VISIONIAS
INSPIRING INNOVATION

SCIENCE & TECHNOLOGY

Classroom Study Material 2025

JUNE 2024 TO MAY 2025

MAINS 365

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SCIENCE AND TECHNOLOGY

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Preface

To the Aspirant Who Dares to Dream

In the quiet corners of libraries across India, in the solitude of late-night study sessions, and in the hearts of millions who dare to dream of serving the nation, lies an unwavering determination to crack one of the world's most challenging examinations – the UPSC Civil Services Examination.

Mains 365 was born from that very spirit of determination and the recognition that success in UPSC CSE Mains 2025 demands more than just hard work; it requires strategic preparation, comprehensive understanding, and the ability to connect diverse streams of knowledge into coherent, impactful answers.

Q.1 Why 90% of UPSC aspirants fail to crack mains?

- **Scattered Information:** Jumping between multiple sources creates confusion.
- **Lack of Relevance:** Many resources fail to map current issues with the UPSC syllabus.
- **Missing Analysis:** Factual content without perspectives, stakeholders, or solutions lacks impact.
- **Overlooking Diversity:** Ignoring regional, gender, caste, and economic dimensions limits answer depth.
- **Poor Answer Structure:** Not knowing how to present knowledge effectively.

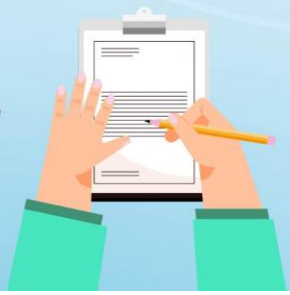
But what if you could overcome ALL these challenges with ONE comprehensive resource?

Q2. Why Mains 365 Science & Technology?

This document is your **one-stop annual compendium** of the most relevant, examinable developments in linking science with governance, economy, environment, and ethics, which helps in writing multidimensional answers strictly according to the UPSC syllabus and evolving examination pattern.

The document helps effectively prepare for the **Science & Technology** portion of **General Studies Paper III.** The document will focus on current and applied science topics, which are increasingly favoured in UPSC Mains. For example, instead of asking "What is DNA?", UPSC may ask "How does CRISPR-Cas9 gene editing technology impacts agriculture and health?"

Q3. How does it enhance answer writing?



Let's take a Question: Non-communicable diseases (NCDs) pose a major public health challenge in India. Discuss the key risk factors contributing to NCDs. Also, outline the major initiatives taken to tackle them and suggest way forward.

Answer: Mains 365 – Science & Technology enables you to answer such questions with ease and precision. For instance:

4.1.1. NON-COMMUNICABLE DISEASES (NCD)

Why in the News? → **CAN BE USED AS INTRODUCTION**

Ministry of Health & Family Welfare launched the Intensified Special NCD Screening Drive.

About Non-Communicable Diseases (NCDs)

- **NCDs** are **chronic diseases that are not transmissible** from one person to another.
- **Types: Cardiovascular diseases, cancers, chronic respiratory diseases** and **diabetes.**
- **Scenario:** NCDs accounts for **74% of all deaths globally** and **63%** of all deaths in India.

INTRODUCTION WITH DATA

Risks Factors for Non-Communicable Diseases (NCDs)

BODY PART : 1

Behavioural Risk Factors	Metabolic Risk Factors	Environmental Risk Factors
Tobacco use (including second-hand smoke)	Raised blood pressure (hypertension)	Outdoor air pollution
Unhealthy diets (excess salt, sugar, fats)	Overweight/obesity	Indoor air pollution
Harmful use of alcohol	High blood glucose levels (diabetes)	
Stress	Abnormal blood lipids (high cholesterol)	

Initiatives for Controlling NCDs

Global

- **SDG target 3.4** aims to reduce premature NCD mortality by **one-third by 2030.**
- **WHO Global Action** Plan for the Prevention and Control of NCDs **2023-2030**

BODY PART : 2

India

- **Affordable Medicines and Reliable Implants for Treatment (AMRIT)** to provide affordable medicines for the treatment of cancer, cardiovascular diseases etc.
- **National Tobacco Control Programme (NTCP):** To reduce production and supply of tobacco products etc.
- **National Programme for Prevention and Control of Cancer, Diabetes, Cardiovascular Diseases and Stroke (NPCDCS)** focuses on NCD prevention.

Recommendations for Prevention and Control of NCDs:

- **NCD Management:** Early detection, treatment, and palliative care via primary healthcare.
- **Digital Health:** Invest in low-cost tools (e.g., chatbots).
- **Fiscal Measures:** Use taxes on tobacco, salt, and sugar to reduce risk factors.
- **Life-Course Approach:** Integrate NCD policies with labour, social protection, and long-term care reforms.

SUGGESTIVE WAY FORWARD

Conclusion:

Non-communicable diseases are a major global health challenge but largely preventable through lifestyle changes, consuming food low in Glycemic Index, early detection, and strong public health measures. A collaborative approach is essential to reduce their impact and ensure better health outcomes.

Q4. What gives my answers extra credibility?

Credibility comes from incorporating relevant examples (like India's Quantum Mission, Bhuvan GIS), using precise terminology (e.g., Nano-urea) and presenting answers in a balanced, analytical format—all elements featured in this document.

Q5. How is it structured for the 3-hour examination?

The document mirrors UPSC's demand: each topic includes a background, applications, challenges, and way forward—ideal for intro-body-conclusion format. This structure helps complete answers within the ideal 7–9-minute window per question.

Q6. Any final pro tip?

Approach this document not as a book to read once but as a repository of frameworks. Internalize the use of contemporary examples and structure your answers with the cues provided. You'll write faster, think clearer, and score better.

Best Wishes,

Team VisionIAS

1. IT, COMPUTERS, ROBOTICS

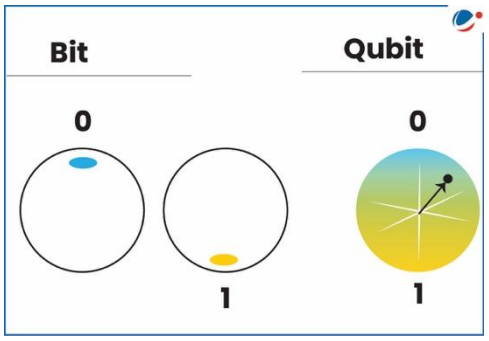
1.1. INTERNATIONAL YEAR OF QUANTUM SCIENCE AND TECHNOLOGY

Why in the News?

UN designated 2025 to be International Year of Quantum Science and Technology**.**

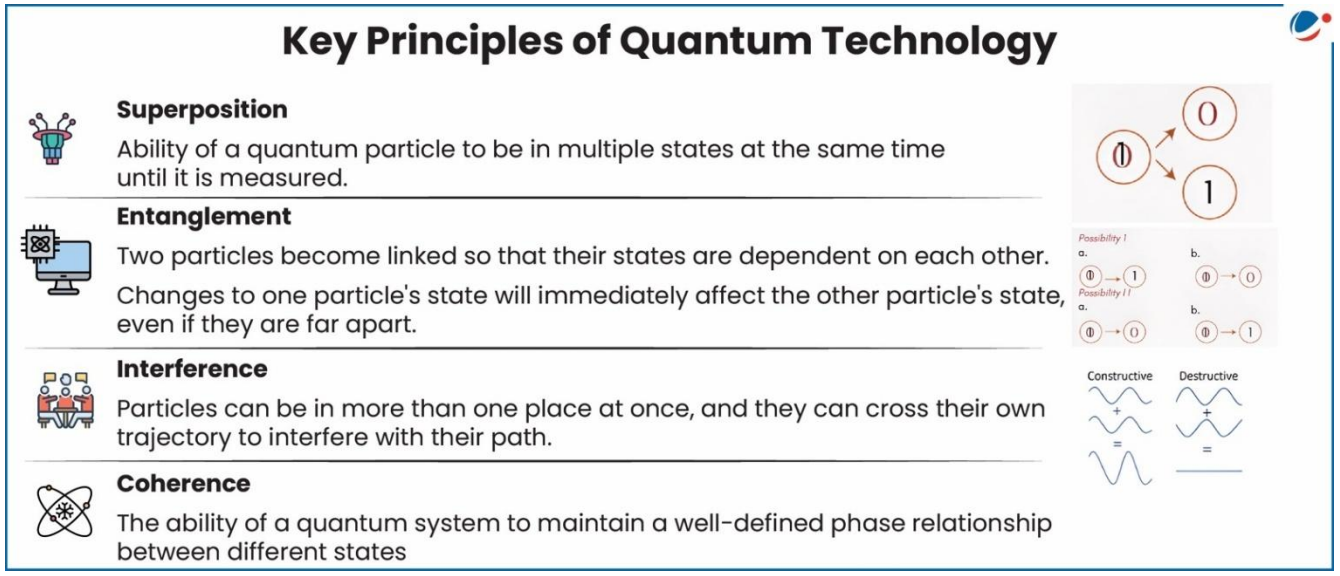
More about the News

- It recognizes 100 years since the initial development of **quantum mechanics when** German physicist **Werner Heisenberg** published a famous paper which led to its discovery.
- Also, **Google has recently launched Willow (quantum chip),** marking a milestone in the development of quantum computing.



About Quantum Chips and Computing

- While regular chips use 'bits' (0 or 1) to process information, quantum chips use **'qubits.**
  - A classical bit can only exist in either a 0 position or a 1 position.
  - Qubits, however, **can also occupy superposition**.
  - While qubits can encode three separate positions, **they are still used to convey information through a binary system.**



Key Applications of Quantum Technology				
Simulations: E.g. **In Health care & well-being (**advancing medical imaging and diagnosis) and Quantum chemistry (developing new vaccines and drugs).	**Communications:** Includes **Quantum key distribution (QKD** is a secure communication method for exchanging encryption keys only known between shared parties.)	**Sensing & Metrology:** E.g. measurements of forces, gravitation, electric fields, etc.	**Material & Devices:** Design and synthesis of Quantum Chips (E.g. Google's quantum chip Willow), etc.	**Quantum AI**: Enables advanced AI models by accessing training data beyond classical computer capabilities.

Challenges in development and adoption of Quantum Technology in India

- **Lack of Regulations**: No clear standards for hardware, software, and communication.
- **High Infrastructure Cost**: Advanced labs and equipment need heavy investment and upgrades.
- **Scalability Issues**: Difficult to scale quantum systems while maintaining coherence and low error.
- **Extreme Cooling Needs**: Qubits require near absolute zero temperatures.
- **Low R&D Spending**: Only ~0.64% of GDP; private sector lags in investment.
- **Tech Gaps**: Need for new quantum-specific programming languages, compilers, and tools.

India's Initiatives in the field of Quantum Technology

- **National Quantum Mission (2023):** Aims to create a vibrant & innovative ecosystem in Quantum Technology.
- **Quantum Enabled Science & Technology (QuEST):** A research program to build quantum capabilities.
- **Quantum Computing Applications Lab** (**QCAL**): To accelerate quantum computing-led research.
- **Other initiatives:** National Mission on Quantum Technologies & Applications (NMQTA), Quantum Computer Simulator Toolkit, Quantum Frontier mission**.**

Way Forward

- **Encourage Private Investment**: Use tax breaks, grants, and PPPs to attract companies.
- **Develop Regional Infrastructure**: Build research facilities across India for wider participation.
- **Create Regulatory Body**: Set up a central authority to govern quantum tech.
- **Enable Tech Transfer**: Bridge academia-industry gap for commercial use of research.
- **Strengthen IPR Framework**: Ensure clear rules for IP ownership, licensing, and transfer.

Conclusion

Quantum Technologies aims to boost innovation and build indigenous capabilities. Prioritizing real-world applications such as advanced drug discovery, and precision navigation can ensure quantum technology addresses critical societal and economic needs.

