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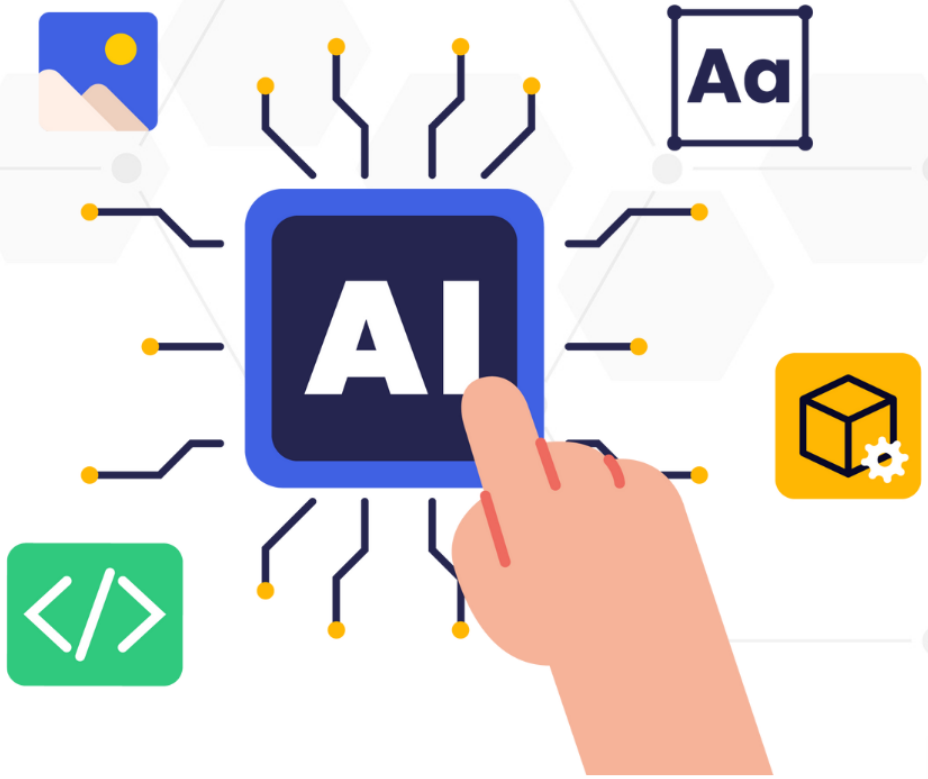
UPSC CSE - 2025

CURRENT AFFAIRS



SCIENCE AND TECHNOLOGY

SCIENCE AND TECHNOLOGY

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SCIENCE AND TECHNOLOGY

CURRENT AFFAIRS

DEEPFAKES

Context:

The **United States** has recently enacted the **"Take It Down Act"** to address the growing threat posed by harmful deepfakes online.

What are Deepfakes?

- **Definition:**
  Deepfakes are **AI-generated synthetic media** (videos, images, or audio) that appear real but are **digitally altered**, often to **deceive viewers**.
- **Technology Used:**
  - Utilizes **deep learning** (a subset of **machine learning**, under **artificial intelligence**) to:
    - Replace faces
    - Alter facial expressions and body movements
    - Synthesize voices
    - Imitate speech in other languages
- **Positive Applications:**
  - **Entertainment:** Visual effects in cinema
  - **E-commerce:** Virtual try-ons using likenesses
  - **Communication:** Multilingual speech synthesis
  - **Education & Accessibility:** Content localization

Concerns Associated with Deepfakes:

1. **National Security:** Potential to **incite violence**, **disrupt investigations**, or **forge false evidence**.
2. **Democratic Integrity:** Spread of **fake political messages** can **mislead the electorate** and **manipulate public opinion**.
3. **Gendered Harassment:** Studies show **90–95%** of deepfakes are **non-consensual pornographic content**, mostly targeting women.
4. **Cyberbullying & Identity Theft:**
   - Can cause **reputation damage**.
   - Used to **create fake IDs**, gain unauthorized access.
5. **Information Disorder:**
   - Erosion of **trust in digital content**.
   - Once misinformation spreads, it's **hard to contain**, even if exposed.

6. **Detection Challenges:**
    - **Video detection** is **computationally more expensive** than images.
    - Requires advanced infrastructure.

Legal and Institutional Response in India:

Legal Measures:

- **IT Act, 2000:** Covers **cybercrime and data misuse**.
- **IT Rules, 2021:**
    - Targets **online harm**, provides for **Grievance Appellate Committees**.
    - Encourages platforms to remove harmful content quickly.

Institutional Framework:

- **CERT-In (Indian Computer Emergency Response Team):**
    - Released advisory on deepfakes.
    - Operates **Cyber Swachhta Kendra** and **CSIRT-Fin** (for financial sector).
- **I4C (Indian Cyber Crime Coordination Centre):** Coordinates national response to cybercrime.
- **National Cyber Crime Reporting Portal:**
    - **Helpline 1930** launched for prompt complaint redressal.

Global Regulatory Trends:

- **EU:**
    - Adopted the **AI Act** to regulate **high-risk AI** use-cases, including deepfakes.
- **USA:**
    - As of September 2024, **23 states** enacted **anti-deepfake laws**.
    - The **"Take It Down Act"** aims to **protect individuals** from malicious deepfake content.
- **Italy:**
    - Constitution and Civil Code **prohibit unauthorized use of personal likeness**.

UPSC Mains Model Questions

Q **"Deepfake technology, though innovative, poses a grave threat to trust, democracy, and individual rights." Critically examine this statement in the context of India's preparedness to tackle deepfake-related challenges.**

Q Discuss the technological, ethical, and legal implications of deepfakes. Evaluate whether existing legal and institutional frameworks in India are sufficient to deal with emerging AI threats.

GENE EDITING

Context:

A U.S.-based research team has successfully developed and delivered a **personalized gene-editing therapy** to treat an infant suffering from a rare **genetic metabolic disorder – CPS1 deficiency** – using the **CRISPR platform**.

About CPS1 Deficiency:

- **CPS1 (Carbamoyl Phosphate Synthetase 1) Deficiency**
  - A **rare genetic liver disorder** affecting the breakdown of **ammonia** (a byproduct of protein metabolism).
  - Results in **toxic accumulation of ammonia**, causing potential **brain and liver damage**.
  - Traditionally managed through a **low-protein diet** and eventual **liver transplant**.
- The new **gene-editing therapy corrected** the defective gene in **liver cells**, demonstrating **precision medicine in action**.

What is Gene Editing?

- Gene editing involves **modifying the DNA** by **inserting, deleting, or replacing** genetic material at specific locations in the genome.
- Utilizes engineered enzymes to perform precise modifications.

Types of Gene Editing:

Type	Description	Target Cells	Heritability
Somatic Genome Editing	Alters non-reproductive (body) cells	Skin, liver, muscle, kidney	**Not heritable**
Germline Genome Editing	Alters reproductive cells or embryos	Eggs, sperm, embryos	**Heritable**

Major Gene Editing Techniques:

Technique	Components	Function	Key Features
ZFNs (Zinc Finger Nucleases)	Zinc finger proteins + FokI enzyme	Cuts specific DNA regions	First genome editing tool; complex and costly

TALENs	TALE proteins + FokI enzyme	Cuts specific DNA regions	Easier and more accurate than ZFNs
CRISPR-Cas9	Guide RNA + Cas9 enzyme	Cuts DNA at desired sites	Fast, cheap, precise; derived from bacterial immune system

Challenges Associated with Gene Editing:

Ethical Concerns:

- **Embryo Research Ethics:** Concerns about **moral status of embryos**, especially in germline editing.
- **Informed Consent:** Future generations **cannot consent** to genetic changes that affect them.
- **Justice & Equity:** Risk of creating **healthcare inequality**; rich may access "designer" genetic traits.

Safety Concerns:

- **Off-target effects:** Edits may accidentally affect **unintended DNA sites**.
- **Mosaicism:** Uneven editing where only some cells are corrected.
- **Global regulatory gaps:** May lead to **controversial uses** like **designer babies**.

India and Gene Editing: Regulatory Status:

- No dedicated law currently, but governed under:
    - **Environment Protection Act, 1986** – for GMOs and biosafety.
    - **ICMR Guidelines** – for biomedical and health research.
    - **Review Committee on Genetic Manipulation (RCGM)** under DBT – regulates gene editing research.

UPSC Mains Model Questions

Q "Gene editing holds the promise of eliminating genetic disorders, but it is fraught with ethical and regulatory dilemmas." Critically examine in the context of CRISPR technology.

Q Compare and contrast somatic and germline genome editing. Do you think India needs a dedicated law for regulating genome editing technologies?

WORLD HEALTH ASSEMBLY (WHA) – FIRST PANDEMIC AGREEMENT

Context:

- The **World Health Assembly (WHA)** has adopted the **world's first international pandemic agreement** under **Article 19 of the WHO Constitution**.
- This is only the **second agreement** under Article 19, the first being the **Framework Convention on Tobacco Control (2003)**.

Legal Basis: Article 19 of WHO Constitution

- Empowers WHA to adopt conventions/agreements on matters within WHO's competence, through a **two-thirds majority vote.**

Key Highlights of the Pandemic Agreement:

1. Pandemic Preparedness and Surveillance

- Reinforces obligations under the **International Health Regulations (IHR), 2005**, aimed at **early detection, prevention, and control** of disease outbreaks.

2. Global Supply Chain & Logistics Network

- Establishment of a **global platform** for timely access to **vaccines, diagnostics, PPEs, and therapeutics** during global health emergencies.

3. Sustainable Financing

- Creation of a **Coordinating Financial Mechanism** under IHR to support **implementation and capacity-building**, especially in developing countries.

4. Pathogen Access and Benefit Sharing (PABS) System

- Under negotiation by an **Intergovernmental Working Group (IGWG)**, to be finalized at next WHA.
- Ensures:
    - Rapid and **transparent sharing of genetic sequence data** and pathogen samples.
    - In return, **pharma companies to provide WHO with 20% of real-time production** of pandemic-related health tools.

