientific instruments into the upper atmosphere for research purposes. They provide valuable data on atmospheric conditions, ionospheric studies, and other space-related phenomena.

Early Developments

- **M-100 (Russia) and Centaure (France):** The first sounding rockets were developed by Russia and France in the early 1960s.
- **ISRO's Beginnings:** India launched its first sounding rocket, the RH-500, in 1963 from Thumba, near Thiruvananthapuram, marking the beginning of its space program.

The Rohini Sounding Rocket (RSR) Program:

- **Consolidation:** Established in 1975, the RSR program consolidated all sounding rocket activities in India.
- **Payloads:** These rockets carried various payloads ranging from 8 to 100 kg, including instruments to study the atmosphere, ionosphere, and solar radiation.

Rocket Fuel

- The Indian Space Research Organisation (ISRO) is using the very poisonous and corrosive fuel UDMH (Unsymmetrical Di-Methyl Hydrazine), combined with the oxidiser nitrogen Tetroxide. This is referred to as a "dirty combo."
- Changing to liquid methane would need the usage of a cryogenic engine, as any gas must be stored at extremely low temperatures to remain liquefied.

Propellant Used in Rocket

- The propellant is a chemical mixture that comprises a fuel and an oxidizer that is burned to provide thrust in rockets.
- For propulsion, fuel is a substance that burns when mixed with an oxidizer.
    - The oxidizer is a substance that releases oxygen in order to be combined with a fuel. The mixture ratio is the proportion of oxidizer to fuel.
    - The condition of a propellant is classified as liquid, solid, or hybrid.
- **Liquid Propellant:** The fuel and oxidizer are stored separately in a liquid propellant rocket and delivered to a combustion chamber by a system of pipes, valves, and turbopumps, where they are mixed and burned to produce thrust.
- Cryogenic propellants are liquefied gases kept at extremely low temperatures, with the most common fuel being liquid hydrogen (LH_2) and the oxidizer being liquid oxygen (LO_2 or LOX).

Cryogenic Engine

- A cryogenic rocket engine uses a cryogenic fuel or oxidizer, which means the fuel or oxidizer (or both) are gases that have been liquefied and kept at extremely low temperatures.
- In comparison to solid and earth-storable liquid propellant rocket stages, cryogenic rocket stages are more efficient and produce greater thrust per kilogram of propellant burned.

Air Breathing Engines

- In the burning of fuel, air-breathing engines utilize oxygen from the environment. The turbojet, turboprop, ramjet, and pulse-jet are among them.

Speed Range	Mach Number
Subsonic	< 0.8
Transonic	0.8 - 1.2
Supersonic	1.2 - 5
Hypersonic	5 - 10
High-hypersonic	10 - 25

- **Types of Air Breathing Engines:**
  - **Ramjet:** A ramjet is a type of air-breathing jet engine that compresses incoming air for combustion without the use of a revolving compressor.
  - **Scramjet:** A scramjet engine is superior to a ramjet engine because it can run at hypersonic speeds while still allowing supersonic combustion. e.g. Scramjet Engine Technology Demonstrator (Scramjet-TD), Hypersonic Technology Demonstrator Vehicle (HSTDV) etc.
  - **Dual Mode Ramjet** (DMRJ) is a kind of jet engine that converts from a ramjet to a scramjet over the Mach 4-8 range, allowing it to function efficiently in both subsonic and supersonic combustion modes. e.g. Air Breathing Propulsion System (ABPS)

ISRO SATELITES

Type	Satellite Name	Purpose
Communication	CMS-01	Launched in 2017 for various communication services, including broadband connectivity and satellite newsgathering.
	GSAT 7A (Angry Bird)	Launched in 2018, provides broadband connectivity to remote areas of India.
	GSAT-11	Launched in 2018, offers high-throughput broadband services for various applications.
Earth Observation	OCEANSAT-3	Launched in 2022, studies oceans and atmosphere, providing data for weather forecasting, climate monitoring, and natural resource management.
	RISAT-2	Radar imaging satellite launched in 2019, used for Earth observation, disaster management, and agricultural applications.
Satellite Navigation	NAVIC (Navigation using Indian Constellation)	India's regional navigation satellite system, providing accurate positioning, navigation, and timing services to users in India and the surrounding region.
Sun Studies	ADITYA L1	Solar mission launched in 2023 to study the Sun's outer atmosphere and solar wind. Solar mission placed at the L1 Lagrange point to observe the Sun's corona and other aspects of solar activity.

ISRO'S INTERPLANETARY MISSION

Mars Orbiter Mission (MOM) [UPSC 2016]

- **Mission:** India's first interplanetary space mission.
- **Launch:** November 5, 2013, aboard PSLV-C25.
- **Significance:** Made India the first Asian country and the fourth in the world to reach Mars in 2014.
- **Objectives:** Study the Martian atmosphere, surface features, mineralogy, and morphology. Develop technologies for interplanetary missions.

Venus: Shukrayaan-1

- **Mission:** India's first planned mission to Venus, designed to study the planet's surface, atmosphere, and geological features.
- **Launch Vehicle:** GSLV Mk II rocket.
- **Orbiter:** A spacecraft of approximately 2500 kg will orbit Venus to gather data.
- **Objectives:** Understand Venus's climate and its evolution, Explore signs of active volcanoes and seismic activity.

India's Missions to Moon

- **Chandrayaan-1**
  - India's first mission to the Moon, was launched in 2008.
  - Chandrayaan-1 reached the lunar orbit 21 days after its launch and after making 3400 orbits around the Moon and transmitting data.
  - In late November 2008, Chandrayaan-1 began experiencing abnormally high temperatures.
  - The last contact with Chandrayaan-1 was on August 28, 2009. It still circles around the Moon.
- **Chandrayaan-2**
  - The failure of Chandrayaan-2, India's second mission to the Moon, to make a soft-landing on the lunar surface had led to much disappointment.
  - The lander and rover malfunctioned in the final moments and crash-landed, getting destroyed in the process
  - But that did not mean the entire mission had been wasted. The Orbiter part of the mission has been functioning normally.

- **Chandrayaan-3**
  - The Chandrayaan-3 mission consists of a lander module, a propulsion module, and a rover.
  - The Chandrayaan-3 Lander has solar panels on four sides, instead of only two in Chandrayaan-2.
  - Chandrayaan-3 is a follow-on mission to Chandrayaan-2 to demonstrate end-to-end capability in safe landing and roving on the lunar surface.
  - The spacecraft departed from the Satish Dhawan Space Centre in Sriharikota on July 14, 2023, and smoothly entered lunar orbit by August 5, 2023.
  - The lander achieved a flawless touchdown near the lunar south pole on August 23, 2023.
  - The total weight of Chandrayaan-3 is 3,900 kg, with the propulsion module weighing 2,148 kg and the lander and the rover both weighing 1,752 kg.

Lunar Probe Exploration Mission (LUPEX)

- **Joint Mission:** A collaborative venture between the Indian Space Research Organization (ISRO) and the Japan Aerospace Exploration Agency (JAXA).
- **Objective:** To explore the Moon's south polar region, focusing on the presence of water and other resources.
- **Launch Vehicle:** Japan's H3 rocket is scheduled to launch the mission.
- **Timeline:** Targeted for launch in 2025.

Key Features:

- **Lander and Rover:** LUPEX will consist of a lander and a rover, developed by ISRO and JAXA respectively.
- **Scientific Instruments:** The rover will carry instruments to measure the water content of lunar regolith, drill and sample lunar materials, and conduct other scientific experiments.
- **International Collaboration:** The mission will also include instruments from NASA and the European Space Agency (ESA).
- **Significance:** Water on the Moon, Future Exploration, Technological Advancement.

OTHER IMPORTANT PROJECTS OF ISRO

Gaganyaan Mission

Gaganyaan is an ambitious Indian space mission aimed at sending humans into orbit. It consists of three planned flights: two unmanned missions and one crewed mission.

Objectives: Gaganyaan aims to demonstrate India's capability in human spaceflight and conduct scientific experiments in microgravity.

- It will also contribute to enhancing India's prestige in the global space arena.

Key Details:

- **Launch Vehicle:** The GSLV Mk III (Launch Vehicle Mark-3) is the powerful rocket chosen to launch Gaganyaan.
- **Orbital Module:** The spacecraft carrying the astronauts will be the Orbital Module.
- **Mission Duration:** The crewed mission will orbit Earth at a low-earth-orbit altitude of 300-400 kilometers for 5-7 days.
- **Astronauts:** Three Indian astronauts, including a woman, will participate in the crewed mission.

Mission Timeline

- **Uncrewed Missions:**
  - The first uncrewed mission is targeted by the end of 2024.
  - Further uncrewed missions are targeted for 2025 and early 2026
- **Crewed Mission:** The final mission will carry three Indian astronauts into space.

GEMINI: Gagan Enabled Mariner's Instrument for Navigation and Information

The GEMINI device, developed by ISRO, is a portable satellite receiver that can be used for communication in areas beyond the reach of traditional cellular networks. It offers a valuable tool for disaster management, especially in remote regions or during emergencies.

Key Features:

- **Satellite Connectivity:** GEMINI connects to ISRO's satellites, enabling communication over long distances.
- **Wide Coverage:** The device can transmit signals up to 300 nautical miles, extending communication reach beyond the limitations of cellular networks.
- **Disaster Management:** GEMINI is particularly useful during storms, strong seas, or tsunamis, providing a reliable communication channel in emergency situations.

GAGAN: India's Global Navigation System

- **Collaboration:** Developed by ISRO and the Airports Authority of India, GAGAN is India's first satellite-based global positioning system.
- **Satellite Network:** GAGAN relies on ISRO's GSAT satellites for precise positioning and navigation services.

Limitation: While GAGAN offers accurate positioning, it currently only supports one-way communication. This means that users cannot make calls using GAGAN.

Mission Shakti

On March 27, 2019, India successfully conducted its first Anti-Satellite (ASAT) missile test, named **Mission Shakti**.

- This mission, carried out by the Defence Research and Development Organisation (DRDO) from Dr. APJ Abdul Kalam Island in Odisha, demonstrated India's capability to develop and deploy a complex missile system with potential applications in space warfare.

Test Objective

- **Mission Shakti aimed to showcase India's ASAT capabilities:** The objective was to destroy a defunct Indian satellite in Low Earth Orbit (LEO) at an altitude of approximately 283 kilometers.
- **Focus on Indigenous Development:** The successful launch emphasized India's ability to develop and execute such intricate missions with entirely indigenous technology.

Missile Used: The mission employed the **Prithvi Delivery Vehicle Mark-II (PDV MK-II)**, developed by DRDO. This missile successfully intercepted and destroyed the targeted Indian Microsat-R satellite.

XPoSat

- **Purpose:** To study the polarization of X-ray emission from celestial sources, providing insights into their radiation mechanisms and geometry.
- **Launch:** Successfully launched on January 1, 2024, aboard the PSLV-C58 rocket.
- **Orbit:** Low Earth orbit at an altitude of approximately 650 km.
- **Mission Duration:** Expected to operate for at least five years.

Scientific Payloads

1. **POLIX (Polarimeter Instrument in X-rays):**
   - Designed to measure the polarization of X-rays in the medium energy range (8-30 keV).
   - Utilizes a collimator and scatterer to filter and analyze X-ray photons.
   - Will observe a few tens of astronomical sources.
2. **XSPECT (X-ray Spectroscopy and Timing):**
   - Provides high-resolution spectroscopy and fast timing capabilities in the soft X-ray energy band (0.8-15 keV).
   - Will study a variety of sources, including X-ray pulsars, black hole binaries, neutron stars, and active galactic nuclei (AGNs).

IceCube **[UPSC 2015]**

The IceCube Neutrino Observatory is the first detector of this type, designed for observing the cosmos from deep within the South Pole ice. An international group of scientists responsible for the scientific research makes up the IceCube Collaboration

Optical illusions **[UPSC 2013]**

Size of the sun at dusk , Colour of the sun at dawn and Twinkle of stars in the sky are examples of optical illusions

NISAR Mission (NASA-ISRO Synthetic Aperture Radar)

- **Purpose:** To study Earth's surface changes, monitor natural hazards, analyze climate patterns, and understand dynamic ecosystems.
- **Collaboration:** A joint mission between NASA and ISRO (Indian Space Research Organization).
- **Launch:** Scheduled for 2025.
- **Category:** Earth observation satellite
- **Launch Vehicle:** GSLV Mk II
- **Launch Site:** Satish Dhawan Space Center, ISRO
- **Orbit:** Sun-synchronous orbit (LEO) at an altitude of 747 km
- **Radar Instruments:**
  - L-band Synthetic Aperture Radar (L-SAR) provided by NASA
  - S-band Synthetic Aperture Radar (S-SAR) provided by ISRO

Significance: Comprehensive Earth Observation, Disaster Monitoring, Climate Change Research, Resource Management

IMPORTANT PERSONALITIES

Vikram Sarabhai

Dr. Vikram Sarabhai was a renowned Indian physicist and astronomer who played a pivotal role in the development of India's space program. Vikram Sarabhai is considered the **Father of the Indian Space Program.**

- **Early Life and Education:**
  - Born on August 12, 1919, in Ahmedabad, India.
  - Received his early education in India and later studied at Cambridge University in England.
- **Founding of the Physical Research Laboratory (PRL):**
  - Established PRL in Ahmedabad in 1947.
  - Focused on research in cosmic rays, astrophysics, and other related fields.

- **Indian National Committee for Space Research (INCOSPAR):**
  - Convinced the Indian government to establish INCOSPAR in 1962.
  - Served as its first chairman.
- **Indian Space Research Organisation (ISRO):**
  - Restructured INCOSPAR into ISRO in 1969.
  - Led ISRO's early development and oversaw its significant achievements.
- **Key Contributions to Indian Space Program:**
  - Launched India's first satellite, Aryabhata, in 1975.
  - Successfully conducted India's first nuclear test in 1974.
  - Played a crucial role in developing India's satellite communication and remote sensing capabilities.
- **Other Achievements:**
  - Established the Indian Institute of Management, Ahmedabad (IIMA).
  - Served as the chairman of the Atomic Energy Commission of India.
  - Received numerous awards and honors, including the Padma Bhushan and Padma Vibhushan.
- **Legacy:**
  - His vision and leadership have had a profound impact on India's scientific and technological development.

S. Somanath

S. Somanath, an eminent rocket scientist has been appointed as the **Chairman of the Indian Space Research Organisation (ISRO)** and the Space Secretary.

Contributions

- He has played a major role in the development of the **Polar Satellite Launch Vehicle (PSLV)** and the **Geosynchronous Satellite Launch Vehicle Mk-III (GSLV Mk-III).**
- He joined the **GSLV Mk-III** project in 2003, and served as Project Director from 2010 to 2014.
  - He is an expert in the area of system engineering of launch vehicles.
- Later on, he contributed to the development of the indigenous **cryogenic stages for the GSLV.**

NASA INITIATIVES

Great Observatory Programme

The Great Observatories Program was a series of four major space-based telescopes launched by NASA between 1990 and 2003. Each telescope was designed to observe a specific range of the electromagnetic spectrum, providing a comprehensive view of the universe.

Telescope Name	Wavelength Range	Purpose	Key Discoveries
Hubble Space Telescope (HST)	Visible and ultraviolet light	Imaging distant galaxies, stars, and nebulae	Age of the universe, evidence for dark energy, formation of stars and galaxies
Compton Gamma Ray Observatory (CGRO)	Gamma rays	Studying high-energy astronomical phenomena	New types of gamma-ray sources (gamma-ray bursts, active galactic nuclei)
Chandra X-ray Observatory (CXO)	X-rays	Observing hot, high-energy objects	Detailed images of hot gas surrounding galaxies and clusters
Spitzer Space Telescope (SST)	Infrared	Observing cool, dusty objects	Exoplanets, galaxy formation, star-forming regions

Perseverance Rover Mission on Mars

NASA's Perseverance rover, part of the Mars 2020 mission, landed at Jezero Crater on Mars in February 2021. Its primary objectives include:

- **Astrobiology:** Searching for signs of ancient microbial life.
- **Sample Collection:** Gathering rock and regolith samples for potential return to Earth.

  The rover is also accompanied by the Ingenuity helicopter, which successfully completed the first powered, controlled flight on another planet.

Parker Solar Probe

- **Mission:** NASA's Parker Solar Probe is a groundbreaking mission designed to study the Sun's outer atmosphere, the corona.
- **Launch:** Launched in 2018, it's the first spacecraft to directly sample particles and magnetic fields from the corona.
- **Objective:** To understand the mechanisms that heat the corona and accelerate the solar wind.

Key Features

- **Heat Shield:** Protected by a 4.5-inch-thick carbon composite shield, the probe can withstand temperatures of nearly 2,500 degrees Fahrenheit.
- **Instruments:** Equipped with a suite of instruments to measure the solar wind, magnetic fields, and other properties of the Sun's environment.
- **Record-Breaking Speed:** traveling at over 430,000 miles per hour.

Significance: Observations into the Sun's behavior and its influence on the solar system, understanding of solar physics, astrophysics, and space weather.

Lucy Mission

- **Objective:** To study Jupiter's Trojan asteroids, remnants of our solar system's formation.
- **Launch:** Launched in 2021 on a United Launch Alliance Atlas V rocket.
- **Trajectory:** Will utilize Earth's gravity for a slingshot effect, allowing it to reach the Trojan asteroids.