1.2. INTERNET OF THINGS (IOT) AT A GLANCE

Internet of Things (IoT)

- **Refers** to a network of physical devices, vehicles, appliances, and other objects that are embedded with sensors, software, and network connectivity, allowing them to collect and share data.
- It is part of the **larger 4th Industrial Revolution** that seeks the digital transformation by new technologies such as **artificial intelligence, additive manufacturing, augmented/virtual reality, and the Internet of Things (IoT).**

Applications of IoT

Healthcare: Remote patient monitoring, wearable health devices, telemedicine. **E.g., Fitbit, Apple Watch.**	**Agriculture:** E.g., **Fasal, wherein** Bengaluru-based startup provides **IoT-based precision farming** solutions for horticulture.	**Transportation:** Smart traffic systems, **E.g.** FASTag System (NHAI).	**Energy & Utilities:** Energy usage optimization, **E.g.,** India's Smart Meter National Programme.

Initiatives taken to promote IoT

Smart Cities Mission: Uses IoT for transport, water supply, and solid waste management.	**Centre of Excellence for IoT:** It is a Digital India initiative led by MeitY & NASSCOM.	**National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS):** Uses domains like AI, Robotics, IoT. It aims to converge all stakeholders- academia, industry, Government and International Organizations.	**Samarth Udyog Bharat 4.0:** Promote smart manufacturing (Industry 4.0) including IoT.	**Global Standards Initiative on Internet of Things (IoT-GSI) by ITU:** For development of technical standards enabling the IoT on a global scale.

Challenges related to IoT

Security and privacy: E.g. Smart healthcare devices and smart meters risk patient or user data leaks.	**Data overload:** IoT devices generate vast amounts of data, hindering the ability to extract meaningful insights.	**Power Consumption:** IoT devices require constant power or frequent charging, creating problems in remote, off-grid locations.	**Non-Interoperability:** due to the diverse range of devices, protocols, and platforms involved.	**Environment:** Rapid growth of IoT leads to **e-waste** generation and disposal issues.

Way forward to improve IoT

Expand BharatNet: To reach remote farms, enabling IoT in agriculture.	**Manage data effectively:** Businesses should have a clear data management strategy regarding data storage, analysis, and visualization.	**Encourage startups:** Like Stellapps (dairy IoT) through funding and incubation.	**Create national IoT standards:** For device compatibility, security, and data exchange.

1.3. ROBOTIC TECHNOLOGY AT A GLANCE

Robotic Technology

- **Robotic technology** includes **design, construction, operation,** and **use of robots,** that operate by sensing their environment, carrying out computations for decision-making, etc.
- **Status:** India ranks 7th in annual robot installations worldwide. (World Robotics 2024).

Applications of Robotics

Education: E.g., Manav: India's first 3D-printed humanoid robot for educational purposes.	**Healthcare: E.g.,** India's indigenous Surgical robotic system, **SSI Mantra.**	**Agriculture: E.g., TartanSense (BrijBot):** for precision spraying, weed detection, and crop monitoring.	**Space Exploration:** E.g., Vyom Mitra (A spacefaring humanoid robot being developed by the ISRO).	**Defence & Security: E.g., Daksha:** Remotely Operated Vehicle (ROV) developed by the DRDO.

Initiatives taken to promote Robotics in India

Draft National Strategy on Robotics, 2023: It provides for setting up **of the Robotics Innovation Unit (RIU).**	**Artificial Intelligence & Robotics Technology Park (ARTPARK)** in IISc Bengaluru.	**Center for Advanced Manufacturing for Robotics** and Autonomous Systems (CAMRAS).	**I-HUB for Robotics and Autonomous** Systems Innovation Foundation at Indian Institute of Science, Bengaluru.

Challenges in Robotics sector in India

High Costs: E.g., Agricultural robots remain out of reach for **small and marginal farmers** due to high costs.	**Limited Governance Mechanisms:** Absence of separate robotics legislation.	**Low R&D:** India lags behind countries like **Japan, USA, and South Korea** in patents and breakthroughs in robotics.	**Limited access to design, prototyping, and testing facilities:** For robotics further restricts innovation and development.	**Ethical Consideration:** Issues like job displacement, data security, and potential misuse of robots

Way forward for growth of Robotics

Formulate a National Robotics Policy to provide clear direction, standards, and incentives.	**Robotics Clusters could be developed** similar to Electronics Manufacturing Clusters (EMCs).	**Reimagine robot intelligence** with a focus on autonomy, adaptability, and evolution, rather than just pre-programmed tasks, to safely work alongside humans.	**Undertake** exploratory research through mission mode 'moonshot projects' without the assurance of near-term profitability or benefit.

1.4. BRAIN COMPUTER INTERFACES (BCIS)

Why in the news?

Neuralink's 'Blindsight', a Brain-Computer Interface (BCI) implant, received "breakthrough device" status by US Food and Drug Administration (FDA).

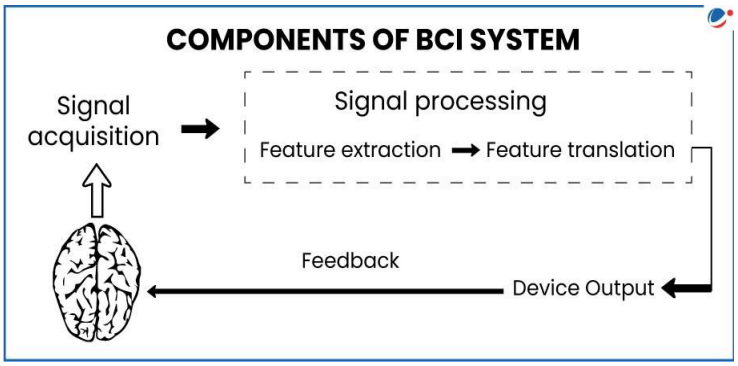
More on the News

- The 'Blindsight' Chip is aimed at helping blind patients to regain their sight.
  - However, regaining of sight will only be possible if the visual cortex is intact.

About Brain-Computer Interface (BCI) implant

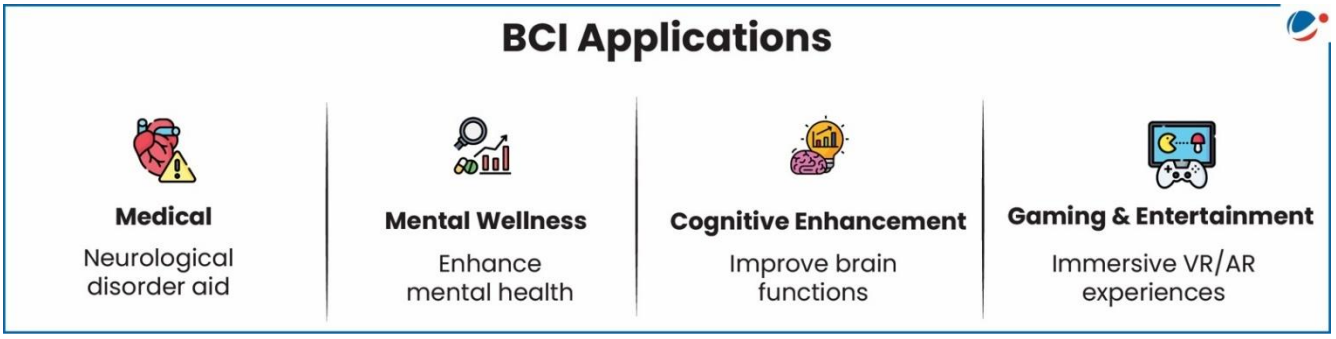
- It is a **computer-based system** that acquires brain signals produced by the **Central Nervous System (CNS),** and translates them into commands for a desired action.

- It is **not a voice-activated or muscle-activated** communication system to read minds**.**
- **An important aspect of BCI is feedback** that helps user **adapt to BCI system.**



Types of BCIs

- **Invasive BCI (Brain Implants)**: E.g., **Neuralink's Implant.**
- **Non-invasive BCI (Surface Detectors) with electroencephalograph (EEG)** attached to scalp.
- **Partially Invasive BCIs (Dura Mater Implant):**
  - **E.g., Electrocorticography (ECoG)** records brain activity by placing electrodes in direct contact with cerebral cortex or surface of the brain.



Challenges in Brain Computer Interfaces:

- **Technical:** Inability to interpret complex neural patterns, environmental interference etc.
- **Risk of infection:** Invasive BCI can damage nerve cells and blood vessels.
- **Brain Tapping**: Intercepting brain signals can compromise privacy, revealing emotions, preferences etc.
- **Stimuli Attacks**: Manipulating feedback could lead to potential influencing behaviour.
- **Cyborgization:** It refers to the process of integrating biological organisms with artificial components, blurring the lines between humans and machines. **E.g.,** Computer-assisted brains, and Built-in weaponry.
- **Ethical Issues:** Neuralink's clinical trials are not registered in the US National Institutes of Health repository Clinical Trials, widening the information and trust gap.
  - There is a view that BCI-mediated action has some characteristics that distinguish it from ordinary behavior, which might go beyond the obtained consent.

Conclusion

BCI implants hold immense potential for communication, and human-machine interaction. Balancing innovation with ethical safeguards, accessibility, and long-term societal impacts will be key to ensuring BCI technology serves humanity responsibly.

1.5. ORGAN-ON-CHIP (OOC) TECHNOLOGY

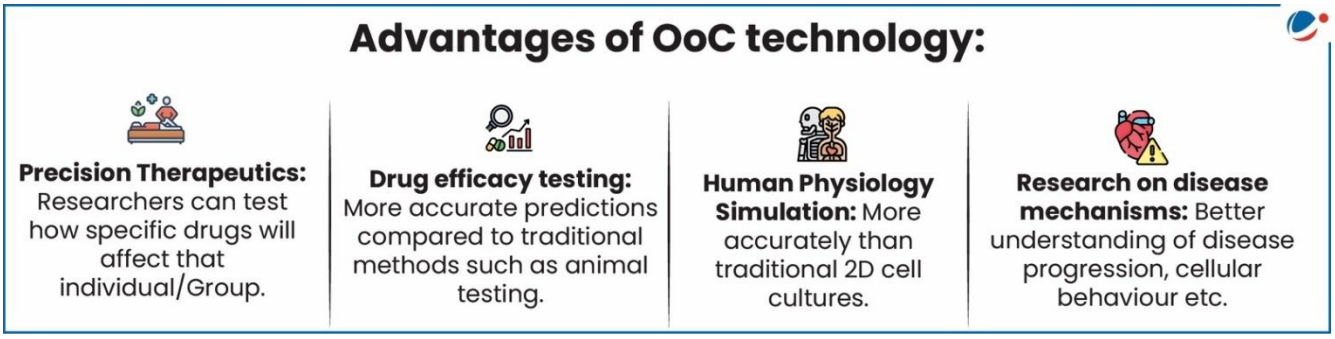
Why in the news?

Organ-on-chip technology, expected to be worth around $1.4 billion by 2032, could boost BioE3 (Biotechnology for Economy, Environment, and Employment) goal to personalize medicine.

Organ-on-Chip (OoC) Technology

- It is **human-relevant 3D culture models which,** also known as **'New Approach Methods' (NAMs).**
  - **3D culture system** allows researchers to recreate human organs and diseases in one dish.

- It is a **micro-scale system** used for **mimicking the human body environment.**
- **Working: Cells** are placed on chip and allowed to grow into **3D structures**.
    - It uses tiny fluid channels to create miniature models of biological organs on chip sized device.



Organ-on-a-Chip device has four key components:

- **Microfluidics**: This **uses tiny channels to deliver cells** to specific locations.
- **Living Cell Tissues**: It involves arranging specific cell types in the right places to mimic tissue functions.
- **Drug Delivery**: Certain tissues need signals to create a realistic environment for tissue growth.
- **Sensing**: To track and measure data to evaluate the chip's function.