5. Enforcement and Implementation

- The agreement will open for **signature and ratification.**
- **Comes into force** after **60 countries ratify** the document.

Significance of the Agreement:

- A step towards **global health equity** and **solidarity** post-COVID-19.
- Aims to **balance public health interests** with **commercial and sovereign interests** in times of global health emergencies.

Challenges Ahead:

- **Global consensus** on data sharing and benefit distribution.
- Concerns of **vaccine nationalism**, **intellectual property rights**, and **technology transfer**.
- Implementation depends on **political will**, **trust-building**, and **capacity development** in low- and middle-income countries.

UPSC Mains Model Questions

Q "The COVID-19 pandemic exposed systemic flaws in global health governance." Examine how the WHO's first Pandemic Agreement attempts to address these gaps.

Q Discuss the significance of the Pathogen Access and Benefit Sharing (PABS) system under the WHO's pandemic agreement. How can India safeguard its interests while participating in global data-sharing mechanisms?

SATELLITE INTERNET SERVICES

Context:

- Indian telecom companies **Airtel and Jio** have signed a deal with **SpaceX** to bring **Starlink's satellite internet services** to India.

What is Satellite Internet?

- **Definition**: A **wireless internet connection** delivered via communication satellites in orbit.
- Unlike traditional **land-based broadband** (fiber, DSL, cable), it does **not require physical infrastructure** like wires.

Architecture of Satellite Internet Systems:

1. **Space Segment**:
    - Constellation of satellites (often **LEO – Low Earth Orbit**).
    - Responsible for **signal transmission and coverage**.
2. **Ground Segment**:
    - Includes **gateway stations, measurement and control systems**.
    - Acts as a **bridge** between satellites and terrestrial networks.

3. **User Segment**:
    - Communication terminals such as **user dishes, routers, modems**.

Major Satellite Internet Projects Globally:

Project	Country	Details
Starlink	USA (SpaceX)	Aims for ~42,000 satellites in LEO
Project Kuiper	USA (Amazon)	Plans to launch 3,200+ LEO satellites
OneWeb	France/UK	2nd-largest LEO constellation
Qianfan Constellation	China	Backed by govt. and Chinese Academy of Sciences

Significance for India:

- **Bridging Digital Divide**: Critical for rural and remote areas where **fiber rollout is unviable**.
- **Disaster Connectivity**: Ensures access in emergencies, moving vehicles, construction sites, etc.
- **Support to Digital Economy**: Enables **e-commerce, e-learning, digital banking**, etc.
- **Strategic Autonomy**: Less susceptible to **cable sabotage or geopolitical disruptions**.
- **Military Application**: Proven use in conflicts (e.g., **Ukraine war** with Starlink support).

Challenges:

1. **Internal Security Risks**:
    - Satellite phones/internet could be misused by **terror outfits** (e.g., recent Pahalgam attack suspicion).
2. **Digital Sovereignty & Privacy**:
    - Cross-border services raise questions about **data storage, access rights, and ownership**.
3. **Regulatory Vacuum**:
    - Global services from private entities may **bypass national regulatory control**.
4. **Monopoly Risks**:
    - Dominance of players like **SpaceX** could lead to **pricing and access issues**.

5. **Latency & Quality**:
    - Generally higher latency than fiber, though **LEO satellites reduce delay (25–50ms)**.
6. **Environmental & Atmospheric Impact**:
    - **Alumina** released during satellite burn-up may cause **ozone depletion**.
7. **Spectrum & Licensing Hurdles**:
    - Negotiations around **VSAT licenses**, and **Ku/Ka-band spectrum pricing** still underway in India.
8. **High Cost & Space Debris**:
    - Deployment is capital-intensive and increases risk of **space junk** and **astronomical interference**.

UPSC Mains Model Questions

Q Discuss the potential of satellite internet services in bridging India's digital divide. In this context, examine the associated regulatory and security challenges.

Q With increasing reliance on private players for satellite internet infrastructure, analyze the implications for India's digital sovereignty and national security.

13TH NATIONAL SEED CONGRESS (NSC) 2024

Context:

- The **13th NSC 2024** was held at the **International Rice Research Institute South Asia Regional Centre (ISARC)** in **Varanasi**, organized by the **Ministry of Agriculture & Farmers' Welfare**.

About National Seed Congress (NSC):

- **Annual event** bringing together **researchers, policymakers, farmers**, and other stakeholders.
- Acts as a platform to:
    - Discuss **innovations in seed production** and **crop improvement**.
    - Strengthen **delivery systems** for quality seeds.
    - Enhance **agricultural sustainability and productivity**.
- **Jointly organized** by:
    - **Union Ministry of Agriculture and Farmers' Welfare**
    - **International Rice Research Institute (IRRI)**

Significance of NSC:

- **Promotes public-private cooperation** in the seed sector.
- Encourages **research-to-farm linkage** in seed technologies.
- Facilitates the exchange of **best practices, policies, and technological breakthroughs**.

About ISARC – Varanasi:

- **South Asia Regional Centre of IRRI**, inaugurated in **2018**.
- A joint initiative between the **Government of India and IRRI**.

Functions of ISARC:

- **Develops**:
  - **Climate-resilient, nutrition-enriched rice varieties**.
  - **Eco-friendly rice cultivation techniques**, like:
    - **Dry Seeded Rice (DSR)**
    - **Alternate Wetting and Drying (AWD)**
- **Trains**:
  - Scientists and farmers on **modern rice cultivation** and seed systems.
- **Promotes**:
  - **Low-methane varieties** and sustainable agricultural practices.
  - **South-South cooperation** in seed technology across **South Asia and Africa**.

About IRRI:

- **Founded in 1960** by the **Ford and Rockefeller Foundations**, supported by the **Philippine Government**.
- **Headquartered** in **Los Baños, Philippines**, with offices in **17 rice-growing countries**.
- Mission: To **reduce poverty, hunger, and malnutrition** through **advanced rice science**.

UPSC Mains Model Questions

Q Discuss the role of National Seed Congress in promoting seed innovation and sustainable agriculture in India.

Q "Quality seeds are the cornerstone of sustainable agricultural development." In this context, evaluate the role of ISARC and IRRI in enhancing seed systems in South Asia.

HYPERLOOP TECHNOLOGY

Context:

India inaugurated its **first hyperloop test track**, a collaboration between **Indian Railways**, **IIT-Madras**, and **TuTr Hyperloop**, marking a significant step towards ultra-high-speed ground transportation in the country.

About Hyperloop:

- **Concept**: Originally popularized by **Elon Musk in 2013**, hyperloop is a **proposed mode of transport** designed to carry **passengers and cargo at speeds exceeding 1200 km/h**.
- Utilizes a **low-pressure tube environment** and **magnetic levitation (maglev)** for near-frictionless, energy-efficient movement.

Working Principle:

1. Low-Pressure Tubes

- **Sealed tubes** with **reduced air pressure** (near-vacuum) to **minimize drag** and allow for ultra-high speeds.
- Often integrated with **solar panels** or other **renewable sources** for **zero-emission energy**.

2. Pods

- Enclosed capsules carrying **passengers or cargo**.
- Designed to ensure **aerodynamic efficiency**, **safety**, and **comfort** similar to aircraft.

3. Magnetic Levitation

- Uses **electromagnets** for both **levitation and propulsion**.
    - **Levitation**: Magnets lift the pod above the track.
    - **Propulsion**: **Linear motors** push the pod forward without physical contact.
- Eliminates traditional **wheel-track friction**, increasing **efficiency and speed**.

Advantages of Hyperloop:

- **Ultra-high speed**: Could reduce travel time significantly (e.g., Mumbai to Pune in under 30 minutes).
- **Low carbon footprint**: Can run on **renewable energy** (e.g., solar), reducing greenhouse emissions.
- **Reduced congestion**: Eases load on traditional road and rail systems.
- **Efficient cargo movement**: Promises a future in **freight logistics** with low cost and high speed.

Challenges and Concerns:

- **High Infrastructure Cost**: Significant investment required for building vacuum tubes and maglev tracks.
- **Safety and Security**: Concerns about system reliability at ultra-high speeds, especially in earthquake-prone or populated areas.
- **Regulatory hurdles**: Absence of a well-defined **policy and safety framework**.
- **Technological feasibility**: Long-term durability, maintenance, and real-world performance are still under testing.
- **Land Acquisition**: Similar to traditional transport projects, **land requirements** may face resistance or delays.

India's Progress:

- The **Hyperloop test track** at **IIT-Madras** aims to:
  - Promote **indigenous R&D** and **Make in India** solutions.
  - Position India as a future **hyperloop-ready nation**.
- Collaboration between **public sector (Indian Railways)** and **private start-ups** like TuTr is a key development model.

UPSC Mains Model Questions

Q **Discuss the science behind Hyperloop technology. In the context of India's transportation needs, evaluate its feasibility and potential benefits.**

Q **Hyperloop promises to revolutionize transport. Critically examine the opportunities and challenges associated with its deployment in India.**

DIAMOND COOLING TECHNOLOGY

Context:

Akash Systems has partnered with India's NxtGen Datacenter to introduce **Diamond Cooling Technology** for high-performance computing applications, particularly in artificial intelligence (AI) and cloud infrastructure.

What is Diamond Cooling Technology?

Diamond Cooling Technology harnesses the **exceptional thermal conductivity** of synthetic diamond to manage heat in **high-power electronic systems**. By integrating diamond materials with advanced semiconductors, this technology ensures efficient **heat dissipation**, enhanced **device longevity**, and **improved performance**.

How It Works?

- **Material Integration**: Synthetic diamonds are bonded with **Gallium Nitride (GaN)** or other semiconductor materials.

- **Thermal Conductivity**:
  - **Single-crystal diamond** has thermal conductivity > **2000 W/m·K**, outperforming copper (~400 W/m·K) and silicon carbide.
  - Diamond dissipates heat via **phonons**—vibrational energy transfer in its atomic lattice.
- **Outcome**: The system maintains low operating temperatures for CPUs, GPUs, power amplifiers, and other heat-sensitive components.