Double Asteroid Redirection Test (DART) Mission

- **Purpose:** To test a spacecraft's ability to intentionally collide with an asteroid and alter its trajectory, demonstrating a potential method for planetary defense against potential asteroid threats.
- **Target:** The Didymos binary asteroid system, consisting of a larger asteroid (Didymos) and a smaller moonlet (Dimorphos).
- **Launch:** Launched in November 2021.
- **Impact:** Successfully collided with Dimorphos in September 2022, altering its orbit.

INTERNATIONAL EFFORTS

Missions to Moon

Early Robotic Missions:

- **Luna 2 (Soviet Union):** The first spacecraft to reach the Moon's surface in 1959.
- **Luna 9 (Soviet Union):** The first spacecraft to achieve a controlled soft landing on the Moon in 1966.
- **Luna 10 (Soviet Union):** The first spacecraft to enter lunar orbit in 1966.

Crewed Missions: Apollo Program (United States)

- **Apollo 8:** The first crewed mission to orbit the Moon in 1968.
- **Apollo 11:** The historic mission that saw Neil Armstrong and Buzz Aldrin become the first humans to walk on the Moon in July 1969.
- **Total Crewed Missions:** A total of twelve astronauts have walked on the Moon, with the last mission being Apollo 17 in 1972.

Recent Developments: Artemis Program

- **NASA's Artemis Program:** Aims to land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface.
- **Future Missions:** The Artemis program will establish a sustainable lunar presence, paving the way for future exploration of Mars and beyond.

Missions to Mars

- **Soviet Probes:** The Soviet Union initiated Mars exploration efforts in the 1960s with a series of probes.
- **Mariner 9 (NASA):** In 1971, Mariner 9 became the first spacecraft to successfully orbit Mars, providing detailed images of the planet's surface.
- **Mars Global Surveyor (NASA):** Launched in 1997, this orbiter conducted a comprehensive mapping mission of Mars, completing its primary objectives in early 2001.
- **Mars Pathfinder (NASA):** Also launched in 1997, this lander carried the Sojourner rover, which explored the Martian surface and collected data.
- **Mars Odyssey (NASA):** Entered Mars orbit in 2001, focusing on studying the planet's mineral composition and searching for water ice.

Voyager Mission

The Voyager missions, launched by NASA in 1977, hold a significant place in space exploration history.

- These twin spacecraft, Voyager 1 and Voyager 2, embarked on a journey to explore the outer reaches of our solar system.

Initial Mission Objectives: Designed for close-up studies of Jupiter and Saturn, focusing on their atmospheres, rings, and larger moons.

Voyager 2's Achievements

- During flybys, Voyager 2 became the first and only probe to:
  - Study Neptune and Uranus, providing crucial data about these gas giants.
- Voyager 2 also holds the distinction of being:
  - The world's second man-made object to orbit the Sun (after Pioneer 10).
  - The only spacecraft to have visited all four gas giants (Jupiter, Saturn, Uranus, and Neptune)

Outer Space Governance

Artemis Accords

- **Established:** In 2020 by NASA and seven founding members (Australia, Canada, Italy, Japan, Luxembourg, UAE, UK)
- **Purpose:** Sets common principles for peaceful exploration and use of outer space, Moon, Mars, comets, and asteroids.

- **Foundation:** Based on the Outer Space Treaty of 1967.
- **Signatories:** India is the 27th signatory, joining other nations committed to these principles.

Existing Outer Space Governance Framework

- **UN COPUOS:** Established in 1958 by the UN General Assembly to oversee space exploration and use.
- **UNOOSA:** Supports UN COPUOS in its work.
- **Key Treaties:**
  - **Outer Space Treaty (1967):** Establishes principles for space exploration and use.
  - **Rescue Agreement (1968):** Addresses rescue and return of astronauts and space objects.
  - **Liability Convention (1972):** Establishes liability for damage caused by space objects.
  - **Registration Convention (1976):** Requires registration of space objects.
  - **Moon Agreement (1979):** Governs activities on the Moon and other celestial bodies (India has not ratified).

India is a signatory to all five of these treaties but has not ratified the Moon Agreement.

International Space Station

The International Space Station (ISS) is a large, habitable spacecraft orbiting Earth at an altitude of approximately 400 kilometers.

- **Countries:** NASA (United States), Roscosmos (Russia), ESA (Europe), JAXA (Japan), and CSA (Canada).
- **Orbit:** Circles Earth every 90 minutes at a speed of about 28,000 kilometers per hour.
- **Inhabitation:** Continuously inhabited since 2011, serving as a home for astronauts from participating countries.

Significance

- **International Collaboration:** The ISS exemplifies successful international cooperation in space exploration.
- **Space Medicine Research:** Provides insights into the effects of long-duration spaceflight on the human body, aiding in the development of countermeasures for future missions to Mars and the Moon.
- **Scientific Research:** Serves as a platform for conducting various scientific experiments in microgravity, expanding our knowledge of space and its implications for Earth.

Recent Developments

- India is seeking to launch its own space station by 2030, joining the league of US, Russia, and China to an elite space club.
- China has been operating its completed Tiangong Space Station for almost two years now and is looking to expand its capabilities with new modules and spacecraft. The three-module, T-shaped Tiangong space station was fully assembled in November 2022, with the arrival of the Mengtian science module.

Space-Based Internet

Space-based internet, also known as satellite internet, is a type of internet connectivity that utilizes satellites orbiting the Earth to provide broadband services.

- This technology offers a potential solution for areas with limited or no access to traditional internet infrastructure, such as rural regions, remote locations, and developing countries.

Key Technologies:

- **Satellite Constellations:** Large networks of satellites are deployed in low Earth orbit (LEO) or geostationary orbit (GEO) to provide global coverage.
- **Ground Stations:** These stations receive signals from the satellites and transmit them to internet service providers.
- **User Terminals:** Customers require specialized antennas and modems to connect to the satellite network.

Benefits of Space-Based Internet: Global Coverage, High Speed, Low Latency, Disaster Recovery.

Challenges and Considerations: High cost, Weather Interference, Regulatory Challenges.

Prominent Space-Based Internet Projects: Starlink (SpaceX), OneWeb, Amazon Kuiper, JioSpace Fiber (Reliance Jio)

7 Defence Technology

INDIAN DEFENCE

Defence is protecting the integrity, sovereignty, international borders and geo-economic interests of a nation. The Indian Defence system has been organised with the **President as the supreme commander** at the helm and the **Ministry of Defence**, which exercises **administrative control over the armed forces**. Indian Defence has been divided into three services:

- **Indian Army:** 1.3 million active personnel organised under six operational and one training command.
- **Indian Air Force:** over 127000 active personnel organised under five operational, one training and one maintenance command.
- **Indian Navy:** Blue water Navy with strength of 58000 plus active personnel.

Blue Water Navy: Navy who has the capacity to project itself over a much bigger maritime area than its maritime borders.

Brown Water Force: Navy whose operations are restricted close to the shore

Green Water Force: Navy who can project themselves into the littoral waters.

Ministry of Defence

The Ministry of Defence comprises five Departments, viz. **Department of Defence** (DOD), **Department of Defence Production** (DDP), **Department of Defence Research & Development** (DDR&D), **Department of Ex-Servicemen Welfare** and also **Department of Military Affairs**.

Defence Acquisition Council

The Defence Acquisition Council (DAC) is the highest decision-making body within the Indian **Ministry of Defence** for procurement matters. Its primary objective is to ensure timely and efficient acquisition of defense equipment and services to meet the needs of the armed forces.

Key Functions

- **Long-Term Planning:** Approves a 15-year Long Term Integrated Perspective Plan (LTIPP) for defence procurement.
- **Acquisition Proposals:** Assesses and categorises acquisition proposals into 'Buy,' 'Buy & Make,' and 'Make' categories.
- **Single Vendor Clearance:** Addresses issues related to single-vendor procurement.
- **Offset Provisions:** Takes decisions on offset requirements for acquisitions exceeding Rs 2000 crore.
- **Technology Transfer:** Oversees technology transfer in 'Buy & Make' category proposals.
- **Field Trial Evaluation:** Evaluates the performance of defence equipment in field trials.

Composition

- **Chairman:** Defense Minister
- **Members:** Chief of Defense Staff (CDS), Chiefs of Army, Navy, and Air Force

The DAC was formed in 2001, following the Group of Ministers' recommendations on reforming the national security system, in response to the Kargil War.

Defence Research and Development Organisation (DRDO)

Established in **1958** with the objective of **Military research**, achieving **self-reliance** in defence technology and development of **advanced technologies** in diverse areas, including missile systems, aeronautics, electronics etc. The **Scientific Advisor** of the **Defence Ministry** is the **secretary of DDRD (Department of Defence)** and **the chairman of DRDO**.

- **Important Contributions of DRDO**
  - **Missile Systems:** Agni series for deterrence, Prithvi, Akash, Nag for various applications.
  - **Aerospace Technologies:** LCA Tejas, PSLV, GSLV for satellite launches.
  - **Radar and EW Systems:** Arudhra, Rohini radars, electronic warfare advancements.
  - **Naval Systems:** Sonar systems, BrahMos supersonic cruise missile.
  - **Armoured Vehicles:** Arjun tank.
  - **UAVs and Drones:** Surveillance, combat UAVs, advancements in drone tech.

Besides the above, DRDO has also played an important role in the development of Nuclear Capabilities, Cyber Security, Biomedical Technologies, Strategic Technologies (AI, Quantum Tech) etc.

Application of Drones **[UPSC 2020]**

1. Spraying pesticides on a crop field
2. Inspecting the craters of active volcanoes
3. Collecting breath samples from spouting whales for DNA analysis.

NTRO (National Technical Research Organisation)

- Technical Intelligence Agency under the National Security Advisor in the Prime Minister's Office, which operates as an autonomous organisation
- Primary objective is the acquisition of technical intelligence involving the interception and analysis of communication signals, imagery intelligence, and cyber intelligence.
- **National Institute of Cryptology Research and Development** functions under it.

Chief of Defence Staff [UPSC 2024]

Background and Establishment

- **Recommendations:** The establishment of the CDS was recommended by the Group of Ministers (GoM) in 2001 and further supported by the **Naresh Chandra Committee in 2012.**
- **Creation:** Created in 2019, with General Bipin Rawat serving as the first incumbent.

Roles and Responsibilities

- **Inter-Service Coordination:** Fosters synergy among the Army, Navy, and Air Force.
- **Military Advisor:** Serves as the single-point military advisor to the Defence Minister.
- **DMA Head:** Heads the Department of Military Affairs, overseeing inter-service procurement and decision-making.
- **Directives:** Provides directives to the service chiefs, though without direct command authority.
- **Rank and Authority:** CDS is a four-star General and heads the Department of Military Affairs.
- **Nuclear Command Authority:** Serves as an advisor to the NCA.

MISSILE SYSTEMS

Considering the importance of guided missile weapon systems in modern warfare, a Special Weapon Development Team (SWDT) was formed in 1958, which was expanded into the **Defence Research & Development Laboratory**(DRDL) in June 1961. Projects under the DRDL include:

- Development of an anti-tank missile system and indigenous rockets initially.
- **Project Devil** (initiated: 1972) for the development of a **medium-range Surface-to-Surface Missile**.
- DRDL (1982 onwards) has undertaken the design and development of various types of missile systems under **the Integrated Guided Missiles Development Programme (IGMDP)**.

Integrated Guided Missiles Development Programme (IGMDP)

IGMDP (**conceived by Dr. A.P.J. Abdul Kalam**) was started in 1983 to develop **Prithvi**, **Trishul**, **Akash**, **Nag** and **a Technology Demonstrator Agni Missile**.

The technology demonstrator missile of the Agni series (**tested in 1989**) was developed under the IGMDP. Afterwards, the **Agni missile program was detached from the IGMDP**.

Surface-to-Surface Ballistic Missiles

- **Prithvi:** A family of short-range ballistic missiles with variants Prithvi I, II, and III.
- **Dhanush:** A naval variant of Prithvi with a range of 350 km.
- **Agni:** A series of medium and long-range ballistic missiles, including Agni-I, II, III, IV, V, and VI.

Surface-to-Air Missiles

- **Trishul:** A quick-reaction, short-range missile with electronic countermeasures.
- **Akash:** A short-range missile system with built-in ECCM (**Electronic Counter-Counter Measures)** capabilities.
  - **ECCM:** Electronic counter-countermeasures is a part of electronic warfare which includes a variety of practices which attempt to reduce or eliminate the effect of electronic countermeasures on electronic sensors aboard vehicles, ships and aircraft and weapons such as missiles.
- **NAG:** An anti-tank guided missile with fire-and-forget capabilities.
  - **NAG missile carrier (NAMICA)**, a BMP II based system with amphibious capability, has been developed.
  - **HELINA (DHRUVASTRA), an abbreviation for Helicopter Launched NAG, is an air-to-surface missile system** mounted on the **Advanced Light Helicopter** (ALH) with an operational range of 0.5-7 km.

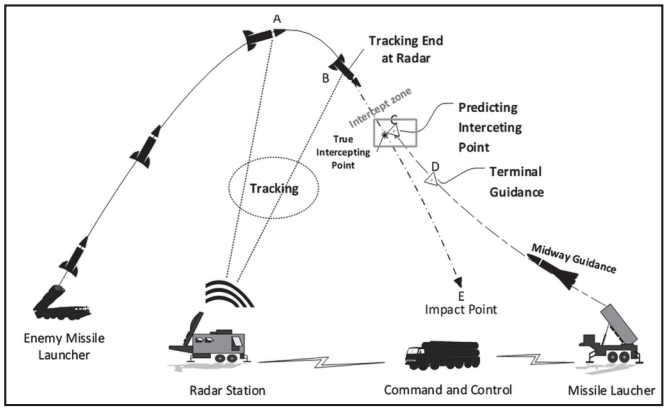
Missile	Range (km)	Payload (kg)	Type
Prithvi I	150	1000	Short-range
Prithvi II	350	500-1000	Medium-range
Prithvi III	350	1000	Medium-range
Dhanush	350	500	Medium-range (naval)
Trishul	9-12	N/A	Surface-to-air

Missile	Range (km)	Payload (kg)	Type
Akash	4.5-25	710	Surface-to-air
NAG	0.5-4	N/A	Anti-tank guided
Agni-I	700-1200	1000	Short-medium range
Agni-II	2000+	1000	Medium-range
Agni-III	3000+	1500	Intermediate-range
Agni-IV	4000	1000	Intermediate-range
Agni-V	5000+	1500	Intercontinental-range
Agni-VI (under development)	9000-12000	3000	Intercontinental-range (MIRV capable)
Agni-P	1000-2000	1000	Medium-range

Ballistic Missile

A ballistic missile follows an arcing trajectory, guided only during specific stages of flight. It uses stored energy to propel itself to a predetermined target, where it delivers one or more warheads. Factors such as gravity, air resistance, and the Earth's rotation influence the missile's path, which is determined by its initial velocity and trajectory.

- **Prahar:** Short-range (150 km), single-stage solid-fuel missile for rapid strikes.
- **Shaurya:** Nuclear-capable, short-range hypersonic ballistic missile (7.5 Mach) with a range of 1,000 km.
- **K Family:** Submarine-Launched Ballistic Missiles (SLBMs) developed by DRDO.
  - **K-4:** Intermediate-range (3500 km) SLBM with a 2.2-ton payload.
  - **K-15 Sagarika:** Short-range (750 km) SLBM with a 1000 kg payload



Ballistic Missile Defense System

Surface-to-Air Missiles:

- **Quick Reaction Surface-to-Air Missile (QRSAM):** Medium-range (5-30 km), single-stage solid-fuel missile for air defense.
- **Medium-Range Surface-to-Air Missile (MRSAM):** Long-range (70 km), high-response missile for neutralising aerial threats.

Long-Range Surface-to-Air Missile (LRSAM):

- **Project Kusha:** India's indigenous long-range air defence system with a range of up to 350 km. (expected to deploy in 2028-29)
- **Capabilities:** Detects and destroys stealth fighters, aircraft, drones, cruise missiles, and precision-guided munitions.
- **High Kill Probability:** Offers a single-shot kill probability of at least 80% and 90% for salvo launches.
- **Salvo:** a simultaneous discharge of two or more guns in military action or the release all at one time of a rack of bombs or rockets.

Cruise Missiles

A cruise missile is a guided missile designed to strike terrestrial targets. Unlike ballistic missiles, which follow an arcing trajectory, cruise missiles fly low and slow, hugging the terrain to avoid detection. This allows them to deliver large warheads over long distances with precision.

Mach: Mach is used as a unit of measurement in stating the speed of a moving object in relation to the speed of sound.