Steps taken for development of Precision Medicine and Organ on chip technology:

- **Amendment of New Drugs and Clinical Trials Rules 2019:** To permit the use of human organs-on-chips.
- **Phenome India Project:** To advance precision medicine.
- **Indian Cancer Genome Atlas (ICGA):** To create a database of cancer data specific to India.

Conclusion

Organ-on-chip technology holds great promise for advancing drug discovery, disease research. With continued investment and innovation, organ-on-chip systems could play transformative role in future healthcare solutions.

1.6. BLOCKCHAIN TECHNOLOGY AT A GLANCE

Blockchain Technology

Blockchain is a decentralized distributed ledger technology to securely record data and transactions over a peer-to-peer network.

Applications of Blockchain Technology

Cryptocurrencies: E.g., Bitcoin, Ethereum offer features like Decentralization, limited supply, borderless transaction.	**Supply Chain Management :** E.g., Coffee Board of India uses blockchain to trace coffee production.	**Voting Systems: E.g. India has developed a** Remote voting system that enables encrypted vote for migrant voters.	**Intellectual Property Protection E.g.,** ResonanceIP Project in collaboration with WIPO uses Blockchain to protect music IP rights.	**Records Management: E.g.,** Blockchain-based **Electronic Health Records (EHRs)** for patient data security.	**Strategic: Eg.** Strategic Crypto Reserve (by USA) is **a government-held stockpile of cryptocurrencies** maintained as **part of national financial reserves** to hedge against economic uncertainties.

Initiatives taken to develop and promote blockchain technology

National Strategy on Blockchain (2021): To create trusted digital platforms through shared Blockchain infrastructure.	**Future Skills PRIME:** For upskilling in Blockchain.	**World Economic Forum's Presidio Principles** for designing blockchain applications.	**Centre of Excellence in Blockchain** (NASSCOM & MeitY).	Vishvasya or National Blockchain Technology Stack which offers **Blockchain-as-a-Service (BaaS) and is** part of the broader **National Blockchain Framework (NBF).**

Challenges related to Blockchain Technology

Non-Interoperability: Different blockchain platforms are often **incompatible** with each other.	**Storage:** Demands heavy storage as data stored is replicated at all the nodes and becomes perpetual.	**Energy Consumption:** Some blockchain models **(like Proof-of-Work)** consume excessive **electricity and computing power.** It further escalates with need for the systems to be kept cool to function.	**Lack of Skilled Workforce:** Despite initiatives like **Kerala Blockchain Academy,** demand far exceeds the supply of talent.	**Legal:** Although Section 43A of the **IT Act, 2000** provides for compensation for failure to protect data but does not have safeguards from the perspective of blockchain.

Way forward to further streamlining Blockchain

National Level Blockchain Framework (NLBF) for scaling, deployments for developed applications, creating shared infrastructure, etc.	**Focus on research in the domains of** interoperability, scalability & performance, consensus mechanisms etc.	**Expand Use Cases Beyond Cryptocurrency E.g.,** Maharashtra State Blockchain Sandbox for land records and agriculture.	**Shift towards** energy-efficient models like Proof-of-Stake or consortium blockchains.

1.7. ARTIFICIAL INTELLIGENCE (AI) AT A GLANCE

Artificial Intelligence (AI)

- Enables computers to **simulate human intelligence** and **problem-solving capabilities.** It includes learning, reasoning, problem-solving, and language understanding.
- **Technologies involved:** Machine Learning, Deep learning, Large Language Models, etc.
- **Potential:** AI is expected to raise India's annual growth rate by **1.3%** points by 2035 and can add $1 trillion to India's economy by 2035 (NITI Aayog).

Applications of AI

Generative AI: To create original content—such as text, images, video, audio or software code—in response to a user's prompt or request.	**Education:** **E.g.,** AI-driven Optical Mark Recognition (OMR) systems in entrance exams.	**Manufacturing** **E.g.,** Tata Steel uses AI-driven predictive maintenance to monitor equipment health.	**Energy:** **E.g.,** NTPC uses AI for **solar and wind energy forecasting** to optimize power generation.	**Agriculture:** **E.g.,** use of **Agri-bot,** for Weather forecast, Smart drones, Farming Data.

Initiatives taken to promote AI

IndiaAI Mission: A comprehensive **national-level program to democratize and catalyze the AI innovation ecosystem through PPP.**	**National AI Portal (INDIAai):** A joint venture by MeitY, National e-Governance Division **(NeGD) and NASSCOM.**	**AI Research Analytics and Knowledge Dissemination Platform (AIRAWAT):** provides a common compute platform for AI research.	**BharatGen Programme:** Focused on creating **Generative AI systems** in various Indian languages.	**National AI Skilling Program:** Enhancing AI skills through customized training modules with industry leaders.

Challenges related to AI

Data Privacy and Security: AI systems rely heavily on large datasets, often containing **sensitive personal information.**	**Ethical Issues:** Biased AI models can make decisions that unfairly target or exclude certain groups, etc.	**Lack of Transparency:** Internal workings of AI Based model are not known by users (considered as black boxes).	**Infringing Intellectual property rights:** Many artists have claimed that their artworks were recreated by AI	**Accountability:** For instance, who will be held liable in case of accident of a self-driving car

Way forward

Strengthen data protection laws (like India's Digital Personal Data Protection Act, 2023) to safeguard users' privacy.	**Invest in Explainable AI (XAI)** research to make algorithms **interpretable and accountable.**	**Inclusive AI Development:** Design AI systems that reflect diverse languages, cultures, and social contexts, etc.	**Promote "Responsible AI for All" strategy by NITI Aayog** promotes ethical and inclusive AI development.

1.7.1. NOBEL PRIZE IN PHYSICS 2024

Why in the News?

Nobel Prize in Physics 2024 has been awarded to **John J. Hopfield and Geoffrey Hinton** for foundational discoveries and inventions that **enable Machine Learning (ML) with Artificial Neural Networks (ANNs)**.

About the Discovery

- **John Hopfield invented Hopfield network**, a type of **recurrent neural network** that can **store and reconstruct information**.
  - These networks work like a memory system, where they can **store patterns (like images) and retrieve them.**
  - Hopfield networks can be used for **tasks like image recognition and data reconstruction**, making them valuable for various applications in machine learning.
- **Geoffrey Hinton** invented a method (**Boltzmann machine**) that can **independently discover properties in data** and has become **important for large ANNs** now in use.
  - Boltzmann Machine is an **early example of a generative model**, which can **create new patterns or examples** based on what it has learned.

Artificial Neural Networks (ANNs)

- **Definition:** ANN is a **ML program or model** that makes decisions in a **manner similar to the human brain**.
- **Working: Human brain is the inspiration** behind neural network architecture.
  - Human brain cells, called **neurons**, form a complex, **highly interconnected network** and **send electrical signals** to each other to help humans process information.
  - Similarly, an ANN is made of **artificial neurons or nodes** that work together to solve a problem.

Conclusion

The 2024 Nobel Prizes highlight transformative advancements at the intersection of biology, chemistry, and artificial intelligence. These achievements reinforce the importance of interdisciplinary research in addressing complex global challenges and advancing human well-being.

1.8. AI GOVERNANCE AT A GLANCE

AI Governance

AI governance refers to the processes, standards and guardrails that help ensure AI systems and tools are safe and ethical.

8 principles for AI governance

Transparency: AI systems should provide meaningful information about their development, capabilities, and limitations.	**Accountability:** Developers and deployers must take responsibility for AI outcomes.	**Safety, Reliability & Robustness:** AI systems should be resilient to risks, errors, and misuse	**Privacy & Security:** AI systems must comply with data protection laws.	**Fairness & Non-Discrimination:** AI systems should avoid biases and ensure inclusivity.	**Human-Centered Values:** AI systems shouldrespect human oversight and ethical considerations.	**Inclusive & Sustainable Innovation:** AI should distribute benefits equitably.	**Digital by Design Governance:** Leverage digital technologies for effective governance and compliance.

Initiatives taken to Regulate AI

National Strategy for AI (NSAI): NITI Aayog's #AIforAll promotes AI in healthcare, agriculture, and education.	**Responsible AI Principles:** NITI Aayog's guidelines emphasize ethics and accountability with actionable steps.	**Bletchley Declaration, 2023 (India is a signatory):** Signed by 28 countries and the EU, outlines AI opportunities and risks.	**Global Partnership on AI Ministerial Declaration (New Delhi Declaration), 2023:** Built consensus among GPAI members on advancing safe, secure, and trustworthy AI	**Hiroshima AI Process** by G7 nations to determine way forward on regulation of AI.	**European Artificial Intelligence Act** that follows a risk based approach and prohibits certain practices wherein AI violates ethics and safety norms.

1.9. AI AND HEALTHCARE AT A GLANCE

AI and Health Care

AI is revolutionizing healthcare by enhancing diagnosis, treatment, and patient monitoring, leading to more accurate results and personalized care.

Applications of AI in HealthCare Sector

Diagnosis and Treatment Planning: Analyses imaging (such as X-rays), helps in identifying diseases. Eg., Tata Elxsi, is working on AI-powered medical imaging solutions.	**Clinical research and discovery: E.g.** ProteinSGM, a Generative AI model used for protein designing.	**Virtual Health Assistants and Chatbots: E.g.,** Practo is employing the multilingual ability of AI to power its telemedicine service**s.**	**Personalized Medicine: E.g.,** Bengaluru-based startup has developed a digital pathology platform that can by itself analyse blood samples remotely.

Initiatives taken to promote AI in healthcare sector

AI based Health Care Start-ups, E.g., AI based healthcare start-up, **Wadhwani AI** is developing various interventions related to the TB patient care.	**Ayushman Bharat Digital Mission (ABDM),** leverages AI to enhance healthcare delivery and efficiency in India.	**Ethical Guidelines for Application of AI in Biomedical Research and Healthcare** released by ICMR	**iOncology.ai.,** by **All India Institute of Medical Sciences (AIIMS) Delhi for cancer detection.**	**National Health Stack (NHS):** It includes National Health Analytics Platform.

Steps to be taken to further integrate AI in Healthcare

Enhance Doctor-AI Collaboration: Include AI in **medical curriculum** and promote interdisciplinary research.	**Promote Affordable and Scalable AI Solutions:** Scale up initiatives **like Qure.ai, Niramai, and eSanjeevani** across India.	**Incentivising core and applied research in AI.** Public sector investment, particularly in R&D, helps drive private investment.

1.10. AI AND AGRICULTURE AT A GLANCE

AI and Agriculture

The application of AI in agriculture has been widely considered as one of the most viable solutions to address food inadequacy and to adapt to the need of a growing population.

Applications of AI in Agriculture Sector

Pest Management: AI-based pest surveillance systems, like the National Pest Surveillance System aids farmers for healthy harvest.	**Agritech and Data Management:** The "Saagu Baagu" project under AI4AI has enhanced yields and incomes for 7,000 Chilli farmers from Telangana, doubling their earnings.	**Soil Health:** Startups like Fasal and CropIn have developed systems that reduces input costs by up to 20% while improving yields through balanced nutrition.	**Precision Farming: E.g.,** In Karnataka, villages are adopting AI-based smart farming systems that automatically optimize irrigation and fertilization schedules.

Initiatives taken to promote AI in Agriculture

National Strategy for Artificial Intelligence of NITI Aayog emphases on implementing AI in agriculture.	**AI for Agriculture Innovation (AI4AI) initiative,** launched by the World Economic Forum.	**Kisan-eMitra,** an AI Chatbot for the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) Scheme	**National e-Governance Plan in Agriculture (NeGPA):** Promoting the use of modern technologies like AI, Machine Learning, and Data Analytics.