Applications:

Sector	Benefits
AI & Data Centers	Keeps processors **50–75% cooler**, enabling **higher speeds** and **lower power consumption**.
Aerospace & Satellites	Supports **miniaturization** and allows **5–10x faster data transmission.**
Electric Vehicles (EVs)	Enhances thermal control, increasing **range by 30–50%** and extending battery life.

Advantages Over Traditional Cooling:

- **Lower overheating risk** → Reduced thermal throttling
- **Greater device lifespan** → Longer operational efficiency
- **Compactness** → Useful for miniaturized or mobile systems
- **Sustainability** → Lower energy use in cooling large systems (e.g., data centers)

UPSC Mains Model Questions

Q What is Diamond Cooling Technology? How does it improve the efficiency of high-performance computing systems? (GS Paper III – Science and Technology)

Q Discuss the role of advanced thermal management technologies like Diamond Cooling in the development of sustainable digital infrastructure. (GS Paper III – Technology & Environment)

EXPANSION OF THE UNIVERSE & HUBBLE TENSION

Context:

NASA's **James Webb Space Telescope (JWST)** has confirmed that the **universe is expanding faster than expected**, reinforcing similar observations made by the **Hubble Space Telescope**. This discrepancy has deepened the scientific puzzle known as the **Hubble Tension**.

Key Concepts:

Hubble Constant (H_0):

- It denotes the **rate of expansion** of the universe.
- Measured in **km/s/Megaparsec (Mpc)**.
- Typical estimates: ~70 km/s/Mpc.

Hubble's Law:

- **$v = H_0 \times d$**, where
  - v = velocity of galaxy receding
  - d = distance from Earth
  - H_0 = Hubble Constant
- Implies: **farther galaxies recede faster**, indicating expanding space-time.

Hubble Tension:

- Refers to the **discrepancy** between:
  - Early universe expansion rate (from **CMBR** via Planck satellite)
  - Late universe expansion rate (from **supernovae**, **Cepheid variables**)
- **JWST** confirms expansion rate is **~8% faster** than Big Bang predictions, increasing the tension.

Scientific Evidence of Expansion:

1. **Redshift**
   - Light from galaxies shifts to red as they move away → Doppler Effect.
2. **Cosmic Microwave Background Radiation (CMBR)**
   - Residual heat from the Big Bang, uniformly detected across the sky.
3. **Gravitational Lensing**
   - Light from distant galaxies is bent by gravity → helps trace the expansion of cosmic fabric.

James Webb Space Telescope (JWST):

Feature	Details
Launched	December 25, 2021
Orbit	Sun–Earth Lagrange Point 2 (L2), ~1.5 million km away
Purpose	Observe early universe, galaxy formation, exoplanets
Technology	Advanced infrared instruments for deep-space observation
Key Role	Confirms Hubble's findings and refines cosmic distance measurements

India's Contribution:

- **ASTROSAT (2015)**
  - India's first multi-wavelength observatory studying UV, X-ray, and optical spectra.
- **Thirty Meter Telescope (TMT)**
  - India is a key partner in this international collaboration to build one of the world's largest optical telescopes.

UPSC Mains Model Questions

Q **What is the Hubble Tension, and why has it emerged as a critical challenge to the standard model of cosmology? Evaluate the role of new space telescopes in addressing this issue.(GS Paper III – Science and Technology)**

Q **"The discovery of a faster-than-expected expansion of the universe questions our understanding of the cosmos." Discuss the scientific evidence for cosmic expansion and India's contributions to this field. (GS Paper III – Space Science)**

MIRROR BACTERIA

Context:

A global consortium of scientists has raised ethical and biosafety concerns over the **potential synthetic creation of "mirror bacteria"**—organisms with reversed molecular chirality.

What Are Mirror Bacteria?

Mirror bacteria are **hypothetical synthetic microorganisms** that possess **reversed molecular handedness (chirality)** compared to all known life forms.

Property	Natural Life	Mirror Bacteria
Nucleic Acids	Right-handed DNA/RNA	**Left-handed DNA/RNA**
Proteins	Left-handed amino acids	**Right-handed amino acids**
Biological Interactions	Recognizable by natural immune system	**Unrecognizable by natural immunity**

Key Characteristics and Concerns:

1. **Immune Evasion**
   - Natural immune systems detect pathogens via molecular shape.
   - Mirror bacteria would **go unrecognized**, potentially making them **invisible to human immunity**.

2. **Resistance to Natural Predators**
    - Predators like **bacteriophages** and **protists** are unlikely to interact effectively with mirror bacteria.
3. **Antibiotic Resistance**
    - Conventional antibiotics are designed for naturally chiral biomolecules.
    - Mirror bacteria would **not respond**, leading to **complete drug resistance**.
4. **Uncontrolled Environmental Spread**
    - May **outcompete** or **colonize niches** without resistance or ecological balance.
    - Could **disrupt microbial ecosystems** globally.
5. **Health & Biosecurity Risks**
    - If such bacteria mutate or evolve to infect humans, they may **cause untreatable infections**.
    - Raises **bioethical, biosafety, and biowarfare concerns**.

Ethical and Policy Implications:

- **Synthetic biology regulation** is essential.
- International frameworks may be required under platforms like:
    - Convention on Biological Diversity (CBD)
    - Biological Weapons Convention (BWC)
- **Precautionary Principle** should govern further research or application.

UPSC Mains Model Questions

Q What are mirror bacteria? Discuss the potential scientific, ethical, and environmental implications of their synthetic creation.(GS Paper III – Science & Technology, Biosecurity)

Q With the advancement in synthetic biology, threats of synthetic organisms like mirror bacteria are no longer fiction. Analyze the role of global governance in preventing bioethical catastrophes.(GS Paper III – Biotechnology and Ethics)

Infrared Radiation (IR) Regulation – A Novel Indian Advancement

Context:

Scientists from the **Centre for Nano and Soft Matter Sciences (CeNS), Bengaluru**, have developed an innovative approach using **hexagonal boron nitride nanosheets** to regulate **infrared radiation (IR)**. This advancement holds potential in **thermal management, camouflage, and radiative heat shielding**.

What is Infrared Radiation (IR)?

- **Infrared Radiation** is a form of **electromagnetic radiation** with **wavelengths ranging from 780 nm to 1 mm**—longer than visible light, but shorter than microwaves.
- IR radiation is **not visible** but is experienced as **heat** and is emitted by all objects above absolute zero.

Key Characteristics:

Property	Description
Wavelength Range	780 nm to 1 mm
Speed	Travels at light speed in a vacuum
Medium	No medium required; travels through space
Interaction	Easily absorbed/emitted by water, carbon compounds, etc.

Sources of IR:

- **Natural**: Sun, Earth, stars.
- **Artificial**: IR heaters, saunas, industrial lasers.

Significance of CeNS Breakthrough:

- **Material Used**: Hexagonal Boron Nitride (h-BN) – a 2D material known for **high thermal stability, mechanical strength, and chemical inertness**.
- **Applications**:
  - **Thermal Camouflage**: Useful for defense and surveillance by masking heat signatures.
  - **Radiative Heat Barrier**: Regulates temperature in buildings, vehicles, and space systems.
  - **Thermal Management**: Important for electronics, data centers, and wearables.

Relevance of Infrared Regulation:

- IR constitutes nearly **50% of solar radiation**.
- Excess IR exposure can:
  - Elevate **ambient temperatures**.
  - Contribute to **urban heat islands**.
  - Cause **thermal discomfort** and potential **health effects**.
- Effective IR regulation is thus vital in **climate-sensitive architecture**, **energy efficiency**, and **health safety**.

UPSC Mains Model Questions

Q Discuss the scientific and practical significance of infrared radiation regulation. How can innovations like the one by CeNS aid in climate resilience and defense preparedness?(GS Paper III – Science & Technology / Environment)

Q What is infrared radiation? Highlight its natural and artificial sources, and evaluate its implications for human health, infrastructure, and military applications. (GS Paper III – Awareness in the field of Science and Technology)

SPACE BIOTECHNOLOGY

Context:

The **Indian Space Research Organisation (ISRO)** has partnered with the **Department of Biotechnology (DBT)** to enhance research in **space biotechnology**. This collaboration aims to solve key challenges related to **human survival in space**, including nutrient recycling, waste management, microgravity adaptation, and radiation protection.

What is Space Biotechnology?

Space biotechnology is a specialized branch of science that focuses on how **living organisms behave, adapt, and evolve** in **space conditions**, particularly in **microgravity and radiation-heavy environments**. It aims to **support long-duration space missions**, planetary colonization, and **human health in extraterrestrial settings**.

Applications and Significance:

Domain	Application
1. Microgravity Research	Microgravity allows the growth of **high-quality protein crystals**, vital for understanding protein structures and drug development.
2. Radiation Studies	Missions like **NASA's BioSentinel** investigate how cells **respond to space radiation**, helping in DNA repair research.
3. Environmental Engineering	Use of **microorganisms** to recycle waste, generate oxygen, or **convert Martian or lunar regolith into fertile soil** (bioremediation).

4. Human Health	Models diseases in microgravity to develop better **countermeasures for astronauts** and refine treatments on Earth.
5. Life Support Systems	**Bioregenerative systems** that recycle water, oxygen, and waste, enabling **sustainable human presence** in space.
6. Crop Research	Space breeding to develop **high-yield and climate-resilient crops** for space and Earth agriculture.

Global Initiatives:

- **NASA – Space Biology Program**: Explores how biological systems respond to spaceflight.
- **ESA – Biolab**: Aboard the International Space Station (ISS), used to study organisms in microgravity.
- **China – Space Breeding Programs**: Developing **high-yield plant varieties** via mutation breeding in space conditions.

India's Emerging Role:

- **ISRO-DBT Partnership**: Aims to build a robust framework for space biotech by integrating **space platforms and biological science**.
- **Scope**: Waste recycling, microbe-based food generation, astronaut health, and biosensors for environmental monitoring.