Missile	Type	Range (km)	Payload (kg)	Speed	Characteristics
Nirbhay	Subsonic Cruise Missile	750-1000	500	0.7 Mach	Indigenous, low-altitude flight, nuclear capable
Brahmos	Supersonic Cruise Missile	290 (extends upto 400-500 Km)	300	2.8 Mach	India-Russia joint venture, land/sea/air launch, fire-and-forget
Brahmos NG	Supersonic Cruise Missile	290	300	3.5 Mach	Lightweight air-launched version for LCA Tejas

Brahmos II	Hypersonic Cruise Missile	about 1000 km	300	6 Mach	Hypersonic speed, under development
Moskit	Supersonic Anti-Ship Cruise Missile	120	Conventional/ Nuclear	Mach 3 (high altitude), Mach 2.2 (low altitude)	Fastest flying anti-ship missile

Cruise Missile Propulsion

Engine Type	Propulsion Method	Operating Speed	Advantages	Disadvantages
Ramjet	Air-breathing, subsonic combustion	Mach 2+	Simple design, no moving parts	Inefficient at high speeds, launch requirements
Scramjet	Air-breathing, supersonic combustion	Mach 5+	Efficient at high speeds	Complex design, high temperatures
Dual-Mode Ramjet (DMRJ)	Air-breathing, subsonic/ supersonic combustion	Mach 4-8	Efficient across a wide speed range	Complex design
Solid Fuel Ducted Ramjet (SFDR)	Solid fuel, air-breathing	Mach 3-5	Long-range interception, high speed	Solid fuel limitations

Turbojet: The turbojet is an airbreathing jet engine which is typically used in aircraft. It consists of a gas turbine with a propelling nozzle.

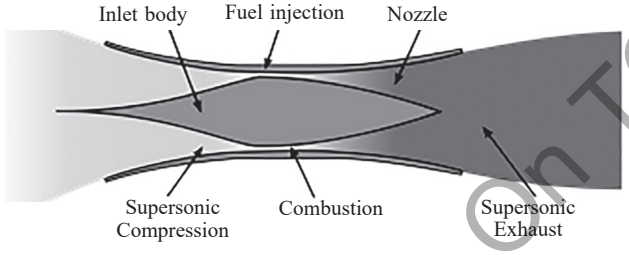


Figure: Scramjet

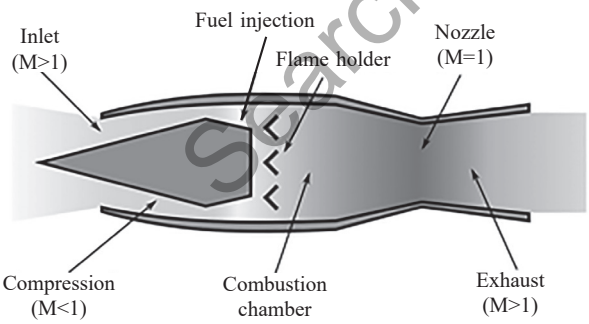


Figure: Ramjet

Comparison of Ballistic and Cruise Missiles

Feature	Ballistic Missile	Cruise Missile
Trajectory	Ballistic	Atmospheric, guided
Target Selection	Predetermined	Can be mobile
Target Size	Suitable for large targets	More suitable for small, mobile targets
Guidance	Brief guided flight, mostly gravity-driven	Self-navigating
Altitude	High elevation	Can fly at very low altitudes
Tracking	Simple to follow	Difficult to track due to low altitude

Anti Ballistic Missile System

India's Ballistic Missile Defense (BMD) Program is a multi-layered initiative to protect the nation from ballistic missile threats. The system is designed to intercept missiles in two phases:

Phase 1 focuses on intercepting missiles with a range of up to 2000 km. Key components include:

- **Prithvi Air Defense (PAD)/Pradyumna:** An exoatmospheric interceptor with a range of 300-2000 km and a maximum altitude of 80 km.
- **Advanced Air Defense (AAD)/ Ashwin:** An endo atmospheric interceptor designed to destroy targets in the lower atmosphere.
- **Prithvi Defense Vehicle:** Similar to PAD but with an enhanced flight altitude of 150 km.
- **Prithvi Defense Vehicle Mk-2 /ASAT:** An exoatmospheric interceptor capable of intercepting missiles or satellites in orbit.

- **Swordfish RADAR:** A long-range tracking radar for detecting and tracking ballistic missiles.

Phase 2 is under development and will be capable of intercepting missiles up to 5000 km. Key components include:

- **Air Defense 1 (AD-1):** A long-range interceptor missile designed for both low exoatmospheric and endoatmospheric interception.
- **Air Defense 2 (AD-2):** A future interceptor capable of neutralizing missiles with even higher ranges.

Other Defence System

Foreign Systems

- **NASAMS-II:** A U.S.-developed system designed to counter threats like cruise missiles, aircraft, and drones. It will complement existing Russian (Pechora) and Israeli (Spyder) defence systems.
- **S-400 Triumf:** A Russian long-range system capable of intercepting aircraft, UAVs, cruise missiles, and ballistic missiles. It offers advanced tracking and targeting capabilities.
- **Iron Dome:** An Israeli system designed for short-range missile defence, known for its high interception rate and ability to discriminate between threats.

Indigenous Systems

- **RUDRAM Anti-Radiation Missile:** Developed by DRDO, RUDRAM is an indigenous missile designed to target enemy radars and air defences.
- **Sudarshan Bomb:** A laser-guided bomb developed by DRDO with a range of up to 50 km.
- **RaIDer-X:** An explosive detection device developed by DRDO and IISc Bangalore.

Future Developments

- India's ongoing efforts to develop indigenous air defense systems, such as the Fractional Orbital Bombardment System (FOBS), demonstrate its commitment to technological self-reliance.
    - **Fractional Orbital Bombardment System (FOBS)** is a warhead delivery system that uses a low Earth orbit to target its destination. It was first developed by the Soviet Union and offers unlimited range. **[UPSC 2022]**

FIGHTER JETS

First Generation

- **MiG-21:** An older model, but still in service; known for its speed and agility. Used primarily for air defense and ground attack missions.

Second Generation

- **MiG-29:** A twin-engine air superiority fighter known for its maneuverability and effectiveness in both air-to-air and air-to-ground roles.

Third Generation

- **Sukhoi Su-30MKI:** A multirole air superiority fighter developed in collaboration with Russia. Known for its advanced avionics, agility, and capability to carry a wide range of weapons.
- **Jaguar:** A ground attack aircraft designed for strike missions.

Fourth Generation [UPSC 2024]

- **Dassault Rafale:** A French multirole fighter jet known for its versatility and advanced technology. Equipped with cutting-edge avionics and weaponry, including nuclear capabilities.
- **HAL Tejas:** An indigenous lightweight, multirole fighter developed by Hindustan Aeronautics Limited. Designed for air-to-air and air-to-ground combat, with advanced features and systems.

Proposed (Next Generation)

Boeing F/A-18 Super Hornet: Considered a multirole fighter with advanced systems.

Eurofighter Typhoon: A European multirole fighter known for its cutting-edge capabilities.

AIRCRAFT CARRIERS

INS Vikramaditya

- **Origin:** Refurbished Russian aircraft carrier Admiral Gorshkov.
- **Commissioned:** Indian Navy, Severodvinsk, Russia.
- **Size:** Largest ship in the Indian Navy, measuring over 285m long, 60m wide, and 60m high.
- **Personnel:** Houses over 1,600 personnel, earning it the nickname "Floating City."
- **Range:** Operational range of over 13,000 km.
- **Aircraft Capacity:** Can carry over 30 aircraft, including MiG-29K/Sea Harrier, Kamov 31, Kamov 28, Sea King, ALH-Dhruv, and Chetak helicopters.
- **Landing Systems:** Features LUNA Landing system for MiGs and DAPS Landing system for Sea Harriers.

INS Vikrant

- **Size:** 262-meter-long aircraft carrier.
- **Power:** Powered by four gas turbines with a total output of 88 MW.
- **Speed:** Maximum speed of 28 knots.
- **Aircraft Capacity:** Can operate 30 aircrafts, including MiG-29K fighter jets, Kamov-31, MH-60R multi-role helicopters, ALH, and LCA (Navy).
- **Aircraft Operations:** Employs STOBAR (Short Take-Off but Arrested Landing) mode and is equipped with a ski-jump and arrester wires.
- **Indigenous Content:** Boasts an overall indigenous content of 76%.

IMPORTANT VESSELS OF THE INDIAN NAVY

Indigenous Vessels

1. INS Astradharini (2015)

- A torpedo launch and recovery vessel, 95% indigenously built.
- Designed by NSTL, M/s Shoft Shipyard, and IIT Kharagpur.
- Has a length of 50 meters and can operate in high seas with a maximum speed of 15 knots.
- Used for technical trials of underwater weapons and systems developed by NSTL.
- Replaced INS Astravahini.

2. INS Kavaratti (2015)

- A Kamorta class anti-submarine warfare (ASW) stealth corvette, 90% indigenous.
- Designed by DND(Directorate of Naval Design) and built by GRSE, Kolkata(Govt. owned undertaking of Ministry of Defence).
- Capable of detecting and prosecuting submarines.
- Uses carbon composites in construction.
- One of four ships commissioned under Project 28, along with INS Kamorta, INS Kadmatt, and INS Kiltan.

3. Project 17 A (Ongoing)

- Guided missile frigates, 75% indigenous.
- Designed by the Indian Navy's Warship Design Bureau.
- Being built by M/s MDSL ((Mazagon Dock Shipbuilders Ltd))and M/s GRSE (Garden Reach Shipbuilders and Engineers).
- Follow-ons of the Shivalik class frigates with improved features.
- Includes four ships: Nilgiri, Udaygiri, Taragiri, and Mahendragiri.

4. Project 15 B (Ongoing)

- Advanced variants of the Kolkata class guided missile destroyers, 75% indigenous.
- Designed by the Warship Design Bureau and being built by M/s MDSL.
- Includes four ships: INS Visakhapatnam, INS Mormugao, INS Imphal, and INS Surat.

Non-Indigenous Vessels

INSV Tarini (2017)

- A 55-foot sailing vessel used for the Navika Sagar Parikrama expedition.
- Not indigenous, but a significant achievement for the Indian Navy.
- Successfully circumnavigated the globe with an all-woman crew.

SUBMARINES

India currently possesses a fleet of 15 conventional diesel-electric submarines (SSKs) and two nuclear ballistic submarine (SSBN). Many of these submarines are over 25 years old and undergoing refits.

Types of Submarines

- **Diesel-Electric Submarines (SSKs):** Use electric motors charged by diesel engines for propulsion. Require frequent resurfacing for air and fuel, making them easier to detect.
  - **Shishumar Class:** Four submarines bought and built in India in collaboration with Germany.
  - **Kilo Class (Sindhughosh Class):** Eight submarines bought from Russia between 1984 and 2000.
  - **Kalvari Class (Scorpene):** Three submarines built in India in partnership with France.
- **Nuclear-Powered Attack Submarine (SSN):** Can stay underwater indefinitely, limited only by food supplies. Equipped with torpedoes, anti-ship cruise missiles, and land-attack cruise missiles.
  - **INS Chakra 2:** Leased from Russia until 2022.
- **Nuclear-Powered Ballistic Missile Submarine (SSBN):** A slow-moving platform for launching nuclear weapons.
  - **Arihant:** India's first SSBN, with three more under construction.

INS Arihant

INS Arihant is a crucial component of India's nuclear triad, providing the capability to launch nuclear weapons from submarines. This strategic advantage is particularly significant given India's "no first use" policy.

- As a nuclear-powered ballistic missile submarine (SSBN), INS Arihant was commissioned in 2016. It is currently armed with K-15 SLBMs with a range of 750 kilometers.
- **INS Arighat:** India's second nuclear powered submarine commisioned in 2024, bolstering India's strategic deterrence.
- **Nuclear Triad** means the capability of delivering nuclear weapons by aircraft, land based ballistic missiles and submarine launched missiles.

Project 75

Entails indigenous construction of **SSK submarines** of **Scorpene design** by **M/s MDSL**. The project includes the commissioning of six vessels, including **INS Kalvari**, **INS Khanderi**, **INS Karanj**, **INS Vela**, **INS Vagir**, and **INS Vagsheer**.

Project 75 (I)

It is a follow-up and improvement over **Project 75. The initiative envisages new SSK submarines** with **fuel cells** and **Air-Independent Propulsion System (AIP)** for the Indian Navy.

UNMANNED AERIAL VEHICLES (UAV)/DRONE AND ROBOTS

UAV/Drone is a military aircraft/land-water based vehicle that is guided autonomously, by remote control, or both and that carries sensors, target designators, offensive ordnance, or electronic transmitters designed to interfere with or destroy enemy targets.

Name	Indigenous/Imported From	Utility
NETRA	Indigenous (DRDO)	Airborne Early Warning and Control System (AEW&C/AWAC) for surveillance, target tracking, and command and control
Lakshya 2	Indigenous (DRDO)	Advanced pilotless target aircraft (PTA) for training air defense systems, simulating enemy aircraft, and evaluating weapon systems
Nishant	Indigenous (DRDO)	Battlefield surveillance, reconnaissance, target tracking, localization, intelligence gathering, and electronic warfare support
Panchi	Indigenous (DRDO)	Tactical UAV with conventional take-off/landing for reconnaissance, surveillance, target acquisition, and communication relay
Daksh	Indigenous (DRDO)	IED identification and handling, nuclear/chemical contamination monitoring, explosive ordnance disposal (EOD), and search and rescue operations
Daksh Mini	Indigenous (DRDO)	Confined space ROV for inspecting hazardous areas, extracting suspicious objects, and supporting search and rescue operations
UXOR	Indigenous (DRDO)	Unexploded ordnance (UXO) handling and detection, neutralizing bombs and missiles up to 1000 kg
UAV-NETRA	Indigenous (DRDO)	Mini UAV for surveillance, reconnaissance, intelligence gathering, and border monitoring
Rustom 2	Indigenous (DRDO)	Long-endurance MALE UAV for intelligence, surveillance, reconnaissance (ISR), electronic warfare, communication relay, and precision strike
Heron	Imported (Israel)	Medium-altitude long-endurance (MALE) UAV for ISR, border surveillance, target acquisition, and communication relay
FireFly	Imported (Israel)	Loitering munition for precision strikes against ground targets
Harpy/Harop	Imported (Israel)	Loitering munitions for electronic warfare and precision strikes
Predator	Imported (United States)	Medium-altitude long-endurance (MALE) UAV for ISR, strike missions, and combat search and rescue
Sea Guardian	Imported (United States)	Maritime surveillance UAV for maritime domain awareness and anti-submarine warfare

INTERNATIONAL ORGANISATIONS AND CONVENTIONS

Biological Weapons Convention (BWC)

It effectively prohibits the development, production, acquisition, transfer, stockpiling and use of **biological** and **toxin weapons**. It was the **first multilateral disarmament treaty** banning an entire category of **weapons of mass destruction (WMD)**. **India has signed and ratified the convention.**

Organisation for the Prohibition of Chemical Weapons (OPCW)

It is the **implementing body for the Chemical Weapons Convention** based in Hague, Netherlands, which oversees the global endeavour to permanently and verifiably eliminate chemical weapons. **India is a signatory and party to the Chemical Weapons Convention.** **[UPSC 2016]**

Australia Group

It is an informal forum of countries which seeks to ensure that **exports do not contribute to the development of chemical or biological weapons.** All states participating in the Australia Group are parties to the **Chemical Weapons Convention (CWC)** and the **Biological Weapons Convention (BWC)** and **do not undertake any legally binding obligations. India** was **admitted into the group in 2018**.

Wassenaar Arrangement

The Wassenaar Arrangement is the first multilateral body focused on **export controls for conventional arms and**

dual-use goods and technologies, and it comprises 42 states (**including India**). **It is consensus-based, with decisions taken on a politically binding basis**.

Missile Technology Control Regime

The Missile Technology Control Regime (MTCR) is an informal political understanding among states that **seeks to limit the proliferation of missiles and missile technology.** It places particular focus on missiles capable of delivering a **payload of at least 500 kg** to a distance of **at least 300 km**-so called '**Category I**' or '**MTCR-class**' missiles. Currently, 35 countries are members of the MTCR, **including India (2016)**.

Nuclear Suppliers Group (NSG)

The NSG is a group of forty-eight nuclear supplier countries that **seeks to ensure that nuclear trade for peaceful purposes does not contribute to the proliferation of nuclear weapons or other nuclear explosive devices**. **India is not a member of the NSG**, the main reason being its refusal to sign the **Nuclear Non-Proliferation Treaty.**

Comprehensive Test Ban Treaty

It **bans all nuclear explosions**, whether for military or peaceful purposes. The 1996 treaty has so far been signed by 187 states and ratified by 178 states, **yet not in force**. The treaty **awaits signature and ratification** from **India**, **Pakistan**, and **North Korea** and, in addition, requires the **United States**, **China**, **Israel**, **Iran** and **Egypt** (which have already signed) to formally ratify it.

Treaty on the Non-Proliferation of Nuclear Weapons (NPT)

It is a landmark international treaty whose objective is to **prevent the spread of nuclear weapons and weapons technology**, to **promote cooperation in the peaceful uses of nuclear energy** and to **further the goal of achieving nuclear disarmament and general and complete disarmament**. **India** has **not signed the NPT**.

The Treaty on the Prohibition of Nuclear Weapons (TPNW)

Opened for signature in 2017, **it prohibits States Parties from developing, testing, producing, manufacturing, acquiring, possessing, or stockpiling nuclear weapons or other nuclear explosive devices**. The treaty entered into force on 22 January 2021, and **India has neither signed nor ratified it**.