Challenges in implementing AI in agriculture

Accuracy: Missing data in parameters like **soil** health, **local** micro-climates, or pesticide usage.	**High Cost of AI Technology:** Agricultural drones typically cost between Rs 4-5 lakh and have a payload capacity of around 8-10 litres.	**Low Digital Literacy among Farmers:** Many farmers are unfamiliar with using **digital apps or interpreting AI-driven** advisories.	**Fragmented Landholdings:** It make it difficult to implement **uniform AI solutions** like automated irrigation or robotic weed control.

Way forward

Promote Farmer Awareness: Use **Krishi Vigyan Kendras (KVKs)** and extension services to introduce AI tools	**Encourage Localized and Language-Friendly AI Solutions:** Promote voice-assisted and low-tech AI interfaces for smallholder farmers.	**Integrate AI in research and development (R&D)** within institutions like ICAR and state agriculture universities	**Ensure data privacy,** ownership rights, and informed consent under initiatives like AgriStack.

1.11. DEEPFAKES

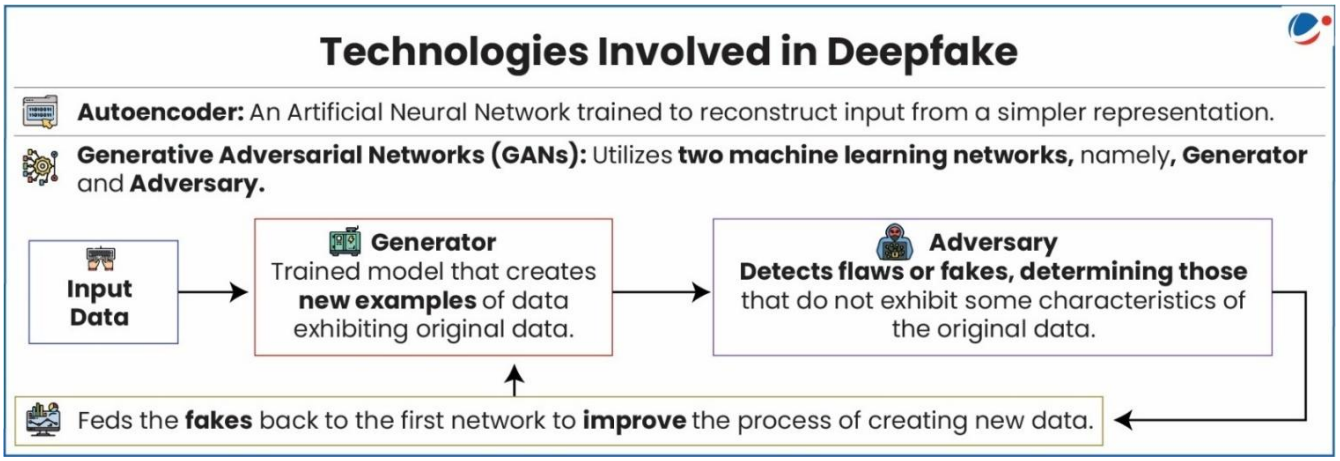
Why in the News?

Recently, the US enacted **Take It Down Act to** tackle harmful deepfakes online.

What are Deepfakes?

- **About:** Deepfake is a **video, photo**, or **audio recording** that seems real but has been **manipulated with AI** blurring the line between **reality** and **manipulation**.
- **Technology Used is "Deep learning"** that represents a subset of **machine learning.**
  - It involves **replacing faces, manipulating facial expressions, synthesising speech, appearing to say or do things** not actually done.

- **Potential Applications:**
  - **Entertainment** (creative effect in movies).
  - **E-commerce** (creating customers likenesses for virtual trial of clothes).
  - **Communication** (Speech synthesis for speaking in another language), etc.



- **Regulation:**
  - **India:** India lacks **specific laws** for **deepfakes and AI-related crimes,** but provisions under some existing legislations offers both civil and criminal relief. **For instance:**
    - **Legal Framework**
      - ✓ **Information Technology Act, 2000 (IT Act):** Applicable to information generated using AI tools.
      - ✓ **IT Rules, 2021:** Provides for **Grievance Appellate Committees** for victims to appeal online.
    - **Institutional**
      - ✓ **Indian Computer Emergency Response Team (CERT-In):** Published an **advisory** on deepfake threats. Operates the **Cyber Swachh Kendra** (Botnet Cleaning and Malware Analysis Centre).
      - ✓ **Indian Cyber Crime Coordination Centre (I4C):** Deals with cyber-crimes in a coordinated manner.
      - ✓ **National Cyber Crime Reporting Portal:** Operationalised a toll-free Helpline number **1930.**
  - **Global:**
    - **EU's Artificial Intelligence Act (AI Act)**.
    - **Italy:** Prohibits the unauthorised use of a person's likeness.

Concerns associated with Deepfakes

- **National Security Risk:** Fake videos can spark violence, disrupt investigations, or create false alibis.
- **Erodes Trust in Democracy:** Fake political content can mislead the public.
- **Victimising Women:** Approximately 90–95% of deepfake videos since 2018 have been non-consensual pornography.
- **Cyberbullying:** Rumours spread faster when coupled with fake images or videos, harming reputations.
- **Identity Theft:** Fake identification documents enable cybercriminals to impersonate individuals or access secure systems.
- **Costly Computation:** Detecting videos (versus images) requires huge investments in computing resources and data handling**.**

Way Forward on dealing with the issues of Deepfakes

- **Enhanced Regulation:** Focus on proactive action, not just post-incident responses.
- **Technological Advancements:** Massachusetts Institute of Technology (MIT) created a **Detect Fakes website** to help people identify deepfakes by focusing on **small intricate details.**
- **Cyber Literacy: Promote media literacy** and **critical thinking** incorporating **digital trust** to protect all**.**

Conclusion

The Indian legal solution to DeepFakes should involve privacy rights, ownership of data, defamation, cybercrime, and intellectual properties protection. Equipping law enforcement agencies and the judiciary with required tools and competencies for investigations as well as prosecutions of offences related to deep fakes

1.12. BIG DATA

Why in the News?

India has joined the UN Committee of Experts on Big Data and Data Science for Official Statistics (UN-CEBD)

About Big Data

- **Definition:** Data whose scale, diversity, and complexity require new architecture, techniques, algorithms, and analytics to manage it and extract value and hidden knowledge from it. It includes
  - **Structured data** (inventory database, list of financial transactions);
  - **Unstructured data** (social posts or videos);
  - M**ixed data sets** (used to train large language models for AI).
- **Major Initiatives for Big Data in India:** Establishment of Centre of Excellence, National Data and Analytics Platform etc.

Applications of Big Data in Various Sectors

- **Logistics: Swiggy in India leverages big data** to assign delivery partners the shortest and most efficient routes.
- **Marketing and Advertising:** Netflix and Amazon use big data to drive personalization and customer satisfaction.
- **Smart Cities:** Resource management, improved infrastructure planning, and AI-driven solutions to urban challenges.
- **Education:** Personalized learning, improving educational quality.
- **Earth Sciences:** Climate and earth studies, weather modelling, and prediction.

Challenges of Big Data

- **Managing Massive Data:** Traditional storage can't handle petabytes or exabytes of data.
- **Handling Diverse Data Types:** Integrating structured, semi-structured, and unstructured data is complex.
- **Challenge of Processing:** Fast data streams from IoT, social media, etc., need immediate processing.
- **Security and Privacy:** Rising threats of breaches and strict regulations (GDPR)
- **Data Analytics: Extracting Insights:** Scaling analytics and shortage of skilled data scientists.

Conclusion

To harness Big Data's full potential, organizations must address challenges like storage, integration, real-time processing, and security. By adopting scalable infrastructure, AI tools, strong data governance, and upskilling talent, Big Data can become a driver of innovation and strategic growth.

1.13. SUPERCOMPUTERS

Why in the News?

Recently, three Param Rudra Super Computing Systems and a High-Performance Computing (HPC) system for weather and climate research under the National Supercomputing Mission (NSM) were launched.

What is a Supercomputer?

- It is a high-performance computing system that delivers exceptional processing power and computational capacity.

- Performance is measured in **floating-point operations per second (FLOPS)** instead of million instruction per second (MIPS) used for regular computers.

- **India's supercomputers:**
  - First: **PARAM 8000** (set up in 1991).
  - India's **largest and fastest AI** supercomputer **AIRAWAT** (with a speed of 13,170 teraflops) was ranked 75th in the Top 500 Global Supercomputing List of 2023.

About the National Supercomputing Mission (NSM)

- **Launched** in 2015.
- **Objective**: To make India one of the world leaders in Supercomputing.
- **Jointly steered by:** DST and MeitY.
- **NSM envisages:**
  - **Installing network of supercomputers with cumulative capacity of 45 PetaFlops**.
  - **Connecting these supercomputers** on National Supercomputing grid– which connects academic institutions and R&D labs over a high-speed network.
  - Development of highly professional High-Performance Computing aware **human resource.**

Applications of Supercomputers

- **Cutting Edge Research**: **Param Pravega supercomputer** caters to quantum mechanics.
- **Governance:** Use of **AIRAWAT system** for language model development for **Digital India BHASHINI program.**
- **Weather forecasting: 'Pratyush'** supercomputer is dedicated to weather and climate research.
- **Internal Security: AIRAWAT-PSAI** was leveraged by C-DOT to identify issuance of benami SIM cards.
- **Health and Medicine**: **PARAM Shakti** facilitated extensive screening of various cancer specific receptors.
- **Disaster Management: PARAM Ganga** was utilized for a study on cloud bursts in Uttarakhand.

Challenges for India

- **Processing & Storage**: Huge data volumes need massive storage space.
- **Energy Demand**: Clusters of processors consume high power.
- **Thermal Management**: Advanced cooling required to prevent heat damage.
- **High Costs**: Design, setup, and maintenance are expensive.
- **Human Resources**: Shortage of skilled personnel to manage supercomputers.
- **Foreign Dependency**: Reliance on China for semiconductors and limited tech sharing from the West.

Way Forward

- **Domestic Manufacturing**: Fast-track India Semiconductor Mission for self-reliant supply chains.
- **R&D Funding**: Increase resources and foster public-private partnerships in HPC.
- **Skilled Workforce**: Establish training programs at C-DAC, IITs, and promote academia-industry collaboration.
- **Green Supercomputing**: Invest in energy-efficient technologies and cooling systems.
- **International Partnerships**: Learn from collaborations like Europe's EuroHPC initiative.

Conclusion

The National Supercomputing Mission strengthens India's global supercomputing position by promoting indigenous development and innovation. With sustained investment, India is set to become a global leader in High-Performance Computing.

1.14. 3-D PRINTING TECHNOLOGY AT A GLANCE

3D Printing Technology

3D printing, or **additive manufacturing**, is a process of creating three-dimensional objects from a digital file **by adding material layer by layer** until the final form is achieved.

Applications of 3-D Printing

Aerospace: **E.g.** Agnikul Cosmos has successfully launched world's first single-piece 3D printed rocket engine SOrTeD.	**Automotive:** **E.g.,** The Mahindra Group has integrated AM into its design process, streamlining prototype development.	**Construction:** **E.g.,** 'Amaze 28', Kerala's first 3D printed building at PTP Nagar KESNIK campus, was constructed in 28 days.	**Healthcare:** **E.g.,** Osteo3D, based in Bangalore, has led 3D printing medical models and surgical guides.	**Consumer Goods:** **E.g.,** Tanishq is making complex designs with 3D printing.

Initiatives taken to promote 3-D printing

National Strategy for Additive Manufacturing, 2022 by **MeitY:** Aspires to achieve 5% of Global AM market share and add nearly US$ 1Bn to the GDP by 2025.	**National Institute of Electronics & Information Technology,** Aurangabad, has established **a 3D printing lab.**	**National Centre for Additive Manufacturing,** set up by MeitY in collaboration with **Telangana in 2023.**	**Centre of Excellence in Additive Manufacturing (AM)** established by IISc for high-performance metallic alloys.