Potential Use of Human Heritable Genome Editing (HHGE) in Space:

- **Disease Prevention**: Eliminating heritable genetic disorders like cystic fibrosis or sickle cell anemia.
- **Space Immunity**: Engineering humans to better **withstand radiation or bone loss** in space.
- **Ethical Concerns**: Need for regulation due to the long-term implications on future generations.

UPSC Mains Model Questions

Q Discuss the role of biotechnology in enhancing the sustainability and safety of long-duration space missions. Illustrate with global and Indian examples. (GS Paper III – Science & Technology)

Q Space biotechnology offers a platform not only for extraterrestrial survival but also for solving Earth-based challenges. Examine. (GS Paper III – Science & Tech / Environment / Health)

RNA EDITING: A New Frontier in Precision Medicine

Context:

In a landmark achievement, **Wave Life Sciences**, a U.S.-based biotech firm, has **clinically demonstrated the world's first RNA editing therapy in humans**, targeting **Alpha-1 Antitrypsin Deficiency (AATD)**, a genetic liver and lung disorder.

What is RNA Editing?

RNA editing is a **post-transcriptional** process that **alters nucleotide sequences in RNA molecules**, enabling changes in the **protein synthesis process** without modifying the underlying DNA.

How RNA Editing Works:

- Uses the enzyme **ADAR (Adenosine Deaminase Acting on RNA)** in conjunction with **guide RNA (gRNA)**.
- ADAR converts **adenosine (A)** to **inosine (I)** in messenger RNA (mRNA).
- The cellular machinery interprets inosine as **guanosine (G)**, effectively changing the mRNA message.
- This corrects genetic defects temporarily, allowing **normal protein production** and **cellular function** restoration.

RNA Editing vs DNA Editing:

Feature	RNA Editing	DNA Editing
Nature	Temporary, reversible	Permanent, irreversible
Mechanism	Works via ADAR enzyme	Uses bacterial enzymes like CRISPR-Cas9
Safety	Lower immune risks	Potential for immune reactions
Therapeutic Use	Suitable for acute or trial-based interventions	Ideal for heritable, permanent changes
Flexibility	Can be reprogrammed or reversed	More rigid and difficult to adjust post-treatment

Benefits & Applications:

- **Disease Therapy**: For rare genetic diseases like AATD, cystic fibrosis, and neurodegenerative disorders.
- **Protein Diversity**: Expands the cell's ability to create varied proteins from the same DNA.

- **Personalized Medicine**: Potential for patient-specific, non-permanent gene correction.
- **Safer Genetic Editing**: Avoids irreversible genome modifications.

Limitations and Challenges:

- **Precision**: Ensuring specific targeting without off-target effects is still difficult.
- **Duration**: Effects are transient; repeated administration may be required.
- **Scalability**: High costs and technical limitations hinder widespread clinical deployment.
- **Regulatory Framework**: Lack of clarity around RNA-based therapies compared to DNA editing tools.

Alpha-1 Antitrypsin Deficiency (AATD) – Use Case

- **Inherited disorder** affecting liver and lungs due to misfolded proteins.
- **RNA editing** offers a pathway to correct protein synthesis **without gene modification**.

UPSC Mains Model Questions

Q RNA editing offers a safer, reversible alternative to DNA editing. Discuss its significance and challenges in the context of genetic therapy. (GS Paper III – Science & Technology)

Q Compare RNA and DNA editing technologies. How can RNA editing redefine the scope of personalized medicine? (GS Paper III – Science & Tech / Biotechnology)

NVS-02 SATELLITE & NAVIC: Strengthening India's Strategic Navigation Autonomy

Context:

ISRO launched **NVS-02**, its 100th satellite, aboard the **GSLV-F15** from **Sriharikota**, marking a significant milestone in India's indigenous satellite navigation capability under the **NavIC (Navigation with Indian Constellation)** system.

About NVS-02 Satellite:

- **Second-generation navigation satellite** under the NavIC system.
- Replaces the aging **IRNSS-1E** satellite, which suffered clock malfunctions.
- Designed for **positioning, navigation, and timing (PNT)** services over India and nearby regions.
- **Lifespan**: 12 years (compared to 10 years of older IRNSS satellites).

- Equipped with an **indigenous Rubidium Atomic Clock**, boosting self-reliance.
- Supports **L1, L5, and S bands**, improving:
  - Accuracy.
  - Civilian usability (e.g., wearables, smartphones).
  - Global interoperability.

About NavIC System (Formerly IRNSS):

- **India's regional navigation satellite system**, developed by **ISRO**.
- Designed for **independent and accurate PNT services** over India and up to **1,500 km beyond borders**.
- **Constellation**: 7 operational satellites:
  1. 3 in **Geostationary Orbit (GEO)**.
  2. 4 in **Inclined Geosynchronous Orbit (IGSO)**.
- **Two service categories**:
  1. **Standard Positioning Service (SPS)** – for civilian users.
  2. **Restricted Service (RS)** – encrypted signals for defense/strategic use.
- **Accuracy**: ~20 meters for positioning, 50 nanoseconds for timing.
- **Interoperability**: Compatible with GPS (USA), Galileo (EU), GLONASS (Russia), BeiDou (China).

Advantages of NavIC Over GPS:

Feature	NavIC	GPS
Orbital Altitude	GEO & IGSO (Higher)	Medium Earth Orbit
Coverage	Focused over India	Global
Signal Strength in India	Stronger due to constant satellite visibility	Weaker at times due to satellite movement
Indigenous Control	Fully developed and maintained by ISRO	Reliant on foreign systems
Military Applications	Encrypted RS service for India	GPS RS not available to India

Strategic and Civilian Applications:

- **Defense**: Secure navigation and missile guidance.
- **Transport & Aviation**: Precision tracking of ships, planes, and railways.
- **Disaster Management**: Real-time support for relief and rescue.
- **Agriculture**: Precision farming and land surveying.

- **Smart Devices**: Navigation in wearables and smartphones through L1 band support.

UPSC Mains Questions (GS Paper III – Science & Technology):

Q **What is the significance of NVS-02 in the evolution of India's regional navigation system? Evaluate how the NavIC system strengthens India's strategic autonomy.**

Q **Compare India's NavIC with the US GPS. How does regional satellite navigation contribute to national security and development?**

Genome India Project (GIP)

Introduction:

The **Genome India Project (GIP)** is a flagship initiative of the **Department of Biotechnology (DBT), Ministry of Science & Technology**, aimed at cataloguing the genetic diversity of the Indian population. It is being implemented in collaboration with over **20 research institutions**, including IISc Bangalore.

Objectives of Genome India Project:

- To collect and sequence the **whole genomes** of **20,000 individuals** representing the diverse population groups of India.
- To create a **genetic biobank** for future medical and scientific research.
- To facilitate the development of **personalized medicine** and **early disease detection**.
- To promote **indigenous capabilities** in genomics and reduce dependence on foreign genetic databases.

Significance:

1. **Healthcare Advancement:**
    - Enables **precision medicine** based on individual genetic profiles.
    - Improves diagnosis of **rare and genetic disorders**.
    - Assists in cancer genomics and pharmacogenomics.
2. **Public Health:**
    - Supports better epidemiological mapping.
    - Aids in vaccine development and outbreak prediction.
3. **Scientific & Strategic Edge:**
    - Enhances India's **bioinformatics and genomics infrastructure**.
    - Positions India as a global player in genomics.
4. **Biodiversity and Agriculture:**
    - Complements other efforts like **Earth BioGenome Project** and **IndiGen**.

- Helps in **crop improvement** and **livestock breeding**.

Conclusion:

The Genome India Project is a landmark step towards a **genomics-driven public health ecosystem** in India. It has the potential to transform healthcare, enrich biodiversity research, and make India a global hub in genetic science.

SCRAMJET ENGINE (Supersonic Combustion Ramjet)

Context:

The **DRDO** has successfully conducted a **120-second ground test** of an **Active Cooled Scramjet Combustor**, marking a significant step in India's hypersonic propulsion technology.

What is a Scramjet Engine?

- A **Scramjet** is a type of **air-breathing jet engine** designed to operate at **hypersonic speeds** (typically **Mach 5 and above**).
- Unlike traditional jet engines or rockets, **scramjets do not carry oxidizers**; they **use atmospheric oxygen** for combustion.
- "Scramjet" stands for **Supersonic Combustion Ramjet**, meaning **combustion occurs while air flows through the engine at supersonic speed**.

Key Features:

- **Air-Breathing Propulsion**: Uses **compressed incoming air** for combustion, eliminating the need to carry liquid oxygen.
- **Efficient at Hypersonic Speeds**: Best suited for speeds **greater than Mach 5**.
- **No Rotating Parts**: Unlike turbojets, scramjets have **no turbines or compressors**, making them structurally simpler but technologically challenging.
- **High Thermal Stress**: Requires advanced cooling systems like **active cooling** due to extremely high temperatures.

Advantages:

- **Greater Efficiency** at high speeds compared to rockets.
- **Reduced Launch Weight** due to elimination of onboard oxidizer.
- Ideal for **hypersonic missiles**, **spaceplanes**, and **next-gen reusable launch vehicles**.

India's Development:

- Developed by: **Defence Research and Development Laboratory (DRDL)**, Hyderabad (under DRDO).

- India is among a few nations (US, Russia, China, EU, Japan) to have demonstrated capabilities in **scramjet testing**.
- Related program: **Hypersonic Technology Demonstrator Vehicle (HSTDV)** – India's experimental hypersonic platform tested by DRDO.

Significance:

- Enhances **India's strategic defense capabilities**.
- Key enabler for **hypersonic weapons** and **low-cost space launch**.
- Boosts India's presence in **next-gen propulsion technologies**.

NANO BUBBLE TECHNOLOGY

Context:

Nano Bubble Technology was recently launched at the **National Zoological Park, Delhi**, to improve **water quality** and support **aquatic life** in enclosed water bodies.