8 Energy : Conventional and Alternative

NON-RENEWABLE (CONVENTIONAL) ENERGY RESOURCE

Non-renewable energy sources are those that cannot be replenished or take a very long time to form. They are finite and include fossil fuels like coal, petroleum, and natural gas, as well as other forms such as asphalt, bioasphalt, LPG (Liquefied Petroleum Gas), PNG (Piped Natural Gas), CNG (Compressed Natural Gas), LNG (Liquefied Natural Gas), and different types of natural gas like sweet and sour gas.

Coal

Coal is a solid fossil fuel formed from ancient plant matter over millions of years. It is primarily used for electricity generation and in industrial processes that require heat.

It accounts for 55% of the country's energy needs.

Types of Coal as per Carbon content

- **Anthracite:** purest form of coal, 86-97% Carbon
- **Bituminous:** 69-86% of Carbon.
- **Lignite:** about 60-70% Carbon.
- **Peat:** 50-60% carbon (formed during 1st stage of coal formation)
- **Coke:** It is a tough, porous and black substance. It is an **almost pure form** of carbon. Coke is used in the manufacture of steel and in the extraction of many metals.
  - Coke is formed by heating coal in an oxygen-free atmosphere at high temperatures for a long time in a process called coking or **destructive distillation.**

Fly Ash **[UPSC 2015]**

Produced by the power plants using coal as fuel.

Fly ash can be used in the production of bricks for building construction. Fly ash can be used as a replacement for some of the Portland cement contents of concrete.

Petroleum

- Petroleum is a liquid fossil fuel formed from ancient marine organisms. It is mainly used for transportation fuels (gasoline, diesel) and electricity generation.
- **Fractional distillation:** is a process that separates crude oil into different petroleum products, such as gasoline, diesel, and kerosene. The process works by heating crude oil to create vapors, which then rise up a fractionating column where they condense at different temperatures.

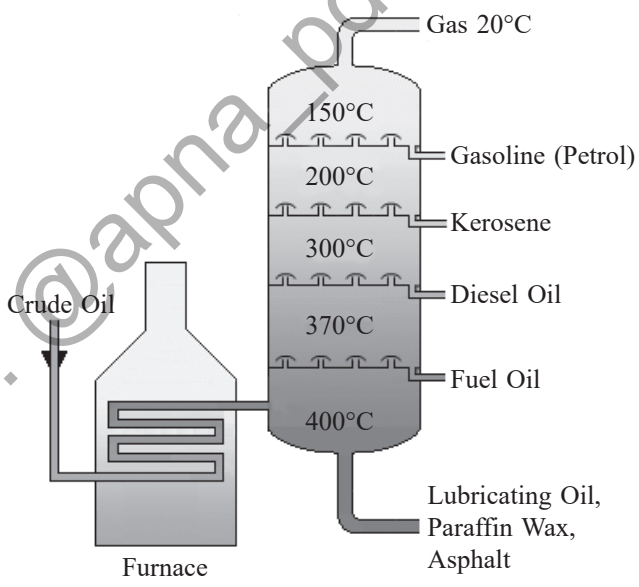


Figure: Fractional Distillation

LPG (Liquefied Petroleum Gas)

Liquefied petroleum gas (LPG) is a flammable mixture of hydrocarbon gases, primarily made up of propane, butane, and isobutane. LPG smells due to the addition of ethyl mercaptan, a chemical with a strong odor, to make it easier to detect leaks.

CNG (Compressed Natural Gas)

CNG is methane stored under high pressure. It is used as a cleaner alternative to gasoline and diesel in vehicles.

Sweet and Sour Gas

These are types of natural gas. Sweet gas has a low sulphur content, making it less corrosive and more environmentally friendly, while sour gas contains higher amounts of hydrogen sulphide and requires more processing to make it safe to use.

Calorific Value of Fuels

Calorific value is a measure of the amount of heat produced by a unit mass or volume of a substance when it undergoes complete combustion. It's often expressed in units like kilojoules per kilogram (kJ/kg) or British thermal units per pound (BTU/lb).

Fuel	Calorific Value (kJ/kg)	Fuel	Calorific Value (kJ/kg)	Fuel	Calorific Value (kJ/kg)
Cow Dung	8000	Petrol	45000	Biogas	40000
Kerosene	45000	Coal	33000	LPG	55000
Wood	22000	Methane	50000	Diesel	45000

RENEWABLE (NON-CONVENTIONAL) ENERGY RESOURCES

Renewable energy sources are diverse and sustainable. They are not finite resources such as coal, petroleum etc. Its forms include solar, wind, geothermal, hydropower, and ocean energy (Including Ocean Thermal Energy Conversion (OTEC) and tidal energy), biomass energy (biofuels), and wave energy. Each of these sources has distinct characteristics and types:

Solar Energy

Solar energy is the harnessing of the sun's energy and converting it into electricity or heat. **[UPSC 2020]**

Photovoltaic (PV) Systems **[UPSC 2014]**

These systems convert sunlight directly into electricity using solar cells. They are widely used for both residential and commercial purposes.

- **Working:** In PV systems, photovoltaic cells, typically made of semiconductor materials like silicon, absorb sunlight. This sunlight dislodges electrons in the semiconductor material, creating a flow of electric current. This process is known as the photovoltaic effect.

Concentrated Solar Power (CSP)

It uses mirrors or lenses to concentrate a large area of sunlight onto a small area, generating heat that drives an engine connected to an electrical power generator.

Difference Between Solar PV Panels and Solar Thermal Panels

- Solar PV (photovoltaic) panels convert sunlight directly into electricity using photovoltaic cells, primarily for electricity generation in residential and commercial settings.
- In contrast, solar thermal panels absorb sunlight to heat a fluid, which is then used for heating purposes such as domestic hot water and space heating. While PV panels are focused on electrical energy production, solar thermal panels are dedicated to providing thermal energy.

Solar Water Pump **[UPSC 2020]**

An electrical pump system that uses one or more Photovoltaic (PV) panels to generate power is called solar water pump system. Submersible pumps, surface pumps, Direct Current (DC) pumps, and Alternative Current (AC) pumps are the four main categories of solar water pumps. Centrifugal and piston pumps can both be driven by solar power.

Solar Rooftop Systems

They are installed on the rooftops of residential or commercial buildings. These systems generate electricity for onsite use and can feed excess power back to the grid.

Solar Parks: These are large-scale solar installations, often developed in collaboration with state governments or big private firms.

- **Current Capacity and Growth:** India aims 500 GW renewable energy installed capacity by 2030. As of October 2024, India's installed solar capacity stands at approximately 94.17 GW (MNRE), having increased 30-fold over the past nine years.
- **Areas of Presence:** Solar energy projects are spread across various states in India.

Rank	State	Solar Capacity	Prominent Solar Plant
1.	Rajasthan	23 GW	Bhadla Solar Park
2	Gujarat	10.13 GW	Charanka Solar Park
3.	Karnataka	9.05 GW	Pavagada Solar Park
4.	Tamil Nadu	8.1 GW	Kamuthi Solar Power Project
5.	Maharashtra	4.8 GW	Sakri Solar Power Plant

Wind Energy

Wind energy involves generating electricity by converting the kinetic energy of wind using wind turbines.

Current Capacity and Growth

- **Installed Capacity:** As on 10 October, 2024 India's installed wind capacity stands 47.72 GW.

Areas of Presence

- **Geographical Spread:** Major wind energy installations are found in states like Tamil Nadu, Gujarat, Maharashtra, and Karnataka, which have favourable wind conditions.
- **Wind Parks:** India has developed several large wind parks. Examples include Jaisalmer Wind Park (1064 MW), Muppandal Wind Farm (1500 MW), etc.

Geothermal Energy

Geothermal energy is derived from the natural heat of the Earth, typically from areas with volcanic or tectonic activity.

- **Properties:** It provides a constant and reliable energy source with minimal environmental impact.
- **Current Capacity and Potential:**
  - **Installed Capacity:** As of 2024, India has not yet started commercial power production from geothermal energy. However, the potential is significant. Site exploration is currently going on in Puga Valley of Ladakh. India is also exploring sites in the state of Arunachal Pradesh.
  - **Potential Capacity:** Estimates suggest that India has the capacity to generate around 10 GW of geothermal energy.

Hydropower

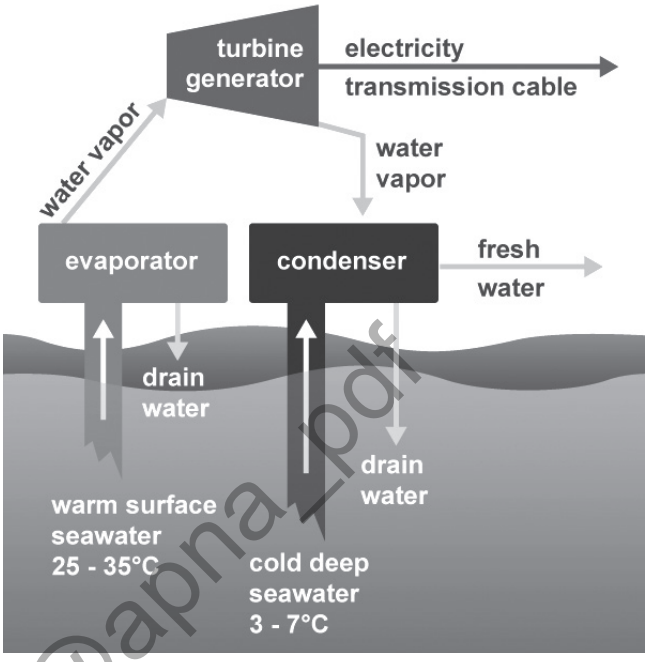
Hydropower uses the energy of flowing water, typically from rivers or streams, to generate electricity.

- **Properties:** It is a renewable and clean source of energy, though large dams can have significant environmental and social impacts.
- **Current Capacity and Growth:**
  - **Installed Capacity:** As on 10 October,2024 Hydroelectric stands at 51.99 GW, with large hydro projects generating 46.92 GW and small hydro power adding 5.07 GW.
- **Pumped-storage hydropower** is a method of storing energy by using two water reservoirs at different elevations. During periods of low electricity demand, excess energy is used to pump water from the lower reservoir to the upper one. When energy demand increases, the stored water is released back down to the lower reservoir, passing through turbines to generate electricity. Unlike batteries that may have limited capacity or duration, PSH can store large amounts of energy over long periods, supporting seasonal energy management. **[UPSC 2024]**

Ocean Energy

Ocean energy encompasses various methods of harnessing energy from the ocean, including thermal gradients, tides, currents and waves.

- Ocean thermal energy conversion (OTEC) is a process or technology for producing energy by harnessing the temperature differences (thermal gradients) between ocean surface waters and deep ocean waters.



- **Current Capacity and Potential:**
  - **Installed Capacity:** As of 2024, India has not yet realised significant commercial capacity in ocean energy.
  - **Potential Capacity:** India is estimated to have a theoretical potential of about 54 gigawatts (GW) of ocean energy, including tidal and wave energy.
- **Areas of Presence:**
  - **Potential Sites: The** Gulf of Kutch and the Gulf of Cambay are identified as potential sites for tidal energy. The long coastline of India offers numerous locations for wave energy and OTEC.

Gas Hydrates

These are crystalline, ice-like compounds composed of water molecules that trap gas molecules within their structure. They form under specific conditions of low temperature and high pressure, typically in deep-sea sediments and permafrost regions. The most common gas hydrates contain methane, but other gases like ethane, propane, and carbon dioxide can also be present.

- **Formation:** Gas hydrates form when water molecules create a cage-like structure around gas molecules under low temperatures and high pressures. These conditions are often found in deep-sea sediments and permafrost regions.
- **Locations:** Gas hydrates are found in marine sediments along continental margins and permafrost regions. The majority are located in deep-sea environments where low temperatures and high pressures prevail. **[UPSC 2019]**

- **Energy Resource:** Methane hydrates are of interest as a potential future energy resource. The methane trapped within hydrates is abundant, and some estimates suggest that it could represent a vast reservoir of natural gas. **[UPSC 2019]**

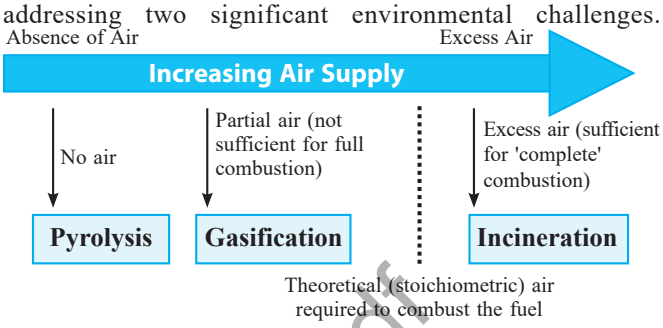
Biomass Energy (Biofuels)

Biomass energy involves using organic materials as fuel to produce electricity, heat, or transportation fuels. These materials include wood, agricultural residues, and other plant-based materials. Biomass is considered renewable because it can be replenished over a relatively short period of time, unlike fossil fuels.

- **Conversion Processes:**
  - **Direct combustion** is the burning of biomass to produce heat, which is then used to generate electricity.
  - **Anaerobic Digestion:** This technique uses microorganisms to break down organic matter in the absence of oxygen, producing biogas.
  - **Fermentation** is the process of converting biomass into ethanol, a type of biofuel.
  - **Gasification and Pyrolysis:** In this technique, biomass is transformed into synthetic gas or bio-oil at high temperatures.
- **Properties:** Biomass can be a sustainable energy source when managed responsibly, though it does produce some emissions when burned.
- **Types of Biomass Energy Systems in India:**
  - **Biomass Power Plants:** These plants use organic materials like agricultural residues, wood, and bagasse to produce electricity.
  - **Biomass Cogeneration:** This involves the simultaneous production of electricity and heat using biomass, commonly practiced in sugar mills.
  - **Waste-to-Energy Plants:** These facilities convert municipal and industrial waste into energy.
  - **Biomass Gasification:** A process where biomass is converted into a gas (syngas), which can be used for power generation or as a fuel. Coconut shells, groundnut shells and rice husk can be used in biomass gasification **[UPSC 2012]**
  - **Biofuels:** Biomass can be processed into biofuels like ethanol and biodiesel, which can be used as substitutes for gasoline and diesel in vehicles.
- **Current Capacity and Growth:** Currently, biopower, including biomass and biogas energy, adds 11.32 GW to the renewable energy mix.
- **Areas of Presence:**
  - **Geographical Spread:** Biomass energy facilities are widely distributed across India, with a higher concentration in agricultural states like Punjab, Haryana, and Uttar Pradesh.
  - **Major Projects:** Many sugar mills in India have adopted biomass cogeneration, and there are numerous waste-to-energy projects in urban areas.

Waste to Power Energy

Waste-to-power energy, also known as Waste-to-Energy (WtE) or Energy-from-Waste (EfW), is a process that converts waste materials into electricity, heat, or fuel through various treatment methods. This approach not only helps in managing waste but also contributes to energy production, thereby addressing two significant environmental challenges.



- **Conversion Processes:** The primary methods include thermal technologies like incineration, pyrolysis, and gasification, as well as non-thermal technologies such as anaerobic digestion and fermentation.
- **Incineration:** Incineration is the process of burning waste materials at high temperatures to reduce their volume, generating ash, flue gas, and heat, often used for energy production.
- **Pyrolysis:** Pyrolysis is the thermal decomposition of organic materials at high temperatures in the absence of oxygen, producing char, liquid bio-oil, and syngas. **[UPSC 2019]**
- **Gasification:** Gasification is a process that converts organic or fossil-based materials into syngas, a mixture of carbon monoxide, hydrogen, and carbon dioxide, by reacting them at high temperatures with a controlled amount of oxygen and/or steam.
- **Anaerobic Digestion:** This biological process breaks down organic waste in the absence of oxygen, producing biogas (mainly methane and carbon dioxide), which can be used to generate electricity and heat.

Polycrack Technology

Polycrack technology is an innovative approach in the fields of waste management and energy production. It represents a significant advancement in converting various types of waste into usable forms of energy. Here's a brief overview covering all aspects of polycrack technology:

- **Basic Principle:**
  - **Heterogeneous Catalytic Process:** Polycrack technology utilises heterogeneous catalytic processes.
  - This process allows for the conversion of multiple feedstocks, including a wide range of waste materials, into hydrocarbon liquid fuels, gas, carbon, and water.
- **Process and operation:**
  - **Conversion of Multiple Feedstocks:** The technology is capable of processing a variety of waste materials, including plastic, rubber, and organic waste.

- **Output Products:** The process efficiently converts waste into several valuable outputs, including hydrocarbon liquid fuels (which can be used as a substitute for fossil fuels), gas (which can be used for heating or electricity generation), carbon (which has industrial applications), and water.

- **Environmental Impact:**
  - **Reduction in Landfill Waste:** By converting waste into energy, Polycrack technology significantly reduces the amount of waste that ends up in landfills.
  - **Lower Greenhouse Gas Emissions:** The technology offers an environmentally friendly solution by minimising the release of greenhouse gases compared to traditional waste disposal methods.
- **Applications:**
  - **Waste Management:** Polycrack technology is primarily used for the treatment of various types of waste, including municipal solid waste, plastic waste, and industrial waste.
  - **Fuel Production:** It converts waste materials into hydrocarbon fuels, which can be used as a substitute for conventional fossil fuels.
  - **Energy Recovery:** The process is capable of recovering energy from waste, contributing to sustainable energy initiatives.