Challenges related to 3-D printing

Expensive: Initial investment in equipment is substantial.	**Limited Materials:** Selection of plastics and metals is not exhaustive.	**Import Dependency:** India depends heavily on imported 3D printers and raw materials.	**Restricted Build Size:** Print chambers have small sizes, larger parts need to be joined after printing.	**Limitations in design:** Layers can delaminate under stress due to the layer-by-layer production process.

Way forward to improve 3-D printing

Encourage domestic production of 3D printers and raw materials to reduce import dependency and costs.	**Promote joint R&D projects between universities,** research institutions, and industry to drive innovation and practical applications.	**Adopting governance mechanism** to regulate standards and other related aspects.	**Promote Sustainable Practices E.g.** use of biodegradable or recyclable materials and energy-efficient printing processes to make 3D printing

1.15. 4D PRINTING

Why in the News?

Indian Researchers developed 4D-Printed Artificial Blood Vessels for Advanced Medical Grafts

About 4D printing

- 4D printing evolves from **3D printing by adding the dimension of time.**
- 4D printed objects **can change shape or function over time in response to environmental stimuli** such as heat, light, or moisture etc.

Applications:

- **Medical Application:** Drug delivery, tissue fabrication, and organ regeneration etc.
- **Soft Robotics:** Due to its Flexibility, deformability with respect to Environment.
- **Aerospace:** By enabling low-cost, durable parts that adapt to extreme conditions. E.g. Nitinol alloy manufacturing.
- **Others:** sensors and flexible electronics, active origami art, self-evolving structures etc.

Advantages:

- **Dynamic Functionality:** By creating adaptive structures beyond the capabilities of traditional 3D printing.
- **Material Efficiency:** By reducing wastages.
- **Complex Design fabrication:** Stereo lithography 4D technique fabricates complex designs efficiently.

Challenges:

- **Unavailability of Technologies:** Limited to few research institutes in the world
- **Material Limitations:** For e.g. Degradation issues on continuous deformation.

Conclusion

4D printing advances 3D printing by enabling dynamic functionality. **Continued material innovation and broader adoption are crucial for unlocking its full potential.**

1.16. KEY WORDS

Keywords				
Quantum Computing	Superposition	Entanglement	National Quantum Mission	Internet of Things (IoT)
Cyber-Physical Systems	Vyom Mitra	Brain-Computer Interfaces	Neuralink	Organ-on-chip Technology
Super-Computers	Blockchain	Decentralized Ledger	4D printing	Additive Manufacturing

1.17. PRACTISE QUESTION

Answer Canvas

What are Brain-Computer Interfaces (BCIs)? Discuss their types and emerging applications. Highlight the key challenges associated with their adoption.

Introduction	Body Part: 1	Body part: 2	Conclusion
Introduce BCIs	Types and Application	Challenges in BCI with examples.	Suggestive way forward tackling technical and other issues.

2. BIOTECHNOLOGY, NANOTECHNOLOGY AND ISSUES RELATING TO INTELLECTUAL PROPERTY RIGHTS

2.1. BIOTECHNOLOGY AT A GLANCE

Biotechnology

- India's bioeconomy has grown from **$10 billion** in **2014** to **$165.7 billion** in **2024,** with a target of $**300 billion** by 2030. (India Bio-economy Report 2025).
- The sector contributes **4.25% to GDP**

Applications of Biotechnology

Environment: **E.g.** BioEnviro Tech (BET) has developed Toxicity Odor Corrosion Sulfides (T.O.C.S.) Remission System for hydrogen sulfide reduction in municipal and industrial wastewater sewer.	**Health & Medicine:** **E.g.,** Recombinant DNA technology has led to the development of drugs like insulin, human growth hormone.	**Agriculture:** Income rose by 40–50% through improved bio-fortified rice in Chhattisgarh.	**Bioenergy:** UNATI Mission Clean Technologies for Swachh Bharat to convert different solid, liquid and gaseous wastes into renewable fuels.	**Space Biotechnology:** Axiom-4 mission and Gaganyaan mission for conducting microgravity, radiation, disease modelling research in long duration space missions

Initiatives taken to promote Biotechnology in India

Biotechnology for Economy, Environment and Employment Policy by DBT, for fostering **High-Performance Biomanufacturing** by adoption of cutting-edge advanced technologies.	**Biotechnology Ignition Grant (BIG):** Up to ₹50 lakh for 18 months to support early-stage startups	**National Biopharma Mission (NBM):** For biopharmaceuticals, vaccines, biosimilars, medical devices, and diagnostics.	**National Speed Breeding Crop Facility** at the National Agri-Food Biotechnology Institute (NABI) in Mohali.	**National Biotechnology Development Strategy (2021-25):** To make India globally competitive in biotechnology and be a **USD 150 billion** Bioeconomy by 2025.

Challenges related to Biotechnology

Low R&D: Less than 1% of India's GDP.	**Intellectual Property Right regime:** Strict standards under Patents Act 2005 and Compulsory licensing.	**Ethical Issues: E.g.** Bio piracy, Designer Babies, Human clinical trials.	**Biosafety and Biosecurity Risks:** Risks of accidental release of genetically modified organisms (GMOs), bioterrorism.	**Genomic Data Security:** Companies handling large genomic databases face the challenge of protecting data.

Way forward to promote Biotechnology

Launch programmes like i3c BRIC-RCB-PhD Program for building a skilled workforce.	**Investing in AI tools for drug discovery,** as seen with startups like **Elucidata** (building an analytical platform for drug discovery teams).	**Collaboration between government** and industry for improving IP regime	**Extend and design PLI schemes** specifically for the biotech sector, particularly for **high-value biopharmaceuticals,** diagnostics.	**Encourage Bio-entrepreneurship** Expand the BioNEST incubator network.

2.2. GENETICALLY MODIFIED ORGANISM (GMO)

Why in the News?

Draft Manufacture, Use, Import, Export, and Storage of Hazardous Micro-Organisms/Genetically Engineered Organisms or Cells (Amendment) Rules, 2024 have been released.

What is Genetically Modified Organism (GMO)?

- **GMO** is a plant, animal or microbe in which one or more changes have been made to the genome, typically using high-tech genetic engineering, in an attempt to alter the characteristics of an organism.
- **Genes can be introduced,** enhanced or deleted within a species, across species or even across kingdoms.
- **Purpose:** such as making human insulin, producing fermented beverages and developing pesticide resistance in crop plants.

Regulations related to GMO

- **Environment Protection Act 1986 (EPA):** Govern the handling of GMOs and products.
- **Genetic Engineering Appraisal Committee:** Responsible for approving commercial cultivation of GM crops.
- **Biological Diversity Act, 2002:** To ensure benefits arising from with local communities.
- **Codex Alimentarius Commission (Codex):** Responsible for developing international food code.
- **Cartagena Protocol on Biosafety:** Deals with the trans boundary movement of living modified organisms.

How GM Crops are developed?

- The development of GM crops starts by isolating a desired gene and inserting it into the plant's DNA using methods like:
  - **Gene Gun** (DNA-coated particles shot into cells).
  - **Agrobacterium Approach:** Bacterium Agrobacterium. tumefaciens transfers the **desired gene** into plant cells.
  - **Electroporation** (electric pulses to introduce DNA).
  - **Microinjection** (direct DNA injection into cells).

GM Crops in India

- **Bt Cotton:** The only GM crop approved for commercial cultivation in India (since 2002). It is resistant to **cotton bollworm.**
- **Bt Brinjal:** Approved by GEAC in 2009 but later faced moratorium.
- **GM Mustard Crop (DMH-11):**
  - GM mustard **has not been released** for commercial cultivation yet.
  - It is a result of a **cross pollination** between **two mustard varieties** ('Varuna' and East European 'Early Heera-2').

Challenges related to GMO

- **Ecological Concerns:** E.g., Bt Corn potentially harms **Monarch butterflies** feeding on wild milkweed.
- **Ethical Concerns:** About inequitable access and benefits of GMOs.
- **Socio-cultural Concerns:** Issues related to **Seed Sovereignty,** impact on **traditional farming** practices.
- **Market Monopoly:** GM crops are controlled by corporations with **IP rights**, risking food security dependence on a few suppliers.
- **Biodiversity Loss:** Use of GM crops may leak GM proteins into the soil, harming beneficial microbes

Conclusion

GMO adoption must be guided by scientific impact assessment, enforced buffer zones for coexistence, increased public R&D in safer seeds, and mandatory labelling to ensure informed choices and sustainability.

2.3. GENOME SEQUENCING AT A GLANCE

Genome sequencing

- It is process of determining **complete genetic material sequence of** an organism's **genome.** It determines the **precise sequence (A, T, C, G and U) of nucleotide bases in DNA/RNA strand.**
- **Whole Genome Sequencing** determines the **entire DNA sequence** of an organism's genome and covers both coding (exons) and non-coding (introns, regulatory regions) regions of DNA.

Applications related to Genome Sequencing

Disease Diagnosis: **E.g.,** BRCA1 and BRCA2 gene sequencing helps assess breast and ovarian cancer risk.	**Anthropology:** **E.g.,** DNA sequencing has played role in understanding human migration and ancestry.	**Agriculture:** **E.g.,** International Wheat Genome Sequencing Consortium improved disease resistance.	**Livestock:** **Eg:** Unified Genomic Chip Designed for **genomic profiling** and **evaluation** of **Indian cattle breeds.**	**Vaccine Development:** **E.g.,** During COVID-19, it is used by **INSACOG** to detect and monitor emerging variants like Delta and Omicron.

Initiatives taken for Genome Sequencing

IndiGen program: To undertake whole genome sequencing of thousands of individuals representing diverse ethnic groups from India.	**One Day One Genome initiative:** To make microbial genomics data more accessible to researchers.	**Human Genome Project (HGP):** aimed to map and sequences the entire human genome.	**Genome India Project (2020):** To build a **catalogue of genetic diversity** that reflect unique diversity of Indian population.	**International HapMap Project:** To identify genetic links to diseases, aids in diagnostic tool development.

Challenges related to Genome Sequencing

Data Accuracy: Sequencing technologies still grapple with errors, particularly in **long-read sequencing.**	**Privacy:** Sensitive information such as genetic composition, medical and family history.	**Lack of regulatory framework:** It limits quality and proficiency standards and leads to misuse of data.	**Data Storage:** Genome sequencing generates massive data **(each genome ~200 GB).**	**Discrimination based on genetic information:** It may prevent access to health benefits such as insurance.

Way Forward related to Genome Sequencing

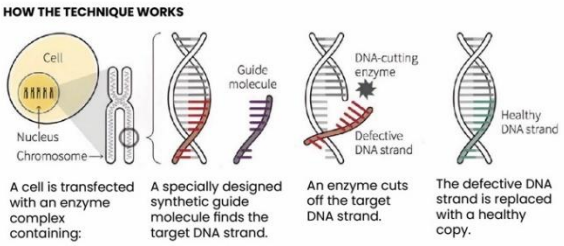
Technologies: **E.g.** Upgrade existing biotechnology labs with **next-generation sequencing (NGS)** technology which can rapidly **sequence large amounts** of DNA or RNA.	**Establish national bioethics committees** for oversight and public engagement.	**Global best practices** e.g. Genetic Information **Non-discrimination Act (GINA) of US.**	**Robust Data Infrastructure:** Establish secure and scalable **cloud-based platforms for storage, analysis, and sharing of genomic data.**

2.4. GENE EDITING AT A GLANCE

Gene Editing

It is a technique that modifies DNA by inserting, deleting, or altering specific sequences, including single bases or entire genes. Major types:

- **Somatic genome editing:** It involves altering non-reproductive cells (e.g., skin, liver, kidney, muscle), meaning the changes are not inherited by offspring.
- **Germline genome editing:** it modifies reproductive cells or embryos, leading to heritable genetic changes passed to future generations. For instance, **Heritable Human Genome Editing (HHGE)** is one such example used to prevent cystic fibrosis, Huntington's disease, and sickle cell anemia.