What Are Nanobubbles?

- **Nanobubbles** are **extremely small gas-filled bubbles**, typically **70–120 nanometers** in diameter (about 2,500 times smaller than a grain of salt).
- They can be created using **any gas** (like oxygen, ozone, CO_2) and infused into a liquid, usually water.
- Unlike regular bubbles that rise quickly and burst, nanobubbles **remain suspended** due to **Brownian motion** and a **negative surface charge**.
- Their **high surface-area-to-volume ratio** significantly enhances **gas exchange** in water.

Key Properties:

1. **Stay Suspended:**
   - Nanobubbles do not float up and burst like conventional bubbles; they **remain stable and suspended** in the liquid.
2. **Uniform Distribution:**
   - Ensures **even distribution of oxygen or other gases**, benefiting aquatic organisms and water quality.
3. **Efficient Oxygenation:**
   - Provide **superior oxygen transfer efficiency**, especially important for fish and aquatic ecosystems.
4. **Electrochemical Properties:**
   - Their **negative surface charge** prevents them from merging (coalescence), enhancing stability and longevity in water.

Applications of Nanobubble Technology:

1. Water Treatment:

- Removes **pollutants, bacteria, and organic matter** from ponds, lakes, and tanks
- Improves **dissolved oxygen levels**, reducing odor and sludge.

2. Agriculture & Aquaculture:

- Enhances **soil aeration**, promoting **root health** and nutrient absorption.
- In aquaculture, it **boosts fish growth**, reduces disease, and increases oxygen in fish ponds.

3. Industry & Cleaning:

- Effective in **cleaning industrial equipment**, removing **biofilms** and **grease** from hard-to-reach surfaces.
- Used in **semiconductor** and **food processing** industries for deep cleaning without chemicals.

4. Oil & Gas Sector:

- Improves **oil recovery** by altering surface tension and enhancing fluid mobility.
- Reduces **chemical usage** in hydraulic fracturing (fracking).

5. Personal Care & Cosmetics:

- Used in **skincare and hygiene products** for better absorption of active ingredients.
  Enhances **hydration of skin and hair**.

Significance for India:

- Aligns with **Swachh Bharat**, **Atmanirbhar Bharat**, and **Sustainable Development Goals (SDGs)**.
- Can be a **low-cost, eco-friendly solution** for:
  - Reviving polluted water bodies
  - Supporting urban and rural sanitation
  - Improving productivity in agriculture and fisheries

Conclusion:

Nano Bubble Technology represents a **cutting-edge, green innovation** that holds the potential to revolutionize **environmental management**, **agriculture**, and **industry** in India. Its deployment in public spaces like zoological parks also raises **public awareness** about sustainable water practices.

UPSC Mains Model Questions

Q Discuss the potential of Nano Bubble Technology in addressing environmental and agricultural challenges in India. What are the limitations and policy interventions required for its wider adoption? (Answer in 250 words)

SRY Gene – Understanding Sex Determination Beyond Chromosomal Norms

Background:

Sex determination in humans has conventionally been viewed as a binary system based on chromosomes: males possessing XY and females possessing XX chromosomes. However, recent studies have shown that this biological framework is more complex than previously thought. The discovery of individuals with an XX chromosomal pattern exhibiting male characteristics due to the presence of the **SRY gene** highlights the nuanced role of genetics in determining sex and identity.

Explanation:

What is the SRY Gene?

The **SRY (Sex-determining Region Y)** gene is a key gene located on the Y chromosome that acts as the master switch for initiating **male sex determination** in mammals.

- **Function**: It encodes a protein known as **Testis Determining Factor (TDF)**.
- **Mechanism**: TDF acts as a **transcription factor**, activating other genes required for the development of **testes**, which then produce hormones that lead to the development of male secondary sexual characteristics.
- It also initiates the formation of **Sertoli cells**, essential for further male reproductive development.

Clinical Implications:

The malfunction, absence, or abnormal placement of the SRY gene leads to various **Disorders of Sex Development (DSDs)**:

- **Swyer Syndrome**: Individuals with XY chromosomes but a defective SRY gene develop female physical traits.
- **XX Male Syndrome**: In rare cases, individuals with XX chromosomes but with the SRY gene (due to translocation) develop male traits, despite lacking a Y chromosome.

Ethical and Scientific Significance:

1. **Challenges Binary Norms**: These findings defy the binary classification of sex based on chromosomes alone and call for a more inclusive understanding of biological sex.
2. **Advances in Medical Genetics**: Help in the diagnosis, classification, and potential gene therapy for DSDs.
3. **Policy & Legal Implications**: Could influence health policies, gender identification laws, and bioethics debates, particularly in issues concerning identity, rights, and privacy.

UPSC Mains Model Questions

Q The discovery of SRY gene anomalies has redefined traditional understandings of sex determination. Discuss the scientific and ethical implications of this development in the context of genetic research and public health. (Answer in 250 words)

Coronal Holes and Their Significance in Space Weather

Introduction:

Coronal holes are large, dark regions observed in the Sun's corona—its outermost layer—that are sources of high-speed solar wind streams. First identified in the 1970s through X-ray imaging by satellites, these features play a critical role in influencing space weather and Earth's geomagnetic environment.

Features of Coronal Holes:

1. **Lower Temperature and Density**
   - Coronal holes appear dark in extreme ultraviolet (EUV) and X-ray wavelengths due to their relatively **cooler temperatures** and **lower plasma density** compared to surrounding regions.
2. **Open Magnetic Field Lines**
   - The magnetic field in these regions is **unipolar and open**, allowing **solar wind to escape** easily into space. In contrast, other regions exhibit looped magnetic field lines that trap solar plasma.
3. **Solar Wind Source**
   - These holes are key origins of **high-speed solar wind streams (HSS)** that travel across the solar system and interact with Earth's magnetosphere.

Location and Dynamics:

- Typically found near **solar poles** during periods of solar minimum.
- Can migrate to **equatorial regions** or form independently.

- May persist for **weeks to months**, with size and location influenced by the **11-year solar cycle**.

Monitoring Instruments:

- **NASA's Solar Dynamics Observatory (SDO)** and **ESA's Solar Orbiter** continuously monitor coronal holes in real-time.
- India's **Aditya-L1 mission**, launched in 2023, is designed to study solar activity—including coronal holes—and their influence on **space weather**.

Impact on Earth and Space Weather:

1. **Geomagnetic Storms**
   - High-speed solar wind from coronal holes interacts with Earth's **magnetosphere**, triggering geomagnetic disturbances.
   - Effects include **intensification of auroras**, satellite damage, and disruptions in electrical grids and communication systems.
2. **Satellite Operations**
   - Solar wind increases atmospheric drag on **low-Earth orbit satellites (LEO)**, affecting their orbits and lifespan.
   - Causes **GPS errors**, **HF radio blackouts**, and **aviation communication disruptions**, especially over polar regions.
3. **Climate and Weather Influence**
   - There is emerging research linking solar wind activity to **upper atmospheric dynamics**, including changes in **ozone distribution**, **cloud formation**, and **precipitation patterns**.
   - Possible correlation with **Indian summer monsoon variability**, though causality is still being explored.

Conclusion:

Coronal holes, while being natural solar phenomena, have significant ramifications for **space-based infrastructure**, **aviation safety**, and potentially even **terrestrial weather systems**. Understanding their structure and behavior is crucial for enhancing **predictive capabilities in space weather forecasting**, making missions like **Aditya-L1** a vital step toward building India's resilience to solar-induced disruptions.

UPSC Mains Model Questions

Q What are coronal holes? Discuss their significance in space weather and their potential impact on Earth's technological infrastructure and climate systems. (Answer in 250 words)

Bacterial Cellulose: A Sustainable Band-Aid for Plants

Introduction:

Recent research has demonstrated the potential of **bacterial cellulose (BC)**—a biopolymer naturally synthesized by bacteria—as a **biodegradable bandage for plants**, offering a revolutionary tool for sustainable agriculture and plant care.

What is Bacterial Cellulose?

Bacterial cellulose is a form of **pure cellulose** produced primarily by bacteria from the Komagataeibacter genus. Unlike plant-derived cellulose, BC is **free from lignin, hemicellulose, and pectin**, giving it **high purity** and unique functional properties.

Key Characteristics:

- **High tensile strength** and **crystallinity**
- **Exceptional water-holding capacity** and **biocompatibility**
- Forms a **three-dimensional nanofibrous network**, ideal for adhesion and protection
- **Fully biodegradable** and **moldable**

Applications Across Sectors:

1. Agriculture and Plant Care

- **Plant wound dressing:** Acts like a Band-Aid to protect injured parts from pathogens.
- **Moisture retention:** Reduces drought stress and aids regeneration.
- **Disease prevention:** Trials in apple orchards (USA), banana plantations (India), and vineyards (France) have shown success in preventing fungal infections and aiding recovery.

2. Biomedical Sector

- Used in **wound dressings**, **skin substitutes**, **tissue scaffolds**, and **drug delivery**.
- Genetically modified BC can release **growth hormones or antimicrobials**.

3. Food and Cosmetic Industry

- **Edible films** and **packaging materials** for extended shelf life.
- Used in **facial masks**, **skin care**, and **hair care** due to high hydration capacity.

4. Industrial Use

- Applications in **acoustic membranes**, **filtration systems**, **high-strength paper**, and **textiles**.

Significance:

The use of bacterial cellulose for plants reflects a **paradigm shift in sustainable agriculture**, providing **non-toxic**, **biodegradable**, and **climate-resilient** solutions. Its adaptability across sectors also highlights its potential as a **green industrial material**.

UPSC Mains Model Questions

Q **Discuss the emerging role of bacterial cellulose in sustainable agriculture and its potential across sectors such as healthcare, industry, and food. (Answer in 250 words)**

Selenium: A Double-Edged Trace Element in Human and Environmental Health

Introduction:

Selenium (Se), a rare trace element, has garnered attention following recent reports of sudden hair loss in Maharashtra's Buldhana district. Investigations traced the cause to selenium toxicity from contaminated wheat supplied via ration shops. This incident has brought to light the fine balance between selenium's health benefits and its potential for toxicity.