SOME RECENT AND ADVANCED ENERGY GENERATION SOURCES

Biofuel

Biofuels are a type of renewable energy that comes from living materials. They are considered renewable because the feedstock material can be replenished easily. Biofuels, particularly ethanol and methanol, are increasingly recognised as sustainable alternatives to conventional fossil fuels. Their blending with petrol is a significant step towards reducing emissions and dependency on oil imports.

Types of Biofuels

Generation	Key Characteristics
1st Generation	Derived from consumable food items (starch, sugar, vegetable oil)
	Known as conventional biofuels (e.g., ethanol from sugarcane)
	Examples: biogas, biodiesel, bioalcohols
2nd Generation	Derived from sustainable non-food feedstocks (waste vegetable oil, forest residue)
	Also known as "olive green" or "cellulosic-ethanol" fuel
3rd Generation	Derived from algae
	Also known as "algae fuel" or "oilage"
	Produces various biofuels (biodiesel, butanol, propanol, ethanol) with high yields
4th Generation	Produced using genetically engineered organisms and feedstocks
	Main organisms: Genetically modified algae and cyanobacteria

- **Ethanol Blending in Petrol:**
  - **Source and Production:** Ethanol, a type of alcohol, is typically produced through the fermentation of sugars found in crops like sugarcane, corn, and beet.
  - **Blending Process:** Ethanol is blended with petrol to create E10 (10% ethanol and 90% petrol), E15, or even E85 (85% ethanol) blends, depending on the country and regulations.
  - **Benefits:** Ethanol blending reduces greenhouse gas emissions, as ethanol burns cleaner than gasoline. It also helps in diversifying energy sources and supports agricultural sectors.
  - **Challenges:** High ethanol blends may require modifications to traditional petrol engines and fuel infrastructure. There's also a debate over the food vs. fuel issue, concerning the use of food crops for fuel production.
- **Methanol Blending in Petrol:**
  - **Source and Production:** Methanol, also known as wood alcohol, can be produced from natural gas, coal, or biomass.
  - **Blending Process:** Methanol is blended with petrol in various proportions, commonly as M5 (5% methanol and 95% petrol) or M15 blends.
  - **Benefits:** Methanol blending reduces carbon emissions and is cost-effective compared to pure petrol. It also offers higher octane ratings, improving engine performance.
  - **Challenges:** Similar to ethanol, methanol can be corrosive and may require engine and infrastructure adjustments. It also has toxicity concerns if mishandled.

Major Types of Biofuels

Biofuel	Source	Production Method	Composition	Advantages
Bioethanol	Corn, sugarcane	Fermentation	Primarily ethanol (C_2H_5OH)	Higher energy content than petrol, reduces emissions
Biodiesel	Vegetable oils, animal fats	Transesterification	Fatty acid methyl esters (FAME)	Less harmful emissions, alternative to conventional diesel
Biogas	Organic waste (manure, food waste)	Anaerobic digestion	Mainly methane (CH_4) and carbon dioxide (CO_2)	Reduces greenhouse gas emissions from waste
Biobutanol	Starch	Fermentation	Butanol ($C_4H_{10}O$)	Highest energy content among gasoline alternatives, reduces emissions, used as a solvent
Biohydrogen	Organic matter	Pyrolysis, gasification, biological fermentation	Hydrogen (H_2)	Perfect alternative to fossil fuel

Maize: **[UPSC 2014]**

1. Maize can be used for the production of starch.
2. Oil extracted from maize can be a feedstock for biodiesel.
3. Alcoholic beverages can be produced by using maize.

Flex-Fuel Vehicles (FFV)

FFVs are specially designed to operate on various fuel types, including blends of gasoline and biofuels like ethanol or methanol. They can even run entirely on these biofuels.

Engine Design: FFV engines resemble those of conventional vehicles but include modified components to handle different fuel blends, especially high ethanol or methanol content.

Fuel Compatibility:

- **Ethanol Blends:** FFVs can use E85 (85% ethanol, 15% gasoline) and other blends like E15, allowing drivers to choose based on availability and preference.
- **Methanol Blends:** Some FFVs operate on M85 (85% methanol, 15% gasoline) and other methanol blends.
- **Gasoline Use:** They can switch to 100% gasoline, providing versatility in fuel choice where biofuel blends are less accessible.

Technological Features:

- **Advanced Fuel Systems:** FFVs have sophisticated fuel injection and engine management systems that detect the fuel blend and adjust combustion processes.
- **Durable Materials:** Corrosion-resistant materials ensure longevity and reliability with high biofuel blends.

Fuel Properties

- **Octane number** measures a fuel's resistance to engine knocking. Higher octane numbers indicate better resistance to premature combustion in gasoline.
- **Cetane number** indicates the ignition quality of diesel fuel. A higher cetane number signifies easier ignition.
- **Flash point** is the lowest temperature at which a substance produces enough vapor to ignite momentarily.
- **Engine Knocking**
  - Engine knocking, also known as detonation, is an undesirable sound and phenomenon that occurs when the air-fuel mixture in the combustion chamber ignites prematurely or unevenly.

National Policy on Biofuels, 2018 [UPSC 2020]

- **Ethanol Blending:**
  - Target **20% ethanol blending** in petrol by **2030** and **10% by 2022**.
- **Biodiesel Production:**
  - Aim to utilize **100% of used cooking oil** for biodiesel by **2023**.
  - Focus on producing biodiesel from non-edible oils.
- **Advanced Biofuels:**
  - Promote development of **second-generation** (lignocellulosic) and **third-generation** (algal) biofuels.
- **Investment and Production Capacity:**
  - Increase biofuel production capacity with incentives for establishing plants in rural areas.

- **Sustainability Criteria:**
  - Set a minimum land use target of **5%** of total cultivable area for biofuel crops.
- **Financial Incentives:**
  - Introduce financial incentives to boost biofuel production and blending.

Hydrogen Fuel

Hydrogen is a clean energy source crucial for a sustainable, low-carbon future. It can be classified into three main types:

1. **Grey Hydrogen**
   - **Production Method:** Produced via steam methane reforming (SMR) using fossil fuels like natural gas.
   - SMR: $CH_4 + H_2O \rightarrow CO + 3H_2$
     - This reaction occurs at high temperatures (typically between 700 °C and 1,000 °C) and is often accompanied by a secondary reaction called the **water-gas shift reaction**, where carbon monoxide reacts with water to produce additional hydrogen and carbon dioxide:
     - $CO + H_2O \rightarrow CO_2 + H_2$
   - **Environmental Impact:** Releases carbon dioxide (CO_2), making it less eco-friendly.
   - **Usage:** Historically the most common type but is facing scrutiny due to its environmental impact.
2. **Blue Hydrogen**
   - **Production Method:** Also produced through SMR with fossil fuels, but employs carbon capture and storage (CCS) to mitigate emissions.
   - **Environmental Impact:** Reduces carbon footprint compared to grey hydrogen.
   - **Usage:** Seen as a transitional option toward renewable hydrogen.

Carbon Capture and Storage (CCS):
CCS technology captures and stores CO_2 emissions from fossil fuel processes, helping combat climate change.

3. **Green Hydrogen** **[UPSC 2023]**
   - **Production Method:** Created through electrolysis using renewable energy sources (solar, wind, hydropower) to split water into hydrogen and oxygen.
   - **Environmental Impact:** Most environmentally friendly, as it emits no CO_2.
   - **Usage:** Sustainable for transportation, industry, and energy storage.

National Green Hydrogen Mission

Approved on January 4, 2023, with an outlay of ₹19,744 crore for FY 2023-30, the mission aims to position India as a global hub for green hydrogen production and export. Key components include:

- **Demand Creation:** Focus on exports and domestic use.
- **SIGHT Programme:** Incentives for electrolyser manufacturing and green hydrogen production.
- **Pilot Projects:** Initiatives in steel, mobility, and shipping.
- **Infrastructure Development:** Establishing green hydrogen hubs and regulatory frameworks.
- **R&D and Skill Development:** Programs for research and public awareness.

Expected Outcomes by 2030

India's green hydrogen production capacity to reach **5 MMT per annum**, significantly reducing fossil fuel imports and averted **50 MMT** of CO_2 emissions.

BATTERY TECHNOLOGY

Batteries and Fuel Cells Chemistry

Battery:

Batteries convert chemical energy into electrical energy through electrochemical reactions. They consist of two electrodes: anode and cathode, separated by an electrolyte.

1. **Operation:**
   - **Charging:** Electrical energy drives ions from the cathode to the anode.
   - **Discharging:** Ions move back to the cathode, generating current.
2. **Example Reaction** (Lithium-ion battery):
   - **Discharge**: $LiCoO_2 + C \rightarrow LixCoO_2 + C$
   - **Charge**: $LixCoO_2 + CxLi \rightarrow LiCoO_2 + C$

Fuel Cells

Fuel cells convert chemical energy directly into electrical energy, typically using hydrogen.

1. **Operation:**
   - **At Anode:** Fuel oxidizes, releasing electrons.
   - **At Cathode:** Electrons combine with protons and oxidant to produce water.
2. **Example Reaction** (Hydrogen fuel cell):
   - **At Anode:** $2H_2 \rightarrow 4H^+ + 4e^-$
   - **At Cathode:** $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Advanced Chemistry Cells (ACCs)

ACCs, or advanced chemistry cell batteries, are crucial for lithium-ion batteries and energy storage systems. They store electric energy through advanced chemical processes, allowing efficient conversion back to electrical energy.

Environmental Impact:

ACCs reduce fossil fuel reliance and help combat global warming, supporting clean energy technologies. Their innovative design positions them as key players in climate change mitigation.

India's Initiatives:

India recognizes the importance of ACCs for sustainable energy. The National Programme on Advanced Chemistry Cell (ACC) Battery Storage aims to decrease import dependency. A Production-Linked Incentive (PLI) scheme encourages domestic manufacturing, attracting various companies.

Sodium-Ion Batteries

Sodium-ion batteries are a promising alternative to lithium-ion batteries. They operate similarly, with sodium ions moving between the electrodes during charging and discharging.

- **Components:**
  - **Anode:** Typically made from hard carbons.
  - **Cathode:** Composed of layered oxides or polyanionic compounds.
  - **Electrolyte:** A sodium salt in an organic solvent.

Lithium-Ion Batteries

Lithium-ion cells have transformed energy storage, known for high energy density and long lifespan.

- **Basic Principle:** Lithium ions move between the anode and cathode during charging (from cathode to anode) and discharging (back to cathode).
- **Components:**
  - **Anode:** Usually graphite.
  - **Cathode:** Lithium metal oxides.
  - **Electrolyte:** Lithium salt in an organic solvent.
  - **Separator:** A porous membrane for ion transfer.

Lithium Resource Status in India:

India ranks among the top 10 countries for lithium resources, with significant discoveries, including 5.9 million metric tonnes in Jammu and Kashmir.

Gravity Batteries

Gravity batteries utilize gravitational potential energy for electricity storage and release. They operate by elevating heavy masses during excess energy generation and lowering them to generate electricity when needed.

- **Components:**
  - **Heavy Mass:** Elevated using surplus electricity.
  - **Cranes/Elevators:** Raise the mass, capturing potential energy.
  - **Energy Release Mechanism:** Converts potential energy back to electricity as the mass is lowered.

FUEL CELLS [UPSC 2015]

Fuel cells generate electricity through electrochemical reactions, primarily using hydrogen. **[UPSC 2015]**

Hydrogen Fuel Cells

- **Operation:** At the anode, hydrogen splits into electrons and protons; electrons create current, and protons combine with oxygen at the cathode to produce water.
- **Applications:**
  - **Transportation:** Used in vehicles, including heavy-duty and long-range transport.
  - **Stationary Power Generation:** Provides electricity for buildings.
  - **Portable Power:** Powers devices in off-grid areas.
  - **Integration with Renewable Energy**: Balances energy supply from sources like wind and solar.

Microbial Fuel Cells (MFCs) [UPSC 2011]

MFCs convert chemical energy to electrical energy using microorganisms.

- **Operation**: Bacteria oxidize organic compounds at the anode, releasing electrons that generate electricity, while protons combine with oxygen at the cathode to form water.
- **Applications:**
  - **Wastewater Treatment:** Degrades pollutants while generating electricity.
  - **Biosensors:** Detects pollutants in water.
  - **Remote Power Sources:** Suitable for low-power devices in remote locations.
  - **Research Tool:** Studies microbial interactions and metabolism.

NUCLEAR SCIENCE AND TECHNOLOGY

Structure of Atom:

The structure of an atom can be understood in terms of its constituent parts. Atoms are made up of three types of subatomic particles: protons, neutrons, and electrons. The protons and neutrons are located in the nucleus at the center of the atom, while the electrons orbit around the nucleus in shells or energy levels.

Particle	Location	Charge	Mass (amu)	Function
Proton	Nucleus	Positive (+)	1	Determines the atomic number and element.
Neutron	Nucleus	Neutral (0)	1	Contributing to the atomic mass, difference in neutrons and same no. of protons leads to isotopes of the same element.
Electron	Orbits the nucleus in shells	Negative (-)	0.0005	Determines the chemical behavior, forms bonds.

STANDARD MODEL OF PARTICLE PHYSICS

The Standard Model is a theory that explains the fundamental particles that make up the universe and how they interact through forces. It categorizes these particles into two main groups: **matter particles and force carriers.**

1. Matter Particles (Fermions)

Matter particles are known as **fermions**, and they are the building blocks of everything around us. There are two types of fermions:

- **Quarks:**
  - Quarks come in six varieties, known as "flavors": Up (u), Down (d), Charm (c), Strange (s), Top (t), and Bottom (b).
  - Quarks combine to form protons and neutrons, which are the components of atomic nuclei.
- **Leptons:**
  - Leptons include particles such as the Electron (e), Muon (μ), Tau (τ), and their corresponding neutrinos (Electron Neutrino, Muon Neutrino, Tau Neutrino).
  - Electrons are the leptons that orbit around the nucleus of an atom and are essential for chemical reactions.

2. Force Carriers (Bosons)

Force carriers are known as **bosons**, and they mediate the fundamental forces that govern how particles interact. The main bosons include:

- **Gauge Bosons:**
  - **Photon (γ):** This particle carries the electromagnetic force, which is responsible for electricity, magnetism, and light.
  - **W and Z bosons:** These particles mediate the weak nuclear force, which is involved in processes like radioactive decay.
  - **Gluons (g):** Gluons are responsible for the strong nuclear force, which holds protons and neutrons together in the atomic nucleus.
- **Higgs Boson:**
  - The Higgs boson is a special particle that gives mass to other particles through a process called the Higgs mechanism. It was discovered in 2012, confirming its role in the Standard Model.

3. Fundamental Forces

The Standard Model describes three of the four fundamental forces: **[UPSC 2013]**

- **Electromagnetic Force:** Mediated by photons, this force affects charged particles and is responsible for electricity and magnetism.
- **Weak Nuclear Force:** Mediated by W and Z bosons, this force is responsible for processes like beta decay in nuclear reactions.
- **Strong Nuclear Force:** Mediated by gluons, this force holds the atomic nucleus together, overcoming the repulsion between positively charged protons.

Note:

- **Gravitational Force** is not included in the Standard Model. It is described by a different theory, General Relativity.

The Standard Model explains how all matter is made up of **fermions (quarks and leptons)** and how they interact through fundamental forces mediated by bosons. It provides a comprehensive framework for understanding the building blocks of our universe and their interactions.

NUCLEAR ENERGY

It is the energy released during nuclear reactions, particularly through processes like nuclear fission and nuclear fusion. These reactions release a tremendous amount of energy from the atomic nucleus.

Types of Nuclear Reactions

There are two primary types of nuclear reactions: nuclear fission and nuclear fusion.

- **Nuclear Fission:** It is the process of splitting a heavy atomic nucleus into two or more lighter nuclei, accompanied by the release of a large amount of energy. The neutrons produced during fission can trigger subsequent fission reactions in nearby fissile nuclei, creating a self-sustaining chain reaction. This is the basis for energy production in nuclear power plants.
- **Nuclear Fusion:** It is the process of combining two light atomic nuclei to form a heavier nucleus, releasing a large amount of energy. Common fusion fuels include isotopes of hydrogen, such as deuterium and tritium.
  - Experimental projects like ITER (International Thermonuclear Experimental Reactor) aim to develop practical and controlled nuclear fusion for energy production.

(ITER)/Artificial Sun Experiment **[UPSC 2016]**

- The International Thermonuclear Experimental Reactor (ITER) is **the most advanced and the world's largest Tokamak,** a major international research project focused on **nuclear fusion.**
- ITER represents a collaborative effort involving 35 countries, including the European Union, the United States, Russia, China, **India**, Japan, and South Korea.
- ITER is often referred to as the **"Artificial Sun Experiment"** because it aims to replicate the conditions and processes that occur in the sun to generate energy on Earth.

Tokamak Concept

ITER utilizes the tokamak concept, a magnetic confinement fusion approach. This involves heating and containing plasma, a superheated state of matter, using powerful magnetic fields. The goal is to initiate and sustain fusion reactions between deuterium and tritium isotopes, releasing significant energy.