Techniques used for Gene Editing

ZFNs (Zinc Finger Nucleases): Zinc finger proteins (targeting) + FokI enzyme (cutting)	**TALENs (Transcription Activator-Like Effector Nucleases):** TALE proteins (targeting) + FokI enzyme (cutting)	**CRISPR-Cas9:** Guiding RNA molecules + Cas9 enzyme (cutting)

Applications of Gene-Editing

Space: E.g., NASA experiments with CRISPR to assess DNA repair in microgravity for future long-term missions.	**Agriculture: E.g.,** India's first genome-edited rice varieties named as DRR Rice 100 (Kamla) and Pusa DST Rice.	**Functional de-extinction: E.g.** Colossal Biosciences bringing back the Dire Wolf by using cloning and gene editing techniques	**Human Enhancements** like bionic limbs, glasses and exoskeletons.	**Material: E.g.,** Spider Silk Production Modified silkworms create steel-stronger silk

Challenges related to Gene-Editing

Bioterrorism: E.g., bioweapons by modifying pathogens to be more virulent or drug-resistant.	**Off-target Effects:** Gene-editing tools may unintentionally alter DNA at unintended sites.	**Germline Editing Risks:** Heritable changes can impact future generations without consent.

Conclusion

The future of gene editing holds immense potential across various fields with advancements in CRISPR technology and AI driving innovation. While ethical considerations and regulatory hurdles remain, gene editing is poised to revolutionize how we approach disease treatment, crop improvement, and more.

2.5. RNA EDITING

Why in the news?

The first successful clinical demonstration of RNA editing in humans was conducted.

About RNA (Ribonucleic acid) Editing

- It is a process that **modifies genetic information on RNA sequences** through insertion, deletion or substitution.
- **Process:**
  - RNA has **four building blocks**: A (Adenine), G (Guanine), U (Uracil), and C (Cytosine).

- **Adenosine Deaminase Acting on RNA (ADAR) converts adenosine in mRNA to inosine,** which mimics function of guanosine.
- Cell detects Inosine in Adenosine's position, triggering cellular response to correct the mismatch.
- The process thus **restores mRNA's original function**, and **cell starts making normal proteins.**

- **Challenges in RNA Editing:** Lack of Specificity and Transient nature and nascent stage of development

Comparison between RNA and DNA editing

- **Form of change: DNA editing** makes **permanent changes** while **RNA editing** makes **temporary changes** which may **fade over time.**
  - Thus, RNA editing is **safer and flexible** compared to DNA editing which may result in **irreversible errors.**
- **Allergic and immune reactions**: **DNA editing** has **higher risk** of undesirable reactions compared to RNA editing.
- DNA editing tools use **proteins** from **certain bacteria** to perform **cutting functions** while RNA editing relies on **ADAR enzymes**, already occurring in **human body**.

Major Types of RNA		
messenger RNA (mRNA) mRNA is made from a DNA template. Its role is to carry protein information from the DNA in a cell's nucleus to the cell's cytoplasm.	**transfer RNA (tRNA)** Serves as a link (or adaptor) between the mRNA molecule and the growing chain of amino acids that make up a protein.	**ribosomal RNA (rRNA)** Helps to form the structure of ribosome, binds mRNA and tRNA to ribosome and directs the translation of mRNA into proteins.

Conclusion

The first successful clinical demonstration of RNA editing marks a significant milestone in precision medicine. By enabling temporary, reversible modifications to RNA, this technique offers a safer and more flexible alternative to DNA editing.

2.5.1. NOBEL PRIZE IN MEDICINE 2024

Why in the news?

Nobel Prize in Physiology or Medicine 2024 has been awarded to Victor Ambros and Gary Ruvkun for the discovery of **microRNA** and its role in **post-transcriptional Gene Regulation.**

About the Discovery

- In 1993, Victor Ambros and Gary Ruvkun discovered **microRNA and** its role in gene regulation after transcription.
  - Till 1993, it was believed that **gene regulation** is limited to **specialised proteins** called **transcription factors**, which bind to specific regions in **Deoxyribonucleic acid (DNA)** and determine which **messenger Ribonucleic acid (RNA)** (mRNA) are produced.
- Discovery revealed a completely **new principle of gene regulation** that turned out to be essential for multicellular organisms, including humans.
  - **Gene regulation** is the process used to control the timing, location and amount in which genes (out of many genes in a genome) are expressed.

About Transcription and Translation

- **Transcription**: It is the process by which the **information** in a **strand of DNA** is copied into a **new molecule of** mRNA.
  - It is carried out by an enzyme called **RNA polymerase** and a number of accessory proteins called **transcription factors**.
- **Translation:** In this, information encoded in mRNA directs the addition of **amino acids** during **protein synthesis**.
  - It takes place on **ribosomes** (site for the synthesis of proteins) in the cytoplasm, where mRNA is read and translated into the string of amino acid chains that make up the synthesized protein.

Significance/Application of the Discovery

- **Cellular Development**: miRNAs are involved in the self-renewal and differentiation of stem cells and development of tissues and organs.
- **Immune Response**: miRNAs regulate innate and adaptive immune responses.
- **Oncogenesis**: Abnormal regulation by microRNA can contribute to cancer, and mutations in genes causing conditions such as congenital hearing loss, eye and skeletal disorders.
- **Disease diagnostics:** Used as biomarkers for human cancer diagnosis, prognosis, and therapeutic targets.

What is microRNA (miRNA)?

- It is a **small non-coding RNA** (single-stranded molecules playing key role in turning DNA instructions into proteins) that helps **cells regulate gene expression**.
- It **controls gene expression by binding with mRNA** and preventing them from being translated into proteins or by degrading/destroying mRNA altogether.
- There are more than a **thousand genes for different microRNAs** in humans, and gene regulation by microRNA is **universal among multicellular organisms**.

2.6. MITOCHONDRIAL TRANSPLANTATION

Why in the News?

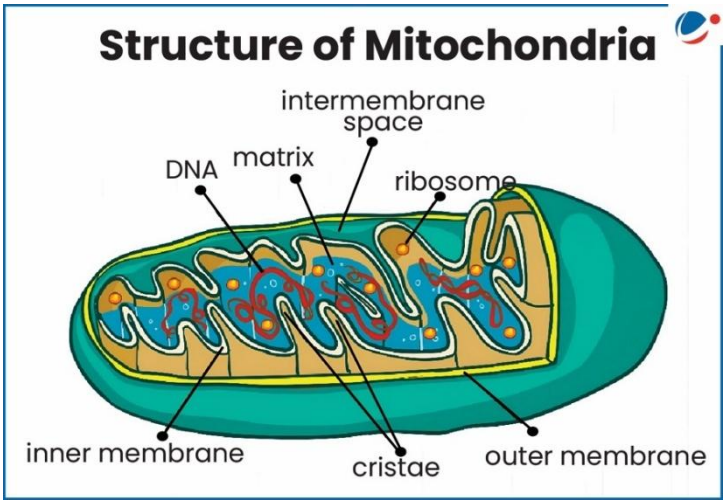
Experts believe that Mitochondria Transplants, a technique that may create a new field of medicine, can cure diseases and lengthen lives.

About Mitochondrial Transplantation

Transporting healthy mitochondria to damaged cells, tissues, or organs has recently become a potential therapeutic method for treating mtDNA related diseases and restoring mitochondrial function of diseased cells.

Applications of Mitochondrial Transplant to cure various aspects of human body:

- **Neural system:** Parkinson, stroke and so on.
- **Dermatologics:** Skin atrophy ecchymosis, striae, acne. Hirsutism, hair loss, impaired wound healing.
- **Muscle System:** Osteoporosis fracture, myopathy.
- **Cardiovascular:** Heart failure, pulmonary hypertension.
- **Ophthalmologic:** Cataracts, glaucoma.
- **Reproduction:** Infertility, diminished ovarian reserve.



Challenges of Mitochondrial Transplant (MT)

- **Cold Storage:** Mitochondria can stay active when stored on ice for approximately 1–2 hours only.
- **High-Tech Requirement:** Requires specialized equipment for mitochondrial isolation and delivery. Currently it is only limited to clinical trials.
- **Immune Response**: Like organ transplants, MT also carries the risk of immune rejection,.
- **Functional Sustainability**: Long-term metabolic compatibility and functionality of MT remains questionable.
- **Ethical Concerns:** MT raises ethical and conceptual concerns over whether it is a form of germline gene therapy, and whether children born following MT are genetically modified.

Conclusion

Mitochondrial transplantation is a promising regenerative therapy for degenerative joint conditions. Future research should focus on standardizing bioengineered mitochondrial transplants to enhance their efficiency and effectiveness.

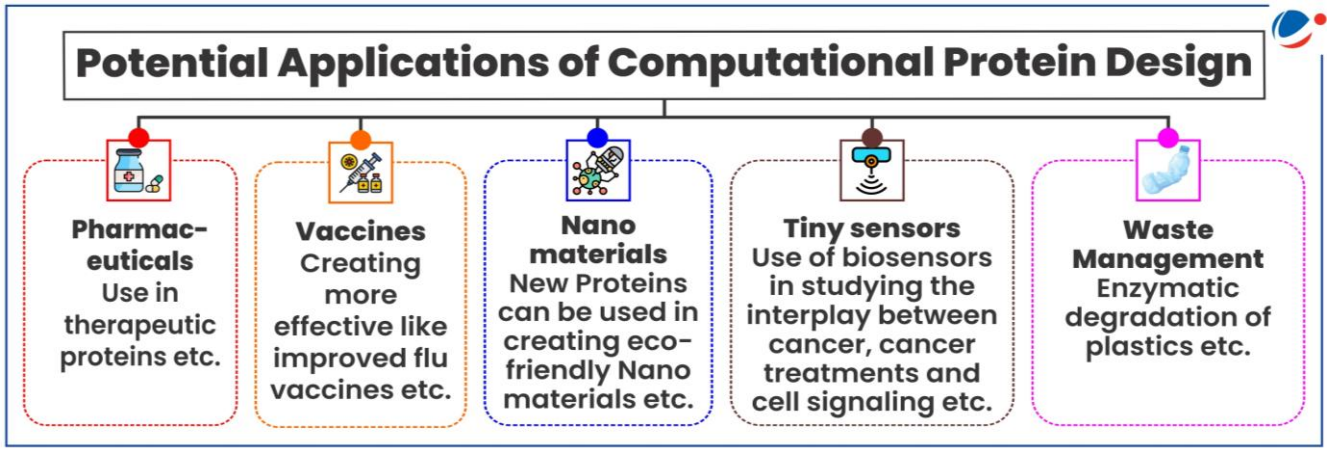
2.7. NOBEL PRIZE IN CHEMISTRY 2024

Why in the News?

2024 Nobel Prize in Chemistry was awarded to **David Baker** for **computational protein design** and jointly to **Demis Hassabis and John Jumper** for **protein structure prediction.**

David Baker's work on computational protein design

- **Computational protein design (CPD)** aims to create new proteins with novel functions or properties not found in nature.
- **David Baker** successfully created new proteins (synthetic proteins), starting with his **first designed protein 'Top7'** in 2003.



Work of Demis Hassabis and John Jumper on protein structure prediction

- **Demis Hassabis and John Jumper** used Artificial Intelligence (AI) to solve a 50-year-old problem of predicting proteins' complex structures i.e., how proteins fold into shapes that determine their functions.
- **Significance of discovery:** Understanding protein shapes is vital for insights into cell function, drug design, antibiotic resistance, enzyme development, and crop resilience etc.

About Proteins

- **Proteins** are one of the **four major types of biomolecules** (the other three being carbohydrates, lipids and nucleic acids).
- They are **biopolymeric structures,** composed of linear chains of **20 naturally occurring amino acids**, linked by peptide bonds.
    - **Composition of amino acids and their orde**r in proteins decide the structure of a protein.