What is Selenium?

- **Chemical Symbol**: Se
- **Atomic Number**: 34
- **Category**: Metalloid (shares properties of metals and non-metals)
- **Occurrence**: Found in metal ores (copper, mercury, lead, silver); often obtained as a **by-product of copper refining**
- **Form**: The most stable form is **gray metallic selenium**, which shows increased electrical conductivity when exposed to light.

Role in Human Physiology:

Selenium is vital in **minute quantities** and performs several physiological functions:

- **Antioxidant Defense**: A key component of the enzyme **glutathione peroxidase**, which protects cells from oxidative stress.
- **Thyroid Health**: Assists in the metabolism of thyroid hormones.
- **Immune System Support**: Strengthens resistance to infections.
- **Reproductive Health**: Plays a role in sperm motility and fertility.
- **Cognitive Function**: Maintains brain health.

Dietary Recommendations:

- **Adults**: 55 micrograms/day
- **Pregnant and Lactating Women**: 60–70 micrograms/day
- **FSSAI Norm**: 40 micrograms/day
- **Dietary Sources**: Brazil nuts (most concentrated), fish, poultry, eggs, whole grains, sunflower seeds.

Selenium Deficiency Disorders:

1. **Keshan Disease** (China): A cardiomyopathy linked to selenium deficiency.
2. **Kashin-Beck Disease**: Osteoarthritis affecting joints and bones.
3. **Other Symptoms**: Infertility, weakened immune response, cognitive impairments.

Selenium Toxicity (Selenosis):

Excess intake can lead to **acute and chronic health issues**:

- **Symptoms**: Nausea, hair loss, brittle nails, metallic taste, garlic breath, skin rashes, fatigue.
- **Neurological Effects**: Dizziness, tremors, and in severe cases, organ failure.
- **Environmental Risks**: Accumulation in aquatic ecosystems leads to **reproductive toxicity in birds and fish**.
    - **Case Study**: **Kesterson Reservoir Disaster** (USA) – High selenium levels caused birth defects in birds.

Relevance to Public Health and Policy:

- The Buldhana incident highlights gaps in **food safety regulation** and the **need for monitoring micronutrient levels in public food supply chains**.
- Reinforces the necessity for **FSSAI and agricultural supply chains** to enforce strict trace element surveillance.
- Emphasizes **biofortification vs. toxicity trade-offs** in food policy.

<u>UPSC Mains Model Questions</u>

Q **Selenium is an essential trace mineral, but its excess or deficiency can lead to serious public health consequences. Examine its biological significance, associated disorders, and the implications for food safety governance in India. (Answer in 250 words)**

Nuclear Energy Mission – A Step Toward Clean Energy Transition

Context:

Announced in the **Union Budget 2025–26**, the **Nuclear Energy Mission** represents a major thrust by India to ramp up its domestic nuclear capabilities, with an ambitious target of **100 GW of nuclear power by 2047**, aligning with India's broader goal of achieving **Net Zero emissions by 2070**.

Key Features of the Mission:

1. **Capacity Expansion**:
    - Current installed capacity: **8.18 GW**
    - Target capacity: **100 GW by 2047**
    - Aims to close the gap through **new reactor deployment**, public-private partnerships, and **modular technologies**.
2. **Private Sector Participation**:
    - Private entities will contribute **land, capital, and infrastructure** (e.g., access to cooling water).
    - The **public sector unit (NPCIL)** will retain control over core operations—design, safety, and maintenance.
    - This PPP model is intended to **accelerate project timelines** and diversify investment.
3. **Deployment of Advanced Nuclear Technologies**:
    - Focus on **Bharat Small Reactors (BSRs)** and **Bharat Small Modular Reactors (BSMRs)**.
    - These technologies emphasize **scalability, modular manufacturing, faster deployment**, and **greater safety**.

Bharat Small Reactors (BSRs)

- Based on India's indigenous **220 MW Pressurized Heavy Water Reactor (PHWR)** technology.
- Designed for smaller grids and **low-carbon electricity** generation
- Have already proven successful in **16 units** across India.
- Intended to **supplement existing grid-based infrastructure** and **replace older, polluting systems**.

Bharat Small Modular Reactors (BSMRs)

- Developed by **BARC** to
    - Replace **retiring coal-fired plants**.
    - Supply **remote and off-grid locations** (e.g., the Northeast, border areas, island territories).

- Modular design allows for **prefabrication**, reduced on-site construction, and improved **cost efficiency**.

Significance of the Mission

- **Energy Security**: Reduces dependency on fossil fuels and imported energy.
- **Climate Action**: Supports India's Nationally Determined Contributions (NDCs) and clean energy goals.
- **Industrial Development**: Stimulates the nuclear manufacturing ecosystem and R&D in advanced technologies.
- **Just Transition**: Repurposing coal-based infrastructure ensures minimal disruption to workers and communities.

Challenges Ahead:

- **Public perception and nuclear safety concerns**.
- **Nuclear liability issues** that have historically deterred private investment.
- Need for **streamlined regulatory clearances** and **robust waste management systems**.
- **International technology transfers and uranium supply constraints**, despite civil nuclear agreements.

Conclusion:

The Nuclear Energy Mission is a **transformative policy push** that integrates innovation, public-private collaboration, and clean technology. Its successful implementation could place India at the **forefront of the global nuclear revival**, bridging the gap between energy demands and climate obligations.

Model Question (GS Paper 3 – Energy, Environment, and Infrastructure)

Q **"India's Nuclear Energy Mission aims to balance the twin imperatives of energy security and climate responsibility." In light of this statement, critically examine the prospects and challenges of expanding nuclear energy capacity through Small Modular Reactors (SMRs) in India.**

DEEP OCEAN MISSION

Context:

India is set to launch its first human underwater submersible under the Deep Ocean Mission (DOM), marking a major step in indigenous deep-sea exploration and marine resource utilization.

What is the Deep Ocean Mission?

The Deep Ocean Mission (DOM) is a flagship Central Sector Scheme launched by the **Ministry of Earth Sciences (MoES)**.

It aims to **develop deep-sea technologies**, explore ocean resources, and **strengthen India's capacity** in ocean engineering, marine biodiversity, and sustainable ocean economy (Blue Economy).

The mission was approved by the **Cabinet Committee on Economic Affairs (CCEA)** with a total outlay of **₹4,077 crore for 5 years**, to be implemented in phases.

Key Objectives:

- **Deep-Sea Exploration:** Mapping and exploration of **minerals, hydrothermal vents, and biodiversity** in India's Exclusive Economic Zone (EEZ) and beyond.
- **Development of Manned Submersibles:** Indigenous design and deployment of **Matsya-6000**, a deep-sea vehicle capable of carrying humans to a depth of 6,000 meters.
- **Deep-Sea Mining Technologies:** Create advanced robotics and machines for **underwater mining** of polymetallic nodules and other resources.
- **Biodiversity and Climate Studies:** Study **marine biodiversity**, **ecosystem dynamics**, and **climate-linked ocean processes**.
- **Ocean Climate Services & Technology Innovation:** Enhance capacity in **ocean observation**, forecasting systems, and coastal sustainability.
- **Support to Blue Economy Policy:** Strengthen marine biotechnology, fisheries, clean energy, and resource security under India's **Blue Economy framework**.

About Matsya 6000:

- **Developed by:** National Institute of Ocean Technology (NIOT), Chennai.
- **Part of:** Samudrayaan Project.
- **Specifications:**
    - Titanium alloy pressure hull, 2.1 m in diameter
    - Capacity: 3 crew members
    - Operational endurance: 12 hours (normal), 96 hours (emergency)
    - Depth: Up to 6,000 meters
- **Significance:** India will become the **6th country** after USA, Russia, France, Japan, and China to undertake a manned deep-ocean mission.

Strategic Significance:

- **Resource Security:** India's EEZ holds huge reserves of polymetallic nodules rich in manganese, cobalt, nickel, and copper.

- **Technological Sovereignty:** Indigenous development of underwater robotics, pressure hulls, and deep-sea sensors boosts **scientific self-reliance**.
- **Climate Resilience:** Enables better **monitoring of oceanic processes** and early warning systems for tsunamis and cyclones.
- **Maritime Geopolitics:** Strengthens India's presence in the Indian Ocean and supports maritime diplomacy.
- **Supports SDGs:** Contributes to **SDG 14 (Life Below Water)**, **SDG 13 (Climate Action)**, and **SDG 9 (Industry, Innovation, and Infrastructure).**

Challenges Ahead:

- **Technological Barriers:** Deep-sea systems need to withstand **extreme pressure, low temperatures, and corrosion**.
- **Environmental Concerns:** Mining activities may harm fragile marine ecosystems and **deep-sea biodiversity**.
- **Funding & Skill Development:** Sustained funding and trained ocean engineers are needed for long-term capacity-building.
- **International Regulation:** India must align with the **International Seabed Authority (ISA)** and **UNCLOS** for responsible deep-sea mining.

UPSC Mains Model Questions

Q **Deep Ocean Mission (DOM) has the potential to position India as a major maritime power. Discuss its strategic and economic significance, along with the environmental and technological challenges involved.**

THERAPEUTIC PROTEINS

Context:

Therapeutic proteins have emerged as a vital tool in modern medicine, with widespread applications in treating **non-communicable diseases** (like cancer and diabetes) and **infectious diseases** (like hepatitis and COVID-19). The rise of **biotechnology and mRNA platforms** has accelerated their development and use.

What Are Therapeutic Proteins?

Therapeutic proteins are **biologically active molecules** designed for use as medicines to prevent, manage, or cure various diseases. They are **produced using recombinant DNA technology** in host organisms such as bacteria, yeast, or mammalian cells.

These proteins replicate or enhance natural biological processes by targeting **specific molecular pathways** in the human body.