Cold Fusion

- It is a type of nuclear reaction that is thought to take place at or near room temperature.
- It would be in sharp contrast to the hot fusion that occurs naturally in stars and artificially in hydrogen bombs and prototype fusion reactors under great pressure and at temperatures of millions of degrees.
- There is currently no accepted theoretical model that would allow cold fusion to occur.

Nuclear Reactor

A nuclear reactor is a complex system designed to initiate and control nuclear fission reactions for generating electricity or heat. The core principle is the controlled splitting of atomic nuclei, which releases a significant amount of energy.

Components of a Nuclear Power Reactor

- **Fuel:** Typically Uranium-235, a fissile material that undergoes nuclear fission.
- **Control Rods:** Made from neutron-absorbing materials (e.g., Boron, Cadmium), these regulate the fission rate.
- **Moderator:** Slows down neutrons for efficient fission reactions (common materials include Heavy water, ordinary water, or graphite). **[UPSC 2011]**
- **Coolant:** Transfers heat from the reactor core to the steam generator (e.g., Heavy water, Helium, or water).
- **Steam Generator:** Converts water into steam to drive turbines.

Characteristics of water [UPSC 2021]

- Water can dissolve more substances than any other liquid because it is dipolar in nature.
- The surface of a lake is frozen in severe winter, but the water at its bottom is still liquid .The reason for this is the density of water is maximum at 4°C. **[UPSC 2011]**

How Nuclear Reactors Work

1. **Fission:** Nuclear fuel undergoes fission, releasing heat energy.
2. **Heat Transfer:** The coolant circulates through the reactor core, absorbing heat.
3. **Steam Generation:** The coolant transfers heat to the steam generator, producing steam.
4. **Electricity Generation:** Steam drives turbines to generate electricity.

Types of Reactors

1. **Pressurized Heavy Water Reactor (PHWR):**
   - **Coolant & Moderator:** Heavy water (deuterium oxide, D_2O).
   - **Fuel:** Typically uses natural uranium (uranium-238), which sustains a nuclear chain reaction without extensive enrichment.
   - **Control Rods:** Boron rods are adjusted to control the power output.
2. **Small Modular Reactors (SMRs):**
   - **Capacity:** Up to 300 MW(e) per unit.
   - **Characteristics:** Smaller and modular, allowing for factory assembly and transport.
3. **Gas-Cooled Reactors (GCRs):**
   - **Coolant:** Uses gas (e.g., helium, carbon dioxide).
   - **Operation:** Can operate at significantly higher temperatures, achieving thermal efficiencies up to 50%.
   - **Applications:** Besides power generation, they can be used for hydrogen production and water desalination.
4. **Light Water Reactors (LWRs):**
   - **Coolant & Moderator:** Ordinary water.
   - **Types:**
     - **Boiling Water Reactor (BWR):** Heats water directly to produce steam.
     - **Pressurized Water Reactor (PWR):** Heats pressurized water to produce steam in a secondary circuit.
5. **Fast Reactors:**
   - **Fuel Breeding:** Converts non-fissile uranium-238 into fissile plutonium for fuel.
   - **Key Characteristics:** Utilizes fast neutrons and often relies on plutonium, with no moderator for increased efficiency with uranium-238.

Radioisotope Thermoelectric Generators (RTGs) [UPSC 2024]

RTGs are devices that convert the heat released by the decay of radioactive isotopes into electrical power.

Components: Typically consist of a radioisotope heat source, thermoelectric converters, and a thermal insulation system.

Common Isotopes: Plutonium-238 is the most commonly used isotope due to its favorable half-life and heat output.

Working Principle: The heat from radioactive decay generates a temperature difference across thermoelectric materials, producing electricity via the Seebeck effect.

NUCLEAR POWER IN INDIA

Nuclear energy is the **fifth-largest** source of electricity in India, contributing about 3% of the country's total electricity generation.

Current Status:

- **Installed capacity:** 8180 MW as of July 2024
- **Number of reactors:** 24 operating reactors across 7 nuclear power plants
- **Types of reactors:** Primarily pressurized heavy-water reactors (PHWRs), with some light-water reactors (LWRs)

- **Contribution to electricity generation:** Approximately 3% (2022-23)
- **Plans for expansion:** Increase nuclear power capacity to 22,480 MW by 2031, accounting for nearly 9% of the energy mix by 2047.

India's Three-Stage Civil Nuclear Power Programme

India's Three-Stage Nuclear Power Programme, proposed by **Dr. Homi J. Bhabha** in the 1950s, aims to create a self-sustained nuclear power industry.

Stage I: Pressurized Heavy Water Reactors (PHWRs)

- **Fuel:** Utilizes natural uranium, which contains trace amounts of fissile uranium-235.
- **Mechanism:** Heavy water (deuterium oxide) serves as both coolant and moderator, effectively slowing down neutrons to sustain a chain reaction.
- **Byproduct:** Produces plutonium-239 (Pu-239) for further stages.

Stage II: Fast Breeder Reactors (FBRs)

- **Fuel:** Utilizes plutonium-239 as fuel.
- **Mechanism:** Operates on fast neutrons, breeding more plutonium from uranium-238 and producing uranium-233.
- **Implementation:** BHAVINI, a wholly owned GoI undertaking under department of Atomic Energy, has been established for this stage. India's first indigenous Fast Breeder Reactor (500 MWe) at Kalpakkam, Tamil Nadu started core loading of fuel on 4 March,2024.

Stage III: Thorium-Based Reactors

- **Future Goals:** Aims to use thorium-232 as fuel, breeding uranium-233, potentially expanding India's nuclear fuel resources.
  - This is desired goal as India has abundant Thorium reserves along Coastal plains in forms such as Monazite sands etc. (World's highest - about 25% Thorium reserves are in India)

Safety Standards in Nuclear Power Plants

Regulatory Framework:

- Each country with nuclear power plants has a regulatory body responsible for overseeing the safety of nuclear facilities. Example: Independent regulatory bodies like the Atomic Energy Regulatory Board (AERB) in India establish and enforce strict safety standards for nuclear power plants.

International Standards:

- Organizations such as the International Atomic Energy Agency (IAEA) and the World Association of Nuclear Operators (WANO) play crucial roles in developing and promoting international safety standards.
- The IAEA's safety standards provide guidance and recommendations that member states can adopt to enhance the safety of their nuclear facilities.

Resources in India for Nuclear energy

Uranium in India

- India has estimated uranium reserves of around **4,23,222 tonnes,** ranking 15th globally.
- India is the world's **8th largest producer of uranium,** with annual output exceeding 600 tonnes.
- India currently relies heavily on uranium imports, primarily from **Russia, Australia, and Kazakhstan.**

Enriched Uranium

- It is uranium whose concentration of the isotope uranium-235 (U-235) has been increased compared to natural uranium.
- Natural uranium typically consists of approximately **99.3%** of Uranium-238 (U-238) and **0.7%** of Uranium-235 (U-235).

Types of Enriched Uranium

- **Low-Enriched Uranium (LEU):** It refers to uranium with a higher concentration of U-235 than natural uranium but still **below 20%.** It is used as fuel in **commercial nuclear power reactors.**
- **Highly Enriched Uranium (HEU):** It has a U-235 concentration of **over 20%. [UPSC 2023].** It has been historically used in **military applications**, including the production of **nuclear weapons.**

Thorium in India

India has vast reserves of thorium, estimated at over **500,000 tons,** accounting for roughly **25%** of the world's known reserves.

Distribution of Thorium in India

- It is predominantly found associated with minerals like monazite, zircon, and ilmenite.
- **Beach sands** and **placer deposits** along the eastern coast constitute the largest source of thorium.
- Inland deposits, including carbonatite intrusions and pegmatites, contribute to the overall reserves.

[UPSC 2022]

- **Major Thorium Deposits:** Andhra Pradesh (31%),Tamil Nadu (22%),Odisha (20%),Kerala (12%),Gujarat (3%), Bihar (2%).

Potential Benefits of using Thorium

- **Resource abundance:** Thorium is approximately **four times more abundant than uranium** in the Earth's crust, making it a more sustainable long-term fuel source.
- **Fuel breeding:** Although not directly fissile, **thorium-232** can be converted into fissile **uranium-233** through **neutron capture.**

- **Reduced waste:** Thorium-based reactors produce less long-lived radioactive waste compared to uranium reactors.
- **Enhanced safety:** Thorium-based reactor designs can incorporate inherent safety features that make them less susceptible to accidents.

Differences between Thorium and Uranium **[UPSC 2012]**

Aspect	Thorium	Uranium
Abundance	More abundant in the Earth's crust.	Abundant, but isotopes like U-235 require enrichment.
Nuclear Reactor Use	Used in Advanced Heavy Water Reactors (AHWRs) in India's program.	Used in various reactors, including PWRs and BWRs.
Fertile Material	Thorium-232 is fertile, converting into fissile uranium-233.	Uranium-238 is fertile, converting into fissile plutonium-239.
Fuel Cycle	Breeds fissile uranium-233; part of India's Three-Stage Program.	Involves U-235 enrichment; spent fuel contains fission products.
Proliferation Risks	Fewer proliferation risks.	Greater proliferation concerns with traditional fuel cycles.
Waste Products	Expected to produce less long-lived radioactive waste.	Generates long-lived radioactive waste.
Economic Considerations	Economic viability under development.	Established infrastructure for uranium-based energy.
Safety Features	Associated with specific safety features.	Modern reactors have safety features, but some designs pose risks.

INDIA'S NUCLEAR POWER & ENERGY POLICY

Pillars of India's Nuclear Policy

- **No First Use (NFU):** India commits to never initiating a nuclear attack, even if facing conventional aggression.
- **Credible Minimum Deterrence:** Maintains a nuclear arsenal sufficient to deter adversaries from nuclear attacks.
- **Peaceful Use of Nuclear Energy:** Emphasizes using nuclear energy for power generation and medical applications.

India's Nuclear Energy Program

- **Passive Phase (1945-1974):**
  - **1945:** Tata Institute of Fundamental Research (TIFR) established by Homi J. Bhabha.
  - **1948:** Atomic Energy Commission (AEC) established.
  - **1954:** Department of Atomic Energy (DAE) formed.
  - **1969:** Nuclear Power Grid connected to the Tarapur Plant.
  - **1974:** First nuclear test, "Smiling Buddha," leads to international sanctions.
- **Active Phase (1987-Present):**
  - **1987:** Nuclear Power Corporation of India Limited (NPCIL) established.
  - **2022:** 22 operational nuclear reactors with a total capacity of 6,780 MW; 10 reactors under construction with 8,000 MW capacity.

Institutions Involved in Nuclear Energy R & D

- **Department of Atomic Energy (DAE):** Oversees nuclear energy programs, ensuring safety and regulations.
- **Bhabha Atomic Research Centre (BARC):** Premier facility for peaceful nuclear applications and multidisciplinary research.
- **Global Centre for Nuclear Energy Partnership (GCNEP):** Promotes international collaboration through research projects, expert exchanges, and training programs.
- **Atomic Minerals Directorate for Exploration and Research (AMD):** Responsible for exploring and assessing atomic minerals in India.

Command and Control of Nuclear Weapons

- **Nuclear Command Authority (NCA):** Established in 2003 to oversee nuclear weapon operations, comprising the Executive and Political Councils.

- **Strategic Nuclear Command:** Custodian of India's nuclear arsenal, responsible for executing nuclear policy.

Nuclear Energy Agreements

- **Key Agreements:**
  - **United States (2008):** Indo-US Civil Nuclear Agreement for civilian nuclear cooperation.
  - **France (2008):** Covers fuel supply and joint research.
  - **Russia (2009, 2018):** Agreements for plant construction and uranium supply.
  - **Canada (2010), Australia (2014):** Focus on nuclear fuel supply and cooperation in safety.
  - **Kazakhstan (2016):** Uranium supply agreement

International Treaties and Arrangements

- **CTBT:** Aims to ban all nuclear explosions; not ratified by several key countries.
- **IAEA Safeguards:** Ensures peaceful use of nuclear technology and implements NPT agreements.
- **Convention on Nuclear Safety:** The CNS is a legally-binding international treaty under which 80 Contracting Parties commit to maintain a high level of safety at civilian, land-based nuclear power plants by setting international benchmarks to which the Contracting Parties subscribe.
- **Non-Proliferation Treaty:** Multilateral treaty to prevent nuclear weapons proliferation; India did not sign, citing its discriminatory nature.

RADIOACTIVITY BASICS

Radioactive Decay

Radioactive decay is the spontaneous loss of energy from an unstable atomic nucleus, often resulting in radiation. Types include:

- **Alpha Decay:** Emission of an alpha particle (two protons, two neutrons).
- **Beta Decay:** Emission of a beta particle (electron or positron).
- **Gamma Decay:** Emission of a high-energy gamma ray.

Decay Law & Half-Life

The rate of decay is proportional to the number of radioactive nuclei present, with a constant decay probability per unit time. The **half-life** is the time required for half of the atoms in a sample to decay.

Applications of Radiation Technologies

Medical Applications:

- **Diagnostic Imaging:** X-rays for medical imaging.
- **Radiation Therapy:** Using X-rays and gamma rays to treat cancer.
- **Nuclear Medicine:** Radioactive tracers (e.g., technetium-99m) for imaging and diagnosis, including PET scans for metabolic processes.

Industrial Applications:

- **Non-Destructive Testing (NDT):** X-ray and gamma-ray techniques for inspecting materials in aerospace and manufacturing.
- **Food Irradiation:** Extends shelf life and enhances safety by preventing microorganism growth.
- **Sterilization:** Gamma radiation and electron beams sterilize medical equipment and food products.
- **Materials Modification:** Changes properties of materials through ionizing radiation.

Research and Monitoring:

- **Particle Accelerators:** Used for fundamental research, materials science, and isotope production.
- **Radiation Monitoring:** Essential for safety in nuclear facilities and medical settings.

Agricultural Applications:

- **Radiation in Agriculture:** Gamma radiation induces mutations for new crop varieties and pest control.
- **Soil Moisture Measurement:** Neutron probes and gamma-ray techniques assess soil moisture for efficient irrigation.

Space Exploration & Environmental Remediation:

- **Nuclear Propulsion:** Nuclear thermal propulsion and RTGs are being considered for space missions.
  - Radioisotope thermoelectric generators (RTGs) provide electrical power to spacecraft using heat from the natural radioactive decay of plutonium-238, in the form of plutonium oxide.
- **Decontamination:** Techniques like soil washing and phytoremediation use radiation for cleanup efforts..

9 Miscellaneous Topics, Contribution of Indian Scientists and Nobel Prizes

NANOTECHNOLOGY

- **Definition:** Nanotechnology involves the manipulation and engineering of materials at the atomic and molecular scale, typically between **0.1 and 100 nanometers (nm)**. **At this scale, materials exhibit unique physical, chemical, and biological properties** that differ from their bulk counterparts, these properties are governed by quantum physics.

Applications of Nanotechnology:

1. **Health Sector:**
   - **Technologies:** Targeted drug delivery using liposomes, enhanced imaging with gold nanoparticles, and tissue engineering with nanofibers.
   - **Scientific Principles:** Utilizes nanoscale materials for precise interactions at the cellular level, improving treatment efficacy.
2. **Food Industry:**
   - **Technologies:** Nano-encapsulation for flavours, nanosensors for freshness monitoring, and improved food packaging.
   - **Scientific Principles:** Incorporates nanoscale materials to enhance flavour retention, monitor quality, and provide antimicrobial properties.
3. **Electronics:**
   - **Technologies:** Nanoscale transistors, quantum dot displays, and enhanced lithium-ion batteries.
   - **Scientific Principles:** Leverages nanomaterials to create faster, more efficient electronic components, improving performance and miniaturization.
4. **Energy Efficiency:**
   - **Technologies:** Nanocatalysts for fuel cells, nanotech solar cells, and nanomaterial-based insulation.
   - **Scientific Principles:** Enhances energy conversion and storage through improved reactivity and thermal management at the nanoscale.
5. **Textiles:**
   - **Technologies:** Nano-coatings for waterproof fabrics, antimicrobial textiles, and nanosensors in wearable health monitoring.
   - **Scientific Principles:** Uses nanomaterials to impart desirable properties, such as water resistance and bacteria inhibition, enhancing functionality.
6. **Environment:**
   - **Technologies:** ***Graphene filters*** for water purification, nanoparticles for pollutant cleanup, and photocatalytic materials for degradation of contaminants.
   - **Scientific Principles:** Employs nanoscale materials for efficient pollutant removal and environmental monitoring.
7. **Transportation:**
   - **Technologies:** Lightweight ***nanocomposites*** in car frames and nanomaterials in electric vehicle batteries.
   - **Scientific Principles**: Reduces weight and improves energy efficiency in vehicles through advanced material properties.
8. **Space:**
   - **Technologies:** Radiation protection coatings and lightweight nanocomposites for spacecraft.
   - **Scientific Principles**: Enhances structural integrity and reduces weight, improving spacecraft performance.
9. **Nanorobots:**
   - **Definition:** Nanorobots (or nanobots) are engineered machines at the nanoscale (~50–100 nm) designed for specific functions, such as targeted drug delivery.
   - **Scientific Principles:** Utilize principles of nanotechnology to operate at the cellular level, allowing for precise therapeutic interventions.
10. **Magnetic Hyperthermia Mediated Cancer Therapy:**
    - **Process:** Magnetic nanoparticles (iron oxide) are injected into tumor sites and heated using an alternating magnetic field to target and kill cancer cells while minimizing damage to surrounding healthy tissue.