Key Functions of proteins

- **Structural Support:** E.g., **Actin,** found in the filaments of muscle fibres, provides mechanical support and determines cell shape.
- **Catalysts:** Proteins act as **enzymes,** facilitating biochemical reactions. E.g., **amylase** breaks down starches into sugars during digestion.
- **Hormones:** E.g., **Insulin** plays a key role in regulating metabolism.

- **Antibody:** Antibodies bind to specific foreign particles, such as viruses and bacteria, to help protect the body. E.g., Immunoglobulin G (IgG) etc.
- **Transport/storage:** E.g., **Ferritin** stores iron in cells and **GLUT-4** enables glucose transport into cells.

2.7.1. RECOMBINANT PROTEINS (RPS)

Why in the News?

Researchers at Indian Institute of Science (IISc) have developed a **new process for production of recombinant proteins**.

What are Recombinant Proteins (RPs)?

- These are **modified or manipulated proteins encoded by recombinant DNA (rDNA)** for increasing production of proteins, modifying gene sequences, and manufacturing useful commercial products.
  - **rDNA** is **artificially made DNA strand** that is **formed by combination** of two or more DNA molecules.
  - rDNA technology can be used to **combine (or splice) or transfer DNA from different species or to create genes** with new functions.

Production of Recombinant Proteins

- RPs such as vaccine antigens, insulin and monoclonal antibodies, are **mass-produced by growing modified bacterial, viral or mammalian cells** in large bioreactors.
  - Most widely used organism is **yeast Pichia pastoris** (now called Komagataella phaffii) and it utilizes methanol for production of RP.
  - However, methanol is **highly flammable and hazardous**, requiring stringent safety precautions.
- **Researchers** have now developed an **alternative safer process** that relies on a common food additive called **mono-sodium glutamate (MSG).**
- **Escherichia coli (E. coli)** is also one of the organisms of choice for RP production due to its well-characterized genetics, rapid growth, and high yield production.

Applications of Recombinant Proteins

- **Biotherapeutics**: Produce insulin, growth hormones, monoclonal antibodies.
- **Vector Vaccines**: Safer vaccines without live pathogens.
- **Agriculture**: Create GM crops and enhance animal feed nutrition.
- **Environment**: Aid bioremediation to break down pollutants.

Conclusion

The growing need for personalized medicine requires flexible production platforms. There is also a focus on sustainable production practices. Recombinant proteins are expected to continue playing a significant role in various fields.

2.8. NANOTECHNOLOGY AT A GLANCE

Nanotechnology

- **Refers** to the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanoscale.
- **Nanoscale** refers to dimensions between approximately **1 and 100 nanometers.**
- **Status of India:** Since 2016, secured the **third position** in the global ranking through its contribution to Nanoscience and technology publications **(Department of Science and Technology).**

Applications related to Nanotechnology

Energy: **E.g.,** Semiconductor developed by Kyoto University makes it possible to manufacture solar panels that double the amount of sunlight converted into electricity.	**Food:** Nanobiosensors could be used to detect the presence of pathogens in food	**Water Management:** **E.g.,** nano-enabled reverse osmosis systems.	**Electronics:** **E.g.,** Carbon nanotubes are close to replacing silicon as a material for making smaller, faster and more efficient microchips.	**Environment:** Eg., Detects contaminations such as mercury ions in lake water.

Initiatives taken to promote Nanotechnology

Nano Science and Technology Initiative (NSTI) in 2002 to promote research and development in advanced area of Nano S&T.	**Mission on Nano Science and Technology (Nano Mission),** 2007	**Nano-electronics Innovation Council** set up by MeitY.	**Indian Nanoelectronics Users Programme-Idea to Innovation (INUP-i2i) initiated** by MeitY for undertaking research and skill development.	**Nano Science and Technology (INST),** first Nano-Science Institute at Mohali, Punjab.

Challenges related to its adoption

Impact on Health: Nano-sized spherical solid materials will easily enter the lungs and reach the alveoli.	**Environmental Concern:** It can form new form of non-biodegradable pollutants.	**Lack of Skilled Workforce:** Number of students following undergraduate and graduate degrees in the area is low.	**Ethical Concern:** For instance, nano-based products may be used in warfare, invade people's privacy etc.	**Other:** High costs for acquisitions of IPR, lower participation of private sector in R and D, etc.

Way Forward

Promoting Academy and Industry Linkage, this will facilitate funds for Academies and products developed by them can be easily commercialized.	**Coordination with various international/ inter-governmental organizations** to develop standards, safe lab practices and risk governance.	Increasing funding of **Nano Mission** and establishing more dedicated institutes.

2.9. NANOTECH AND AGRICULTURE AT A GLANCE

Nanotech and Agriculture

Nanotechnology offers promising applications in agriculture, potentially revolutionizing crop production and management.

Applications of NanoTech in Agriculture

Nano fertilizers: Enhance nutrient uptake. **E.g. Nano Urea**	**Nano pesticides:** reducing toxicity, improving the shelf-life, and increasing the solubility of poorly water-soluble pesticides. **E.g.,** Nano Silver	**Food Processing:** Nanoemulsions minimize the requirement for stabilizers, owing to their protection against food breaking and split-up.	**Reducing post-harvest losses:** Edible coatings are used as a liquid on food to protect untreated foods from worsening via hindering dehydration.	**Nanotechnology in Crop Breeding:** Aid in the development of genetically modified crops by enabling precise manipulation of plant genes at the nanoscale.

Initiatives for Promotion of Nanotech in Agriculture

Guidelines for evaluating nano-agri inputs and products: Released by the Department of Biotechnology.	**National Agricultural Innovation Project (NAIP):** Several projects have been initiated to explore the applications of nanotechnology in agriculture.	**Skill development training programme on nanotechnology:** By Indian Council for Agriculture Research (ICAR)	**Nano Fertilizer Plant (NFP):** Established by IFFCO at Phulpur, Prayagraj.

2.10. NANOTECH AND HEALTHCARE AT A GLANCE

Nanotech and Healthcare

Nanotechnology along with other emerging technologies like AI is paving way for the precision medicine in the Health care.

Applications of Nanotech in Healthcare

Clinical investigation: e.g., **Gold nanoparticle** is used for the detection of targeted sequences of nucleic acids, as potential treatments for cancer and other diseases.	**Better imaging** tools for earlier diagnosis, more individualized treatment options, and better therapeutic success.	**Drug delivery:** Nanotech materials can contain hydrophobic and hydrophilic drugs, protect drugs from chemical and enzymatic degradation etc.	**Gene sequencing:** Technologies through design and engineering of advanced solid-state nanopore materials.

Challenges related Nanotech in Healthcare

Creates 'free radicals' which can harm body cells. E.g. cobalt and chromium nanoparticles cross skin barrier and damage fibroblasts.	**Triggers an acute inflammatory** reaction when it enters in circulation system, as these particles are recognized and identified by the immune system of the body as "invader" particles.	**Other:** high cost, controlling their activity in sensitive environments, environmental impacts, etc.

Way forward

Nanomedicines Targeting various disease must be meticulously designed in order to achieve the safest and most efficacious regime.	**Clinical trials** should be adequately conducted before using the products.	**A dedicated authority** needs to be established to govern the Development and other mechanism of the nanotech in health care.

2.11. NANOTECH AND DEFENCE AT A GLANCE

NanoTech and Defence

In the different spheres of defence ranging from armory to first aid, application or products made from nanotechnology can be seen.

Significance/Applications

Nano-Sensors: Detect chemical and biological weapons. Nano-devices may also be applied to detect or even decrease radio-activity.	**Body Armour:** Silicon dioxide nanoparticles in a liquid polymer which hardens on ballistic impact (Shear Thickening Fluid).	**Health Aid:** Nanomedicines and bandages for wound healing.	**Advanced weapon/equipments:** E.g. Nanotechnology is being applied to aluminum to change phases and microstructure in order to make it perform like titanium - but without the weight.	**Other:** Silver-packed foods as antibacterial and antiviral, Adaptive camouflage, etc.

Challenges related to Nanotechnology in Defence

Use of nano weapons/equipment may lead to the so-called nanowars, a new age of destruction.	**Widespread availability of these devices** would inevitably lead to their use for criminal activity and terrorist attacks.	**Medical applications developed** to improve soldiers' endurance and performance, would also need careful regulation.

Conclusion

Ensure responsible use of nanotechnology in defence requires global regulatory standards, START-like treaties for transparent collaboration, and strong safeguards to prevent advanced nano-weapons from reaching non-state actors.

2.12. GRAPHENE

Why in the News?

Recently, MeitY launched **India Graphene Engineering and Innovation Centre** (IGEIC) under the vision of **Viksit Bharat@2047**.

About Graphene

- **Discovered** in 2004 by Geim and Novoselov (Nobel Prize 2010).
- **Key Features**:
  - Allotrope of carbon; basic unit of graphite.
  - Single 2D layer of carbon atoms in a hexagonal lattice.
  - Made via Chemical Vapour Deposition, graphite cleavage, exfoliation, hydrogen arc discharge, etc.
- **Production**: China and Brazil lead in production; India produces ~1/20th of China's output.

Properties of Graphene

- **Strength**: 200 times stronger than steel, 6 times lighter.
- **Transparency**: Absorbs only 2.3% of light (ideal for displays and solar cells).

Graphene's Application

Electronics
Graphene's role in creating faster and more efficient semiconductors

Water Filtration
Graphene's application in nanoporous membranes for desalination.

Biomedical
Graphene's use in tissue engineering, drug delivery, and biosensors

Energy Storage
Graphene's use in high-capacity batteries and supercapacitors

Environmental
Graphene's ability to absorb liquids, aiding in environmental cleanup.

Defence
Graphene's strength making it suitable for armour and ballistic protection.

- **Impermeability**: Blocks all gases, including hydrogen and helium.
- **Quantum Effects**: Exhibits Quantum Hall effect, useful in metrology and quantum computing.

India's Initiatives to promote Graphene

- **Graphene-Aurora program:** To fill the gap between R&D and commercialization.
- **India Innovation Centre for Graphene (IICG):** Set up in Kerala and funded by MeitY.
- **Research Institution:** IIT Roorkee-incubated **Log 9** has patented a technology for Graphene-based ultracapacitors and **Centre for Nano and Soft Matter Sciences (CeNS)** is actively involved in Graphene research.

Conclusion

Ongoing research is driving innovations in Graphene composites, hybrid materials, and scalable processing techniques. As these efforts mature, Graphene could become a cornerstone material, enabling breakthroughs in high-performance devices, energy efficiency, and sustainable technologies across multiple sectors.

2.13. KEY WORDS

Keywords				
CRISPR-Cas9	Gene Editing	RNA Editing	Genetically Modified Organisms (GMO)	Nanomedicine
Mitochondrial Transplant	Recombinant Proteins	Graphene	Bioenergy	Nano-Sensors

2.14. PRACTISE QUESTION

Answer Canvas

While gene-editing offers varied applications, it comes with its own set of challenges. Discuss.

Introduction	Body Part: 1	Body part: 2	Conclusion
Introduce Gene-Editing	Write Applications with examples	Challenges related to Gene-Editing	Write balanced conclusion considering ethical issues.

3. AWARENESS IN THE FIELD OF SPACE

3.1. SPACE SECTOR AT A GLANCE

India's Space Saga

- Indian space economy is valued at $8.4 billion, accounting for 2% of the global space market.
- **Contribution to Economy:** It contributed ₹20,000 crore to GDP in the last decade and supported 96,000 jobs.