Forms of Therapeutic Proteins:

1. **Hormones:** Replace or supplement deficient natural hormones. Examples: Insulin (diabetes), Growth Hormone (dwarfism).
2. **Enzymes:** Replace missing or faulty enzymes. Examples: Factor VIII (hemophilia), Dornase alfa (cystic fibrosis).
3. **Monoclonal Antibodies (mAbs):** Target specific antigens to block disease progression.
   Examples: Trastuzumab (breast cancer), Rituximab (lymphoma).
4. **Cytokines:** Modulate immune system response.
   Examples: Interleukins (cancer therapy), Interferons (hepatitis, multiple sclerosis).
5. **Fusion Proteins:** Engineered hybrids that combine multiple protein functions.
   Example: Etanercept (rheumatoid arthritis).
6. **Protein-Based Vaccines:** Use protein subunits to stimulate immune protection.
   Examples: Novavax COVID-19 vaccine, HPV vaccine for cervical cancer.

Key Features and Benefits:

- **Highly Specific:** Designed to target precise molecules, reducing side effects.
- **Naturally Derived:** Mimic or replace human proteins, often with minimal toxicity.
- **Biocompatible:** Well tolerated by the body, suitable for long-term use.
- **Essential for Rare Diseases:** Enable treatment of genetic or enzymatic disorders lacking alternatives.

Role in Personalized & Precision Medicine:

- **Tailored Therapies:** Integration with mRNA and gene-editing tools (e.g., CRISPR) enables **customized treatment** for individual patients.
- **Gene Therapy Support:** Therapeutic proteins are used as vectors or products in **gene therapies**, potentially offering cures for genetic disorders.
- **Biomarker-Driven Use:** Patients can be stratified based on biomarkers for **targeted interventions** (e.g., HER2-positive cancers).

Challenges in Therapeutic Protein Use:

- **Immunogenicity:** Can trigger immune reactions, reducing effectiveness or causing side effects.

- **Complex Manufacturing:** Requires advanced biotechnological infrastructure, quality control, and cold-chain logistics.
- **Aggregation Risk:** Proteins may clump during production or storage, leading to reduced efficacy or toxicity.
- **High Costs:** Expensive to develop, produce, and store, making accessibility an issue.

Significance for India:

- Supports **Atmanirbhar Bharat** in biotechnology and pharmaceuticals.
- Enables development of **biosimilars** and indigenous vaccines.
- Promotes growth in **biopharma and health innovation**, especially in combating **non-communicable diseases.**
- Encourages **biotech startups** and public-private collaboration through schemes like **PLI for Pharmaceuticals.**

Model UPSC Mains Question:

Q Therapeutic proteins are transforming modern medicine by offering targeted, biologically compatible treatments. Discuss their potential in addressing India's health challenges and examine the hurdles in their widespread adoption.

CHANDRAYAAN-5

Context:

The Government of India has recently approved the **Chandrayaan-5** mission, marking the next major milestone in ISRO's lunar exploration program. This mission includes significant international collaboration and technical upgrades.

About Chandrayaan-5:

- **Chandrayaan-5** will feature a **250 kg rover**, a tenfold increase in mass compared to the **25 kg 'Pragyan' rover** used in **Chandrayaan-3**, implying advanced scientific instrumentation and mobility.
- This mission is being developed **in collaboration with Japan**, strengthening India's space diplomacy and technological exchange in space research.

Key Features and Goals:

- **Enhanced Payload Capacity:** With a heavier rover, Chandrayaan-5 is expected to carry more sophisticated instruments for in-situ analysis.
- **Focus on Resource Mapping:** Likely to include experiments related to **lunar water ice**, **soil composition**, and **geothermal studies**.

- **Technological Advancement:** Will build on ISRO's experience from Chandrayaan-3 in landing technology and autonomous navigation.

Previous Chandrayaan Missions Overview:

1. **Chandrayaan-1 (2008):**
   - India's first lunar mission.
   - Discovered **water molecules on the Moon**, a landmark scientific achievement.
   - Orbited the Moon and mapped its surface using **mineralogical and chemical imaging spectrometers**.
2. **Chandrayaan-2 (2019):**
   - Intended to demonstrate soft-landing on the Moon's south pole.
   - **Orbiter successfully entered lunar orbit** and continues to transmit valuable data.
   - **Vikram lander crash-landed**, causing a partial failure.
3. **Chandrayaan-3 (2023):**
   - A follow-up mission focused solely on lander and rover systems.
   - On **August 23, 2023, Vikram Lander achieved a successful soft landing** near the south pole.
   - The **Pragyan Rover** conducted elemental analysis and soil profiling.
4. **Chandrayaan-4 (Planned for 2027):**
   - Aims to **collect lunar regolith (soil)** and **bring samples back to Earth**—India's first sample-return mission.

ChaSTE Experiment:

- **Full Form:** Surface Thermophysical Experiment.
- **Function:** Measures surface and sub-surface temperatures on the Moon to determine thermal gradients and soil behavior.
- **Historic Achievement:**
  - **First probe to successfully deploy a thermal sensor in lunar soil**.
  - Gathered **in-situ thermal data up to 100 mm depth**, critical for confirming **water ice deposits**.

Global Comparison of Similar Missions:

1. **ESA's Philae Lander (2014, Comet 67P):**
   - Carried **MUPUS** to collect temperature data.
   - Failed due to awkward landing and lack of surface contact.

2. **NASA's InSight Lander (2018, Mars):**
    - Equipped with **HP³ (Heat Flow and Physical Properties Package)**.
    - Failed due to **low soil friction** and improper probe placement.

India's **ChaSTE experiment** is the **first mission to overcome these technical hurdles**.

Significance for India:

- Boosts India's standing in lunar research and planetary exploration.
- Advances **ISRO's capability in crewed and robotic interplanetary missions**.
- Enhances scientific understanding of **Moon's thermal dynamics and potential habitability zones**.
- Supports **international cooperation**, particularly in the **Indo-Pacific space research architecture**.

Model UPSC Mains Question

Q India's lunar missions, especially Chandrayaan-3 and the upcoming Chandrayaan-5, reflect the country's growing prowess in space technology. Discuss the scientific and strategic implications of India's lunar exploration program, with reference to the ChaSTE experiment.

WHITE HYDROGEN

Context:

France has recently discovered a **46 million-ton natural reserve of white hydrogen** in the **Lorraine Basin (Moselle region)**, drawing global attention to this underexplored source of clean energy.

What is White Hydrogen?

- **White hydrogen** refers to **naturally occurring, geologically produced hydrogen gas** trapped in underground rock formations.
- It is formed through **natural geological reactions**, such as:
    - **Serpentinization**: a reaction between **water and iron-rich minerals** in the Earth's crust.
    - **Radiolysis**: breaking of water molecules due to **radioactive decay** in rocks.
- Unlike **green** (from renewable-powered electrolysis) or **blue** hydrogen (from natural gas with carbon capture), **white hydrogen requires no human-induced production process.**

Key Features of White Hydrogen:

1. Naturally Formed:

- Produced in situ beneath the Earth's surface through slow, continuous chemical reactions over millions of years.

2. Low Carbon Footprint:

- As there's no industrial energy input required for its formation, **its extraction emits minimal or no CO_2**, making it one of the cleanest forms of hydrogen.

3. Economically Viable:

- Estimated **production cost of ~$1 per kilogram**, significantly lower than green hydrogen (which ranges between $3–6/kg).

4. High Energy Potential:

- One of the most **energy-dense and clean fuels**, white hydrogen could power sectors like **mobility, industry, and power generation**.

Significance of the Moselle Discovery (France):

- The **46 million-ton reserve** could power **global hydrogen demand for years**, making it one of the largest known natural deposits.
- The discovery has triggered international interest in **mapping and exploring natural hydrogen reserves**, especially in regions like the USA, Australia, Russia, and parts of Africa.

Advantages Over Other Hydrogen Types:

Feature	White Hydrogen	Green Hydrogen	Blue Hydrogen
Source	Naturally occurring	Electrolysis (renewables)	Natural gas with CCS
Carbon Emissions	Negligible	Zero (but energy-intensive)	Low (dependent on capture)
Production Cost	~$1/kg	$3–6/kg	~$2/kg
Energy Input	None (natural)	High	Moderate

Challenges Ahead:

- **Exploration & Mapping**: No global infrastructure or geological survey frameworks currently exist for systematic white hydrogen exploration.
- **Extraction Technology**: Requires development of safe, efficient drilling and storage systems to handle pure hydrogen.

- **Policy & Regulation**: Lacks dedicated international or national regulatory frameworks for natural hydrogen mining.

Significance for India:

- India's **National Green Hydrogen Mission** focuses on green hydrogen, but white hydrogen could offer:
  - A **low-cost, scalable, and clean alternative**.
  - Opportunity for **collaborative exploration** in geologically rich regions like the **Himalayas, Western Ghats, and Deccan Plateau**.
  - **Reduced reliance on imported fossil fuels**, aiding India's **net-zero emissions target by 2070**.

Model UPSC Mains Question

Q What is white hydrogen, and how does it compare with other types of hydrogen energy? Discuss its potential as a sustainable fuel source for India's clean energy transition.

GREAT RED SPOT

Context:

Recent space-based observations have revealed new insights about the **Great Red Spot** on **Jupiter**, showing that the atmosphere above and around this giant storm is more dynamic than previously known.

What is the Great Red Spot?

- The **Great Red Spot** is a **massive anticyclonic storm** (high-pressure system) located in **Jupiter's Southern Hemisphere**.
- It is the **largest known storm in the Solar System**, persisting for over **150 years**—possibly even longer.

Key Features:

1. Size & Scale:

- Diameter: **15,400 miles** (~24,800 km), **almost twice the size of Earth**.
- Covers roughly **one-sixth the diameter of Jupiter**.

2. Wind Speeds:

- Winds inside the storm reach up to **270 miles per hour (434 km/h)**.

3. Colour & Appearance:

- Appears as a **giant reddish oval**, but its **exact coloration source remains unknown**.
- May involve **chemical reactions between ultraviolet light and compounds like phosphorus or sulphur**.