Government Initiatives to Promote Nanotechnology

- **Mission Nano:** Supports basic research and establishes centers of excellence, focusing on acquiring advanced nanotechnology equipment.
- **Program for Nanotechnology:** Managed by the Department of Information Technology to develop nanoelectronics research and infrastructure.

- **Initiative on Nanoscience and Technology (NSTI):** Established by the Department of Science and Technology to focus on nanomaterials applications, including medicine and drug delivery.
- **Nanotechnology and Science Mission (NSTM):** Aims to promote research and development in nanotechnology, emphasizing human resource development and international collaboration.

Project UNNATI

- **Definition:** Project UNNATI is a capacity-building initiative by the Indian Space Research Organization (ISRO) focused on nanosatellite development.
- **Objective**: Enhance skills of participants from developing nations in nanosatellite building, integration, and testing.
- **Background:** Commemorates the 50th anniversary of the UN Conference on Outer Space Exploration and Peaceful Uses **(UNISPACE+50).**
- **Implementation:** Conducted in three batches over three years by ISRO's U.R. Rao Satellite Centre (URSC) for 90 officials from 45 countries.
- **Curriculum:** Includes theoretical and practical training on nanosatellite utility, space debris regulations, design, reliability, quality assurance, and assembly.
- **First Batch:** Began on January 17, 2019, with 30 participants from 17 countries.

MOLECULAR MACHINES

Definition: Molecular machines, or nano machines, are tiny devices at the molecular scale that perform specific **mechanical tasks** when supplied with energy, designed based on molecular biology and chemistry principles.

Core Technology

- Composed of individual molecules or assemblies that can move and change shape in response to stimuli like light, heat, or chemical signals.

Types

- **Molecular Motors:** Convert chemical energy into mechanical motion, akin to biological motors (e.g., ATP synthase).
- **Molecular Switches:** Alter configurations in response to external signals.
- **Molecular Rotors:** Feature rotating components that can move in a controlled manner.

Applications

- **Medicine:** Targeted drug delivery to specific cells or tissues, particularly in cancer treatment.
- **Nanorobotics:** Development of nanorobots for cellular repair and minimally invasive surgeries.
- **Material Science:** Creation of smart materials that adapt their properties based on environmental changes.

Recognition: The **2016 Nobel Prize in Chemistry** was awarded to Jean-Pierre Sauvage, Sir Fraser Stoddart, and Bernard Feringa for their work on molecular machines, highlighting the field's potential.

SUPERCONDUCTIVITY

- **Definition:** Superconductivity is a phenomenon where certain materials exhibit zero **electrical resistance** and expel magnetic fields when cooled below a specific **critical temperature**.
- **Zero Electrical Resistance:** In the superconducting state, materials conduct electric current without any energy loss, resulting in highly efficient electricity transmission.
- **Meissner Effect:** Superconductors expel magnetic fields from their interior, allowing them to repel magnets. This property enables magnetic levitation, which has significant applications in technologies such as maglev trains.
- **Critical Temperature:** Superconductivity occurs only below a specific temperature, known as the critical temperature (Tc). For most traditional superconductors, this temperature is extremely low, close to absolute zero (-273°C).
- **Applications:**
  - **Magnetic Resonance Imaging (MRI):** Superconducting magnets are essential for high-precision imaging in MRI machines.
  - **Maglev Trains:** Superconductors facilitate frictionless, high-speed trains that float above tracks due to the Meissner effect.
  - **Power Grids:** Superconductors are being investigated for efficient power transmission with minimal energy loss over long distances.

OSMOSIS AND REVERSE OSMOSIS

Osmosis

- **Definition:** The **passive movement of water molecules** through a **semipermeable membrane** from an **area of lower solute concentration to higher solute concentration**, aiming to balance concentrations.
- **Mechanism:** Relies on natural osmotic pressure, allowing water to pass while preventing solutes from moving freely.
- **Applications:** Involves water absorption in plants, fluid balance in animal cells, and kidney filtration.

Reverse Osmosis (RO)

- **Definition**: An artificial process that forces water through a semipermeable membrane from an area of high solute concentration to low concentration using external pressure, against the natural flow of osmosis.
  - **Mechanism:** Requires energy to overcome osmotic pressure, blocking solutes and larger particles while allowing only water molecules to pass.

- **Applications:** Commonly used in desalination of seawater, purification of drinking water, industrial wastewater treatment, and home water purification systems.

WATER FILTRATION TECHNOLOGY

1. Reverse Osmosis (RO):
- **Core Technology:** Forces water through a semipermeable membrane under pressure.
- **Science:** Effectively filters out salts, heavy metals, and dissolved solids, making it suitable for desalination and household purifiers.

2. Ultraviolet (UV) Filtration:
- **Core Technology:** Uses UV light to disinfect water.
- **Science:** Disrupts the DNA of bacteria, viruses, and other pathogens, ensuring biologically contaminated water is purified.

3. Carbon Filters:
- **Core Technology:** Utilises activated carbon for adsorption.
- **Science: Adsorbs** organic compounds, chlorine, and harmful chemicals, enhancing taste and odour, commonly employed in home water filtration systems.

4. Carbon Nanotube Filtration:
- **Core Technology:** Employs carbon nanotubes for advanced filtration.
- **Science:** Blocks nanoparticles, bacteria, and viruses while allowing water to pass through, still in the experimental stage with promising applications for efficient filtration.

5. Membrane Bioreactors (MBRs):
- **Core Technology:** Combines biological treatment processes with membrane filtration.
- **Science:** A bioreactor breaks down organic matter, while membranes separate treated water from solids, producing high-quality effluent in wastewater treatment.

6. Microfiltration and Ultrafiltration:
- **Core Technology:** Uses membranes with small pores (0.1 to 0.01 microns).
- **Science:** Removes suspended particles, bacteria, and some viruses, utilised in water treatment plants and household systems to enhance water quality.

7. Ion Exchange:
- **Core Technology:** Utilises resin beads for ion replacement.
- **Science:** Replaces unwanted ions (e.g., calcium and magnesium) with sodium or potassium ions, primarily used in water softening systems.

8. Hydrogel:
- **Core Technology:** Composed of three-dimensional polymer networks.
- **Science:** Retains large amounts of water while capturing heavy metals from industrial wastewater; also used in drug delivery systems and mobile air-conditioning.

9. Distillation:
- **Core Technology:** Involves boiling water and condensing steam back into liquid form.
- **Science:** Leaves impurities behind, effectively purifying water in laboratories and applications where energy use and mineral removal are crucial.

Oilzapper: **[UPSC 2011]**

Oil zapper is a microbial product containing oil-degrading bacteria. It is used for bioremediation to clean up oil spills by breaking down hydrocarbons into non-toxic substances, offering an eco-friendly solution for environmental contamination.

POLLUTION CONTROL TECHNOLOGIES

1. Electrostatic Precipitators (ESP):
- **Core Technology:** Uses electrostatic charges to remove particulate matter from exhaust gases.
- **Science:** Relies on electromagnetism to attract and capture particles.

2. Baghouse Filters:
- **Core Technology:** Employs fabric bags or filters to trap particulate matter.
- **Science:** Utilises mechanical filtration principles to separate solids from gases.

3. Scrubbers:
- **Core Technology:** Uses liquid sprays or gases to remove harmful gases or particulates.
- **Science:** Applies chemical absorption principles to neutralise pollutants.

4. Catalytic Converters:
- **Core Technology:** Converts harmful gases (CO, NOx) into less harmful emissions (CO_2, N_2, H_2O) using a catalyst.
- **Science:** Accelerates chemical reactions without consuming the catalyst.

5. Flue Gas Desulfurization (FGD):
- **Core Technology:** Removes sulphur dioxide (SO_2) from exhaust gases using chemical absorbers like lime or limestone.
- **Science:** Involves acid-base neutralisation reactions.

6. Biofilters:
- **Core Technology:** Uses microorganisms to decompose pollutants, such as Volatile Organic Compounds (VOCs).
- **Science:** Demonstrates the application of microbiological processes in air treatment.

7. **Cyclone Separators:**
   - **Core Technology:** Separates particles from gases using centrifugal force.
   - **Science:** Utilises fluid dynamics to achieve separation based on density differences.
8. **Activated Carbon Filters:**
   - **Core Technology:** Adsorbs pollutants like VOCs and heavy metals onto activated carbon.
   - **Science:** Utilises adsorption principles involving the chemical affinity of pollutants to carbon surfaces.
9. **Wet Scrubbers:**
   - **Core Technology:** Captures gaseous pollutants by passing them through a liquid medium (water or chemicals).
   - **Science:** It is particularly effective in controlling sulfur dioxide (SO_2), hydrogen chloride (HCl), ammonia (NH_3), and other acid gases, as well as dust particles and volatile organic compounds (VOCs).
10. **Oxidation Ponds and Lagoons:**
   - **Core Technology:** Uses microbial processes to degrade pollutants in wastewater.
   - **Science:** Employs natural biological treatment methods based on microorganism metabolism.
11. **Plasma Arc Technology:**
   - **Core Technology:** Uses high-energy plasma to break down hazardous waste and pollutants.
   - **Science:** Relies on thermal decomposition and ionisation processes to convert waste into less harmful components.
12. **Anaerobic Digesters:**
   - **Core Technology:** Bioreactors that decompose organic waste in the absence of oxygen, producing biogas.
   - **Science:** Utilises anaerobic bacteria for biochemical breakdown of organic materials.
13. **Membrane Filtration:**
   - **Core Technology:** Removes contaminants using microfiltration, ultrafiltration, or reverse osmosis.
   - **Science:** Employs pressure-driven processes to separate particles based on size.
14. **Incineration:**
   - **Core Technology:** Burns hazardous waste at high temperatures to reduce volume and destroy toxins.
   - **Science:** Involves combustion processes that convert waste into ash, gases, and heat.
15. **Photocatalytic Oxidation:**
   - **Core Technology:** Uses UV light and catalysts to degrade air pollutants such as VOCs and odours.
   - **Science:** Facilitates photochemical reactions that break down pollutants into harmless byproducts.

TECHNOLOGY IN TRANSPORTATION

1. **Maglev (Magnetic Levitation):**
   - **Core Technology:** Uses electromagnetic forces for lift and propulsion.
   - **Physics Involved:** Electromagnetism enables trains to float above tracks, minimizing friction, leading to higher speeds and reduced wear on components.
2. **Hyperloop:**
   - **Core Technology:** High-speed transportation in low-pressure tubes with passenger pods using magnetic levitation and air propulsion.
   - **Physics Involved:** Vacuum environment reduces air resistance, and magnetic levitation reduces friction, allowing for extremely high speeds.
3. **Electric Vehicles (EVs):**
   - **Core Technology:** Powered by electric batteries that store and convert chemical energy into electrical energy.
   - **Chemistry Involved:** Rechargeable lithium-ion batteries rely on electrochemical reactions to store and release energy efficiently.
4. **Autonomous Vehicles:**
   - **Core Technology:** Utilises advanced sensors, cameras, and artificial intelligence for navigation.
   - **Physics Involved:** LiDAR and RADAR technologies operate based on the principles of light and sound waves to map surroundings and detect obstacles.
5. **Drones:**
   - **Core Technology:** Unmanned aerial vehicles (UAVs) for transportation and delivery.
   - **Physics Involved:** Aerodynamics principles govern flight stability and control; propulsion is achieved through electric motors and propellers.
6. **Smart Traffic Management Systems:**
   - **Core Technology:** Employs real-time data from sensors and GPS for traffic optimization.
   - **Physics Involved:** Data analysis involves statistical mechanics and dynamics to predict and manage traffic flow efficiently.
7. **Connected Vehicle Technology:**
   - **Core Technology:** Vehicles equipped with communication technologies for data exchange.
   - **Physics and Chemistry Involved:** Uses radio frequency communication and networking principles to enhance vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) interactions.

INTELLECTUAL PROPERTY RIGHTS

Intellectual Property Rights (IPRs) refer to the exclusive rights granted to owners over their **inventions, designs, literary, artistic works, and trade symbols**. These rights allow owners to control the use of their intellectual property for a limited period.

Categories of Intellectual Property Rights

- **Copyrights:** Protects original literary, artistic, and musical works. In India, the Copyright Act grants exclusive rights to creators.
- **Trademarks:** Distinguishes goods or services using symbols, names, and logos. Governed by the **Trademarks Act of 1999**, which aligns India's trademark laws with international standards.
- **Patents:** Protects inventions, granting exclusive rights for up to 20 years. The **Indian Patents Act, 1970**, amended in 2005, prevents **"evergreening"** of patents and ensures compliance with TRIPS.
- **Industrial Design:** Protects the aesthetic aspects of mass-produced objects. Governed by the **Designs Act** in India.
- **Trade Secrets:** Protects confidential business information. Though India lacks a specific statute, trade secrets are protected under common law.
- **Geographical Indications (GI):** Identifies products from a specific region with a unique reputation, governed by the **Geographical Indications of Goods (Registration and Protection) Act, 1999**.
- **Plant Varieties Protection:** Protects new plant varieties under the **Protection of Plant Varieties and Farmers' Rights Act (PPV&FR), 2001**. It also balances breeders' rights with farmers' rights to save and use seeds.

International Conventions Related to IPR

- **TRIPS Agreement:** Administered by WTO, TRIPS sets minimum standards for IPR protection, including GIs, patents, and compulsory licensing.
- **Lisbon Agreement:** Administered by WIPO, this agreement facilitates the international protection of appellations of origin.
- **Berne Convention:** Ensures international **copyright** protection without formalities.
- **Paris Convention:** Provides a framework for the protection of **industrial property**, including inventions and trademarks.
- **WIPO Copyright Treaty (WCT):** Extends copyright protection to the digital environment.
- **Patent Cooperation Treaty (PCT):** Simplifies the international patent filing process by recognizing a single patent application in multiple countries.

THE CONTRIBUTIONS OF INDIAN SCIENTISTS

Indian scientists have made remarkable contributions across various fields, significantly advancing **global knowledge and innovation.** Their pioneering work, ranging from mathematics and physics to biology and space technology, has not only enhanced **scientific understanding** but also played a crucial role in **societal development and technological progress,** both within India and internationally.

1. Srinivasa Ramanujan Aiyangar (1887–1920)

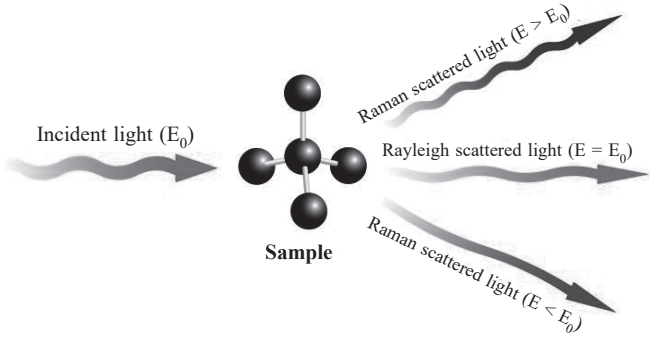
- **Field:** Mathematics
- **Contributions:**
  - Ramanujan is celebrated for his pioneering contributions in the fields of **mathematical analysis, number theory, and infinite series.**
  - Despite lacking formal training, his intuition and originality led him to derive over 3,000 mathematical results, including properties of highly composite numbers, the **Ramanujan prime, the Ramanujan theta function, and partition formulae.**
  - In 1911, he published in the same journal a brilliant research paper on **Bernoulli** numbers. This got him recognition, and he became well known as a mathematical genius.

2. Chandrasekhara Venkata Raman (1888–1971)

- **Field:** Physics
- **Contributions:** He is best known for his work on the **scattering of light** and the discovery of the **Raman effect,** which is the change in the wavelength of light that occurs when a light beam is deflected by molecules.

Raman Effect

When light hits a molecule, most of it just bounces back in the same way (this is called **elastic scattering**). But a small part of the light gets scattered in a different direction, with its energy slightly changed. This happens because the light interacts with the vibrations of the molecules in the substance, and that changes the color (or wavelength) of the light.



Rayleigh scattering is elastic, meaning that the scattered light has the same energy and wavelength as the incident light, while **Raman scattering** is inelastic, meaning that the scattered light has a different energy and wavelength than the incident light.

This change in light's energy is what we call the **Raman Effect**. It's used in various scientific fields, like studying the composition of materials **(Raman Spectroscopy)**.

3. Jagdish Chandra Bose (1858–1937)

- **Field:** Physics, Biophysics, and Botany
- **Contributions:**
  - In recognition of his work on **"The Electromagnetic Radiation and Polarisation of Electric Rays,"** he was knighted in 1917 and became a Fellow of the Royal Society of London in 1920. This distinguished him as the first Indian physicist to achieve this honour in the field of physics.
  - Bose is credited with making significant contributions to the field of **radio and microwave optics.** He pioneered the investigation of **radio and microwave optics,** and he significantly contributed to plant science by experimenting with plant stimuli.