4. Longevity & Stability:

- Unlike storms on Earth that weaken over land, Jupiter's lack of a solid surface allows storms to **persist for centuries**.
- The **deep atmosphere and energy from Jupiter's internal heat** may help sustain it.

5. Atmospheric Behavior:

- Recent data shows that **atmosphere above and around** the Great Red Spot is surprisingly **energetic and hot**.
- The storm extends **far above Jupiter's main cloud layers**.

Why Has It Lasted So Long?

- Jupiter is a **gas giant** with **no solid landmass** to interrupt or dissipate the storm.
- The planet's **fast rotation (10 hours)** helps generate and sustain strong jet streams.
- Possible **lack of surface friction** and **continuous internal heat** may contribute to its long-term existence.

Changes Over Time:

- Although persistent, the **Red Spot changes in size, shape, and color** over time.
    - It has **shrunk** significantly in recent decades.
    - Sometimes appears **more orange or pale**, influenced by chemical and atmospheric changes.

Scientific Significance:

- Provides clues about:
    - **Atmospheric dynamics** of gas giants.
    - The behavior of **high-pressure systems**.
    - **Storm evolution** in planetary atmospheres without solid surfaces.
- Helps researchers understand **climate and weather systems** beyond Earth.

Similar Phenomena:

- Other gas giants like **Saturn and Neptune** also exhibit **long-lasting storms**, though none match the scale or visibility of the Great Red Spot.

<u>Model UPSC Mains Question</u>

Q What is the Great Red Spot on Jupiter? Discuss the factors that contribute to its longevity and how its study enhances our understanding of planetary weather systems.

DOPPLER EFFECT

Context:

The Ministry of Consumer Affairs is inviting public feedback on proposed regulatory norms for **Doppler radar equipment** used in **speed detection of vehicles**, highlighting the growing role of radar-based enforcement and measurement technologies.

What is Radar?

- **Radar** (Radio Detection and Ranging) is a remote sensing technology that **uses radio waves** to detect and track objects.

- It **transmits electromagnetic waves** that reflect off objects (targets), and by analyzing the returned signals, it determines their **distance, speed, direction, and size**.

What is Doppler Radar?

- **Doppler radar** is a type of radar that uses the **Doppler Effect** to measure **velocity** (speed and movement direction) of objects such as:
    - **Vehicles** (for speed monitoring),
    - **Precipitation systems** (for weather forecasting),
    - **Cloud formations** and **wind speeds**.
- **Real-time applications** include:
    - **Weather forecasting**
    - **Aviation**
    - **Highway traffic enforcement**

What is the Doppler Effect?

- Described in **1842** by Austrian physicist **Christian Doppler**.
- It is the **apparent change in frequency** (or wavelength) of waves (sound, light, or radio) as perceived by an observer **moving relative to the source** of the wave.

Everyday Example:

- When an **ambulance siren** passes by, its pitch seems **higher as it approaches** and **lower as it moves away**—this is the Doppler Effect.

In Radar Use:

- A **moving object** (like a car or a storm cell) reflects radar waves **with a frequency shift**. This shift is used to calculate its **speed and direction**.

Types of Doppler Radars:

1. **X-band Radar**
    - Frequency: **8–12 GHz**
    - Use: Detecting **small particles** like **raindrops**, snowflakes
    - Pros: High resolution
    - Cons: Affected by **heavy precipitation**
2. **C-band Radar**
    - Frequency: **4–8 GHz**
    - Use: **Regional weather monitoring**
    - Pros: Moderate range and weather penetration
3. **S-band Radar**
    - Frequency: **2–4 GHz**
    - Use: **Long-range tracking** of weather systems (e.g., cyclones)
    - Pros: Effective during **heavy rainfall**

Applications of Doppler Radar:

1. **Weather Forecasting**
    - Tracks **rain intensity**, storm movement, wind speed, and **cyclone development**.
2. **Aviation**
    - Assists in detecting **turbulence**, wind shear, and **approaching weather systems**.
3. **Traffic Enforcement**
    - Used in **speed guns** to detect **over speeding vehicles**.
4. **Military & Defense**
    - Guides **missiles**, monitors **enemy aircraft**, and supports **border surveillance**.
5. **Healthcare**
    - Used in **Doppler ultrasound** to assess **blood flow** and detect **circulatory issues**.

Significance for India:

- Supports **real-time weather warnings** (e.g., cyclones, floods).
- Enhances **road safety enforcement** using radar-based speed monitoring.
- Critical for **space, defense, and disaster preparedness**.

Model UPSC Mains Question:

Q Discuss the principle and applications of the Doppler Effect in modern technology. How does Doppler radar contribute to disaster management and public safety in India?

INTERNATIONAL YEAR OF QUANTUM SCIENCE & TECHNOLOGY – 2025

Context:

The **United Nations General Assembly** has officially declared **2025 as the International Year of Quantum Science and Technology (IYQ)** to promote global awareness, education, and innovation in the field of quantum technologies.

Background:

- **Proposed by:** UNESCO (May 2023), led by **Mexico**.
- **Supported by:** Ghana at the UNGA in June 2024.
- Celebrates **100 years** since foundational developments in **quantum mechanics**.
- Aims to align with **UN Sustainable Development Goals (SDGs)**, especially in education, innovation, and partnerships.

What is Quantum Technology?

Quantum technology applies principles of **quantum mechanics**—the physics of the very small (atoms and subatomic particles)—to develop next-generation technologies.

Key Concepts:

- **Superposition:** A particle can be in **multiple states simultaneously** until observed.
- **Entanglement:** Particles become **interlinked**, and a change in one instantly affects the other, regardless of distance.
- **Quantum Tunnelling:** Particles can **pass through barriers** that are insurmountable in classical physics.

Core Areas of Quantum Technology:

1. **Quantum Computing**
    - Uses **qubits** to perform complex calculations in parallel.
    - Applications: **Cryptography, AI, climate modelling, financial forecasting, and drug discovery**.

2. **Quantum Cryptography**
    - Utilizes **Quantum Key Distribution (QKD)** for **unbreakable encryption**.
    - Ensures secure communication as any interception disrupts the quantum state.
3. **Quantum Sensing**
    - Enables ultra-precise **measurement of time, gravity, and magnetic fields**.
    - Crucial for **defense, geology, navigation, and medical diagnostics**.
4. **Quantum Communication**
    - Facilitates **ultra-secure data transmission**.
    - Paves the way for **quantum internet** and inter-satellite secure links.
5. **Quantum Materials**
    - Design of materials with superior properties, e.g., **superconductors** and **energy-efficient devices**.

India and Quantum Technology:

- India is the **7th country** globally to enter the quantum tech domain after the **US, China, Austria, Finland, France, and Canada**.
- **National Quantum Mission (NQM)** launched in 2023 with an outlay of ₹6,003 crore.
- Focus: Develop **quantum computers, quantum encryption systems, atomic clocks, quantum sensors**, and skilled workforce.
- **IIT-Bombay & TCS** developed India's **first quantum diamond microchip imager**.
- **World Quantum Day:** Celebrated annually on **April 14**.

Significance of IYQ 2025:

- Raises **global public awareness** of quantum science.
- Encourages **cross-border collaboration** in quantum research and innovation.
- Promotes responsible use of quantum tech to address challenges like **cybersecurity, healthcare, and climate change**.
- Supports curriculum development in quantum science for **future-ready education systems**.

Model UPSC Mains Question:

Q Quantum technology promises to revolutionize multiple sectors of the economy. Discuss its core principles and applications. Also, examine India's preparedness and policy direction in harnessing quantum advancements.

PRAVAHA – CFD Software by ISRO

Context:

ISRO has developed a new **Computational Fluid Dynamics (CFD) software** called **PraVaHa** – Parallel RANS Solver for Aerospace Vehicle Aero-thermodynamic Analysis – for simulating airflow and heat transfer around aerospace vehicles.

What is PraVaHa?

PraVaHa is an **indigenous CFD tool** developed by ISRO to simulate **fluid dynamics** and **aero-thermal behavior** of aerospace vehicles using **numerical methods**.

It solves **Reynolds-Averaged Navier–Stokes (RANS) equations**, which govern the conservation of:

- **Mass**
- **Momentum**
- **Energy**

These are critical for predicting **aerodynamic loads** and **heat transfer** in high-speed atmospheric flight.

Key Features:

Aerodynamic Analysis:

- Simulates **airflow behavior** around launch vehicles, spaceplanes, and reentry capsules.
- Calculates **lift, drag, pressure distribution**, and **shockwave interactions** during supersonic/hypersonic flight.

Aerothermal Analysis:

- Evaluates **thermal loads** due to atmospheric friction and **high-speed heating**.
- Useful for designing **thermal protection systems (TPS)** in spacecraft.

Parallel Processing:

- Built to run on **high-performance computing clusters**, allowing faster simulations for complex vehicle geometries.

Applications of PraVaHa:

1. **Gaganyaan Mission:**
    - Used for analyzing **HLVM3 human-rated launch vehicle**, **Crew Escape System (CES)**, and **Crew Module (CM)**.
    - Helps ensure **structural safety** and **thermal integrity** under various flight conditions.
2. **Reusable Launch Vehicles:**
    - Supports aerodynamic simulations for **winged vehicles**, such as RLV-TD.
3. **Hypersonic Testing:**
    - Enables the design and simulation of **vehicles flying at Mach 5 and beyond**, crucial for missions like **AVATAR** and **Scramjet demonstrators**.

Significance for India:

- **Reduces dependency on foreign software** like ANSYS Fluent or COMSOL.
- Aids in **cost-effective, accurate modeling** of complex aerospace problems.
- Promotes **self-reliance in space R&D**, aligning with Atmanirbhar Bharat.

Model UPSC Mains Question:

Q Discuss the significance of indigenous aerospace simulation tools like PRAVAHA in enhancing India's technological self-reliance. How do such innovations support missions like Gaganyaan and reusable launch vehicles?