4. Homi Jahangir Bhabha (1909–1966)

- **Field:** Nuclear Physics
- **Contributions:** Bhabha is known as the **father of the Indian nuclear programme.** He was the founding director of the **Tata Institute of Fundamental Research and the Trombay Atomic Energy Establishment (now Bhabha Atomic Research Centre).**

5. Vikram Ambalal Sarabhai (1919–1971)

- **Field:** Space Science
- **Contributions:**
  - Dr. Vikram Ambalal Sarabhai, a prominent figure in modern India, was the founder of the Indian Space Research Organisation (ISRO), and he also spearheaded the launch of India's inaugural satellite, Aryabhatta.
  - Under the **mentorship of Dr. C.V. Raman**, he delved into the study of **cosmic rays,** culminating in a Ph.D. from Cambridge University. His **research on cosmic rays** revealed their origin as energetic particles from outer space, undergoing alterations influenced by the sun, the Earth's atmosphere, and magnetic forces during their journey to Earth.

6. Satyendra Nath Bose (1894–1974)

- **Field:** Physics.
- **Contributions:**
  - He was a renowned **Indian physicist** known for his work in **quantum mechanics** in the early 1920s. His most significant contribution was the development of **Bose-Einstein statistics** and the theory of the **Bose-Einstein condensate,** a state of matter for a **dilute gas of bosons** cooled to temperatures very close to **absolute zero.**
  - This work laid the foundation for the discovery of the Bose-Einstein condensate phenomenon, a pivotal concept in **quantum physics.** Bose's collaboration with Albert Einstein led to the development of Bose-Einstein statistics, which describe the statistical distribution of identical particles with integer spin, known as bosons, named in his honour.

Bose-Einstein Condensate (BEC)

Bose-Einstein Condensate (BEC) is a unique state of matter that forms when a group of atoms is cooled to temperatures near absolute zero (0 Kelvin or -273.15°C). At such extremely low temperatures, the atoms slow down so much that they begin to behave as a single quantum entity rather than as individual particles. In this state, particles, specifically bosons, occupy the same quantum state, essentially merging into one "super-atom."

BEC is known as 5th state of matter.

- **Near Absolute Zero:** Atoms are cooled to almost no motion.
- **Bosons:** Particles that can share quantum states.
- **Quantum Behavior:** Atoms behave as one large quantum entity.

Bose-Einstein Statistics

Bose-Einstein statistics describe the behavior of **bosons**—particles that can occupy the same quantum state without exclusion, unlike fermions (which follow the Pauli Exclusion Principle). These statistics explain how groups of indistinguishable particles (bosons) distribute themselves among various energy levels, particularly at very low temperatures.

- A key result is that, at extremely low temperatures, bosons tend to cluster in the same energy state, leading to phenomena like the **Bose-Einstein Condensate**. This statistical model was developed by **Satyendra Nath Bose** and further expanded by **Albert Einstein**.

7. Subrahmanyan Chandrasekhar (1910–1995)

- **Field:** Astrophysics
- **Contributions:** Subrahmanyan Chandrasekhar was a distinguished astrophysicist whose contributions significantly advanced the understanding of **stellar evolution.** He is best known for his theoretical work on the physical processes important to the structure and evolution of stars, including his formulation of the **Chandrasekhar limit.** For his profound contributions to the field of astrophysics, **Chandrasekhar was awarded the Nobel Prize in Physics in 1983,** sharing it with William A. Fowler.

Chandrasekhar Limit

The **Chandrasekhar limit** is the maximum mass a white dwarf star can have, about **1.4 times the mass of the Sun**. If a white dwarf's mass exceeds this limit, it cannot support itself through electron degeneracy pressure, and it collapses

into a **neutron star** or a **black hole**. This concept is crucial in determining the fate of dying stars.

8. Har Gobind Khorana (1922–2011)

- **Field:** Biochemistry
- **Contributions:**
  - Har Gobind Khorana was a **Nobel Prize-winning biochemist** of Indian origin, celebrated for his groundbreaking research in **genetics.**
  - His most notable contribution was elucidating the role of **nucleotides** in protein synthesis, which was pivotal in understanding how genetic information is translated into proteins. Khorana's work on the synthesis of **oligonucleotides,** compounds that form the structure of DNA, was instrumental in the development of biotechnology.
  - For his significant contributions to the field of molecular biology, he was awarded the **Nobel Prize in Physiology or Medicine in 1968,** alongside Robert W. Holley and Marshall W. Nirenberg.

Oligonucleotides

Oligonucleotides are short sequences of nucleotides (the building blocks of DNA and RNA). Typically, they consist of about 20 to 25 nucleotides and are used in various biological and medical applications, such as genetic testing, research, and therapies.

They can be synthesised in the lab and used as primers in **PCR (Polymerase Chain Reaction)**, probes in **gene sequencing**, or even as therapeutic agents in **gene editing** technologies like CRISPR.

- **Short DNA/RNA sequences:** About 20-25 nucleotides long.
- **Applications:** Used in diagnostics, gene synthesis, and therapies.

9. M. Visvesvaraya (1861–1962)

- **Field:** Civil Engineering
- **Contributions:**
  - M. Visvesvaraya was an eminent Indian engineer and statesman, widely regarded for his contributions in the fields of **civil engineering** and public works.
  - His most notable work includes the **design and construction of the Krishna Raj Sagara Dam on Kaveri river in Mysore,** which played a pivotal role in transforming the region's irrigation system and agriculture.

10. Tessy Thomas (1963)

- **Field:** Missile Technology
- **Contributions:**
  - She is often referred to as the **"Missile Woman of India"** and has made significant contributions to India's defence research and development.
  - She is the first woman scientist to head a missile project in India, notably the **Agni-IV** missile project, a **long-range nuclear-capable missile.**

11. Shanti Swaroop Bhatnagar (1894–1955)

- **Field:** Chemistry
- **Contributions:**
  - Shanti Swaroop Bhatnagar was a renowned Indian scientist and a pioneer in the field of **chemical research in India.**
  - He is best known for his significant contributions to **industrial chemistry and for establishing the Council of Scientific and Industrial Research (CSIR)** in India, serving as its first Director-General. Bhatnagar's work in the realm of chemical sciences led to the discovery of the **Bhatnagar-Mathur Magnetic Interference Balance,** a key instrument in scientific research.

Bhatnagar-Mathur Magnetic Interference Balance

The **Bhatnagar-Mathur Magnetic Interference Balance** is an experimental apparatus used to measure small magnetic fields, particularly in the context of magnetic susceptibility and related properties of materials. This device is based on the principles of electromagnetic induction and magnetic interaction.

- **Principle of Operation:** It operates on the principle that a magnetic field can exert a force on a current-carrying conductor. By using a balance, it can measure the force produced by the magnetic field on the sample.
- **Components:** The setup typically includes:
  - **Coils:** To generate magnetic fields.
  - **Balance:** To measure the force acting on the sample.
  - **Sample Holder:** Where the material whose magnetic properties are being measured is placed.
- **Applications:** This apparatus is commonly used in material science, physics, and engineering to study the magnetic properties of various substances, including ferromagnetic, paramagnetic, and diamagnetic materials.
  - Ferromagnetism, paramagnetism, and diamagnetism describe different magnetic behaviors. Ferromagnetic materials like iron, nickel, and cobalt exhibit strong magnetic alignment and retain permanent magnetism. Paramagnetic materials such as aluminum, platinum, and liquid oxygen align weakly with external magnetic fields due to unpaired electrons but lose magnetism when the field is removed. Diamagnetic materials like copper, gold, and water generate a weak opposing field when exposed to a magnetic field and are repelled by it. Only ferromagnetic materials can develop permanent magnetism.

12. Salim Ali (1896–1987)

- **Field:** Ornithology

- **Contributions:** Salim Ali, popularly known as the **"Birdman of India,"** was a pioneering Indian **ornithologist and naturalist.** He is best known for his systematic survey of the birds of India and several bird books, including the highly influential **"The Book of Indian Birds."**

13. M. S. Swaminathan (1925)

- **Field:** Agriculture
- **Contributions:**
  - He is a renowned **Indian geneticist** and **international administrator,** celebrated for his leading role in **India's Green Revolution,** a movement that transformed agriculture in India and helped alleviate hunger and poverty in the 1960s and 1970s.
  - His development and promotion of **high-yielding varieties** of wheat and rice significantly increased food production in India, making the country self-sufficient in cereals and preventing widespread famine.
  - The Green Revolution in India, championed by M. S. Swaminathan, introduced high-yielding variety (HYV) seeds to boost food grain production, particularly wheat and rice. HYV wheat seeds were sourced from Mexico, developed by Norman Borlaug, while rice seeds (e.g., IR-8) came from the International Rice Research Institute (IRRI) in the Philippines.
  - These semi-dwarf varieties were bred using plant breeding and genetic modification techniques, making them resistant to lodging and highly responsive to fertilizers and irrigation. The adoption of modern pesticides and irrigation systems further enhanced productivity.

14. Meghnad Saha (1893–1956)

- **Field:** Physics, Astrophysics
- **Contributions:**
  - Meghnad Saha was an eminent **Indian astrophysicist** best known for his development of the **Saha Equation,** a fundamental formula in astrophysics that describes the **physical and chemical conditions** of stars.
  - This equation, crucial in the study of stellar atmospheres, helps in determining the temperature and ionization state of various elements in stars.

Saha Equation

The **Saha Equation** is a mathematical formula used in astrophysics to describe the ionization equilibrium of gases in stars. It relates the ionization states of atoms to the temperature and pressure of the gas.

- **Ionization:** The process by which an atom loses or gains electrons to become an ion.
- **Applications:** Helps in understanding the spectral lines of stars, predicting the population of ionized atoms, and analyzing stellar atmospheres.
- **Formula:** The equation expresses the ratio of the number of ions to neutral atoms in a gas as a function of temperature and electron pressure.

15. Prasanta Chandra Mahalanobis (1893–1972)

- **Field:** Statistics
- **Contributions:**
  - He was a renowned **Indian statistician and scientist,** best known for his pioneering work in statistics. He is credited with the development of the **Mahalanobis distance,** a statistical measure used to analyze the divergence between different data sets.
  - Mahalanobis also played a key role in the formulation of **India's second five-year plan,** which focused on industrialization and economic development.

16. Dr. Dilip Mahalanabis (1934-2022)

- **Field:** Medication
- **Contributions:** He invented the Oral Rehydration Solution (ORS) while working in refugee camps during the 1971 Bangladesh Liberation war. The Lancet called ORS "the most important medical discovery of the 20th century".

17. Upendranath Brahmachari (1873-1946)

- **Field:** Physiology or medicine
- **Contributions:** He synthesized **urea-stibamine** in 1922 and determined that it was an effective treatment for **kala-azar.**

18. Narinder Singh Kapany (1926-2020)

- **Field:** Physics
- **Contributions:** He was an Indian-American physicist best known for his work on fiber optics. Kapany is a pioneer in the field of fiber optics, and known for coining and popularizing the term.

NOBEL PRIZES

The Nobel Prize in Physics 2022

- **Nobel laureates:** Alain Aspect, John F. Clauser, and Anton Zeilinger
- For experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science
- **Entangled photons:** Entangled photons are pairs of photons that are generated in such a way that the state of one photon is intrinsically linked to the state of the other, regardless of the distance between them. This phenomenon arises from the principles of quantum mechanics.
- **Quantum Entanglement:** When two photons are entangled, measuring a property (like polarization) of one photon instantly determines the corresponding property of the other photon.
- Entangled photons are essential in quantum communication, quantum cryptography, and quantum computing, as they enable secure information transfer and the exploration of quantum states.

Bell inequalities are mathematical inequalities that serve as tests to determine whether a set of measurements can be explained by classical physics (local realism) or if they exhibit quantum entanglement. Proposed by physicist **John Bell** in 1964, these inequalities provide a way to test the predictions of quantum mechanics against those of classical physics.

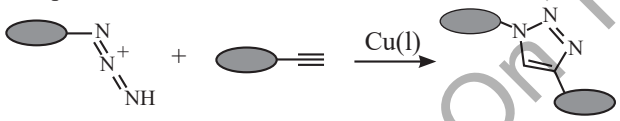
- **Local Realism:** The belief that physical properties exist prior to measurement and that information cannot travel faster than light.
- **Violation of Bell Inequalities:** Experiments that violate Bell inequalities indicate the presence of quantum entanglement and suggest that local realism cannot fully explain the behavior of entangled particles.
- Bell inequalities are fundamental in quantum physics, underpinning many experiments that demonstrate the non-classical nature of reality.

The Nobel Prize in Chemistry 2022

- **Nobel laureates:** Carolyn R. Bertozzi, Morten Meldal, and K. Barry Sharpless
- "For the development of click chemistry and bioorthogonal chemistry"

Click Chemistry

- A class of reactions that are highly efficient, selective, and result in the formation of stable products. The most famous example is the **azide-alkyne cycloaddition**, which is used to join molecules quickly and reliably.
- Used in drug discovery, materials science, and bioconjugation, allowing for the rapid assembly of complex molecules.



azide alkyne triazole

Bioorthogonal Chemistry:

- A subset of click chemistry that describes reactions that can occur inside living organisms without interfering with native biochemical processes. These reactions are designed to be biocompatible and selective.
- Widely used in labeling biomolecules, tracking cellular processes, and developing targeted therapies in living systems.

The Nobel Prize in Physiology or Medicine 2022

- **Nobel laureates:** Svante Paabo
- For his discoveries concerning the genomes of extinct hominins and human evolution.

The Nobel Prize in Physics 2023

- **Nobel laureates:** Pierre Agostini, Ferenc Krausz, and Anne L'Huillier
- "For experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter"

Attosecond Pulse Generation

Attosecond pulse generation refers to techniques that produce extremely short bursts of light (in the order of attoseconds, 10^{-18}) seconds to study the fast dynamics of electrons in atoms and molecules.

The Nobel Prize in Chemistry 2023

- **Nobel laureates: Moungi G. Bawendi,Louis E.** Brus, and **Aleksey Yekimov**
- For the discovery and synthesis of quantum dots

Quantum dots are nanoscale semiconductor particles that exhibit unique optical and electronic properties due to quantum confinement effects. Their synthesis involves various methods to produce these tiny crystals with precise control over their size, shape, and composition.

- **Synthesis Methods:** Common approaches include:
  - **Colloidal Synthesis:** Involves chemical reactions in solution to produce uniform quantum dots.
  - **Epitaxial Growth:** A technique where quantum dots are grown on a substrate layer by layer, often used in electronic applications.
  - **Lithography:** Utilizes patterned surfaces to create quantum dots with specific geometries.
- Quantum dots are used in displays, solar cells, biological imaging, and quantum computing due to their size-tunable emission spectra and high stability.

The Nobel Prize in Physiology or Medicine 2023

- **Nobel laureates:** Katalin Karikó, Drew Weissman
- For their discoveries concerning nucleoside base modifications that enabled the development of effective mRNA vaccines against COVID-19.

Indian Nobel Prize Winners

Name	Year	Category	Field of Contribution
C. V. Raman	1930	Physics	Raman Effect in light scattering.
Har Gobind Khorana	1968	Physiology or Medicine	Work on the genetic code and protein synthesis.
S. Chandrasekhar	1983	Physics	Research on the structure and evolution of stars.
Venkatraman Ramakrishnan	2009	Chemistry	Studies of the structure and function of the ribosome.

Note: This table only mentions Indian Nobel Laureates in the field of Science and Technology.

Other Indian Nobel Laureates include: **Rabindranath Tagore, Mother Teresa, Amartya Sen and Kailash Satyarthi.**

ONLYIAS BY PHYSICS WALLAH

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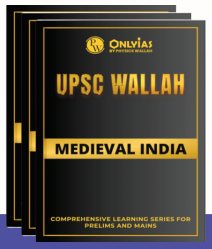

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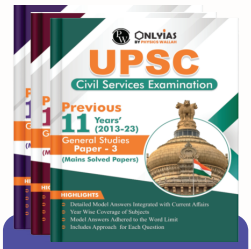

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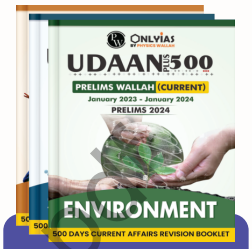

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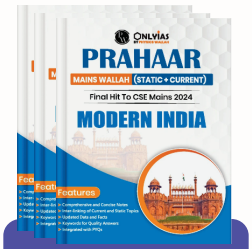

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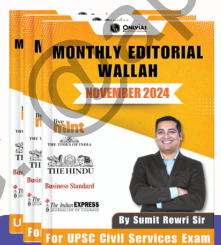

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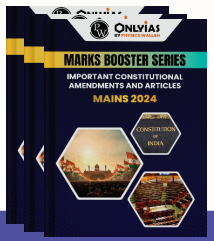

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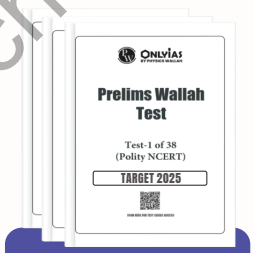

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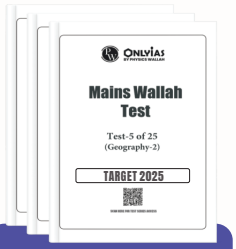

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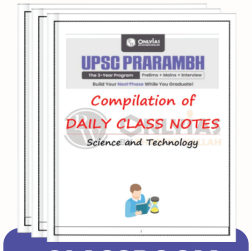

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