Significance of India's Space Program

National Security through Self-reliance: E.g., NavIC (Navigation with Indian Constellation), India's regional navigation system.	**Socio-economic Benefits: Land Digitization: E.g.,** Swamitva scheme leverages satellites for transparent land records.	**Space Diplomacy:** E.g., South Asia Satellite Project, NASA-ISRO Synthetic Aperture Radar (NISAR) Mission, etc.	**Scientific research: Chandrayaan-3** performed experiments using the instruments on **Vikram and Pragyaan.**	**Space Situational Awareness:** ISRO released Indian Space Situational Assessment Report (ISSAR) for 2024. Declaration of **Debris Free Space Mission (DFSM)** to be achieved by all Indian space actors.	**Earth Observation:** Used in Early warning systems, environmental impact monitoring. For eg, EOS-08 mission of ISRO.

How has ISRO achieved so many achievements despite having less resources?

Visionary leader: Vikram Sarabhai or **"Father of Indian Space Program''** emphasized on **bottom-up** approach to larger initiatives.	**Cost Effective Missions:** Mars orbiter mission cost was just $74 million, a fraction of NASA's Maven mission, which had a budget of $670 million.	**Indigenous Technology Development:** 95% of space-components in Indian rockets are indigenous.	**Partnerships and Collaboration:** E.g., ISRO launched PSLV-C59 rocket with European Space Agency's Proba-3 satellites . ISRO and CNES (French Space Agency) announced **TRISHNA.**	**Engaging Private Players:** E.g. There are more than 500 companies that partner with ISRO for providing materials, mechanical fabrication, electronic fabrication, etc.

Challenges that Persist

Dependence on imports: India heavily relies on imported components like semiconductors, carbon fiber, etc.	**Increasing Commercial Competition:** The global space industry is becoming increasingly commercialized, with private companies entering the sector.	**Standardization and quality assurance:** Absence of an Indian Space Quality Standard leads to inconsistencies and reduced trust in domestically produced components.	**Infrastructure Constraints:** Due to the absence of advanced testing and launch facilities accessible to private companies.	**Workforce Shortage** to meet the demands of an expanding space program

Key Future Missions

Chandrayaan-4: It will bring **rock** and **soil samples** back to the Earth.	**Gaganyaan Mission: Human spaceflight capability** by launching crew of 3 members to an orbit and bring them back safely.	**Venus Orbiter Mission (Shukrayaan)** to study the atmosphere of **Venus.**	**Mars Orbiter Mission 2 (Mangalyaan 2):** India's second interplanetary mission to **Mars**.	**Bharatiya Antariksha Station (2028–2035):** A planned space station that would maintain an orbit approximately 400 Km above Earth, where astronauts could stay for 15–20 days.	**Lunar Polar Exploration Mission** in collaboration with JAXA to explore the **Moon's South Pole region.**

3.2. PRIVATISATION IN INDIAN SPACE SECTOR AT A GLANCE

Privatization in Indian Space Sector

Over the next five years, the Indian space economy is expected to grow at a compound annual growth rate (CAGR) of 48%, potentially reaching a $50 billion valuation.
Target: Increasing India's share in the global commercial space economy to **10% by 2030** (currently it stands at 2%).

Need of Promoting Private Sector in Indian Space Sector

Reducing import dependency: India's import costs in the space technology sector are **12 times** higher than the **earnings from exports (2021-22).**	**Freeing up the ISRO from ancillary activities:** Space entrepreneurship could free up ISRO to focus on the **core areas of research and development.**	**Global Competitiveness:** Foreign private companies like SpaceX, Blue Origin, Arianespace, etc. have transformed the global space industry by **cutting costs and turnaround times.**	**Connected socio-economic benefits:** By finding innovative solutions to pressing challenges in areas such as **agriculture, disaster management, or communication.** It will also aid employment generation.

Initiatives to encourage Private Sector in Space

IN-SPACe: An autonomous agency under the Department of Space (DoS) to encourage private sector in space.	**Rs 1,000 crore Venture Capital Fund** for Space Sector under aegis of IN-SPACe.	**New Space India Limited (NSIL):** Schedule 'A' Category Company under DoS. It was set up in 2019, to handle the commercial activities of ISRO	**Indian Space Policy 2023:** Enables end-to-end participation of Non-Government Entities (NGEs) in all domain of space activities.	**Foreign Direct Investment (FDI):** Upto 100% under Automatic route for Manufacturing of components and systems/ sub-systems for satellites, ground segment and user segment.

Challenges of Privatization of Space

Multiplicity of regulations: E.g. approvals needed from DoS, ISRO, Antrix corporation etc.	**Risky Nature of Industry:** Absence of customized insurance products for startups, especially in deep tech and space industries.	**Limited Access to Launch Facilities:** Access to launch facilities and infrastructure, primarily controlled by government agencies like ISRO, can be challenging for private players.	**Technological Competence:** Developing cutting-edge space technology and expertise is costly and time-intensive.

Way Forward

Mapping of current value chain of the sub-segments: Identification of challenges (technology, business and adoption), trends and global benchmarking to define the problem for market creation.	**Comprehensive Space Act** is essential to provide a clear **legal framework** for covering various aspects, such as international obligations, private sector participation, liability frameworks, and ethical considerations.	**Emphasize IFSC's Role** in Supporting Space Technology and the Financial Sector, Creating Synergies for Domestic and International Space Tech Companies	**Introduce financial incentives** for academic institutions and R&D establishments to actively engage with startups.	**Establish a Space Insurance Regulatory Authority** to drive a resilient Indian space insurance market, fostering innovation, mitigating financial risks, and supporting the domestic space industry

3.3. AXIOM-4 MISSION

Why in the News?

The **Axiom-4 Mission** carrying **Indian astronaut** Group Captain **Shubhanshu Shukla** and 3 other astronauts successfully returned on July 15, 2025.

About Axiom-4 (Ax-4) Mission

- It is the **4th private astronaut mission,** to the **International Space Station (ISS),** of private US Company **Axiom Space** in collaboration with **NASA** and **SpaceX.**
- **Key Features:**
  - **Aim**: To "realize the return" to human spaceflight for **India, Poland, and Hungary.**
  - **Ax-4** marks each nation's **first mission to the ISS** in history and with **each nation's first government-sponsored flight in more than 40 years.**
- Following research are to be **executed by ISRO**:
  - **Crop growth**: Study impact of microgravity on 6 crop seed varieties for future space farming.
  - **Cyanobacteria:** Observe growth and activity for use in spacecraft life support systems.
    - Cyanobacteria are aquatic bacteria that can photosynthesize.
  - **Space Microalgae**: Compare metabolic and genetic activity in space vs Earth; potential use as food, fuel, or for life support.
  - **Myogenesis:** Study muscle loss, identify pathways responsible for **skeletal muscle dysfunction** in microgravity and explore therapeutic targeting strategies.
  - **Tardigrades**: Investigate the revival, survival, and reproduction of tardigrades to identify molecular mechanisms of resilience.

Significance for India

- **Development of Gaganyaan Mission:** Offers valuable inputs for medical training, psychological prep, and crew–ground coordination.
  - Group Captain **Shubhanshu Shukla** is one of the 4 astronauts selected for the **Gaganyaan mission.**
- **Development of India's Space Ecosystem:** Encourages growth of India's space industry; aligns with plans for Bharatiya Antariksh Station.
- **National Pride and inspiration:** Indian astronauts in space will inspire Indian youth to pursue careers in science, technology, engineering, and mathematics (STEM).

About Gaganyaan Programme

- **It will be 'India's first Human Space Flight'** mission, approved in 2018.
- **Aim**: Demonstration of **human spaceflight** capability by launching a crew of **3 members** to an **orbit of 400 km (LEO)** for a 3-day mission and bring them back safely to earth.
- **Components of the Gaganyaan**
  - **Launch Vehicle Mark-3 (LVM-3):** Formerly known as GSLV Mk-III, it is a 3-stage rocket:
    - **First stage**: Two solid-fuel boosters strapped to the rocket core.
    - **Second stage**: Two liquid-fuelled, clustered Vikas 2 engines.
    - **Third stage: CE-20 indigenous cryogenic engine**, using liquid hydrogen and liquid oxygen as fuel and oxidiser, respectively.
  - **Orbital module**: Consisting of Crew Module and Service Module.

Major Obstacles for India in launching a Manned Space Mission

- **Technological**
  - **Life support system:** Must ensure air regeneration, temperature control, waste recycling, and food storage.

- **Radiation protection:** Beyond Low Earth Orbit, cosmic radiation and solar particle events pose serious health risks.
- **Spacecraft re-entry and thermal protection:** For re-entry into Earth's atmosphere, spacecraft must withstand temperatures up to 7,000 degrees Fahrenheit.
- **Launch vehicle reliability:** Human-rated rockets must meet stricter safety standards to address complexities including controlled ascent, abort systems, and reusability.

- **Logistical**
  - **Higher cost:** Due to requirement of robust ecosystems including launchpads, testing facilities, tracking stations, etc.
  - **Training and selection of astronauts:** Astronauts need rigorous physical, psychological, and technical training.
    - Additionally, long-term missions also raise concerns of **space-induced psychological issues.**

Conclusion

For India, the collaborations under Axiom-4 Mission, not only **accelerates technological learning** ahead of its proposed Gaganyaan mission but also build **critical human capital and infrastructure** for future long-duration spaceflight.

3.4. BHARATIYA ANTARIKSH STATION (BAS)

Why in the News?

Union cabinet has approved the building of first unit of the Bharatiya Antariksh Station by extending the scope of Gaganyaan program.

About Bharatiya Antariksh Station

- BAS is India's **planned space station for scientific research** which will orbit around **400 – 450km above the Earth's surface**
  - It will have **five modules** and will be built in phases.
- **Targets: The first module** (the Base Module) **will be launch in 2028** and BAS will be operationalized by **2035.**
- **Current Status:** BAS is **currently in conceptualization phase**, under which overall architecture, number and types of modules, docking ports etc. are being studied.

Other Upcoming Space stations:

- **Gateway Space Station:** NASA-led Gateway Program is an international collaboration to establish **humanity's first space station around the Moon** as a vital **component of the Artemis campaign.**
- **Axiom Station**: It is a commercial space station being developed by Axiom Space to operate in low-Earth orbit. It will be the **first commercial space station** in the world.

Significance of BAS

- **Human Spaceflight**: Test astronaut safety for long missions; support India's space goals.
- **Earth Observation**: Better imaging for disaster response.
- **Microgravity Research**: Study health issues like muscle and bone loss.
- **Innovation**: Enable startups to test space tech, boosting jobs, etc.
- **Technological Spin-offs**: Advance materials and algorithms for diverse industries.

Challenges regarding Indian space station:

- **Low R&D Budget**: Limited funding (~0.7% of GDP) restricts scale and experiments.
- **New Technologies**: Need advanced systems for life support, radiation protection, and maintenance.
- **Geopolitics**: Balancing competition and cooperation with major space powers.
- **Astronaut Health**: NASA observes weight-bearing bone loss of **1% to 1.5% per month** in microgravity.

Way Ahead

- **Funding**: Pursue international partnerships and private investment.
- **Capacity Building**: Upgrade ISRO's tech for life support, radiation shielding, and maintenance.
- **Sustainability**: Plan for ongoing maintenance, resupply, and upgrades.
- **Geopolitics**: Balance national interests with global obligations.
- **International Cooperation**: Learn from US and Russian space station experience to lower costs.

Conclusion

India's plans to establish the Bharatiya Antariksh Station mark a bold step toward becoming a leading spacefaring nation. By building its own space station, India not only advances its scientific and technological capabilities but also strengthens its strategic presence in low Earth orbit.

About International Space Station

- It is a large space station that was assembled **in 1998** and operational since **2000.**
- It is maintained in low Earth orbit by a collaboration of five space agencies and their contractors: NASA (United States), Roscosmos (Russia), ESA (Europe), JAXA (Japan), and CSA (Canada
- It is the **largest manmade and habitable** artificial satellite.
- **Altitude:** Installed in the **near-earth orbit** which is about **400 km above the earth.**

3.5. SPACE DOCKING EXPERIMENT

Why in the News?

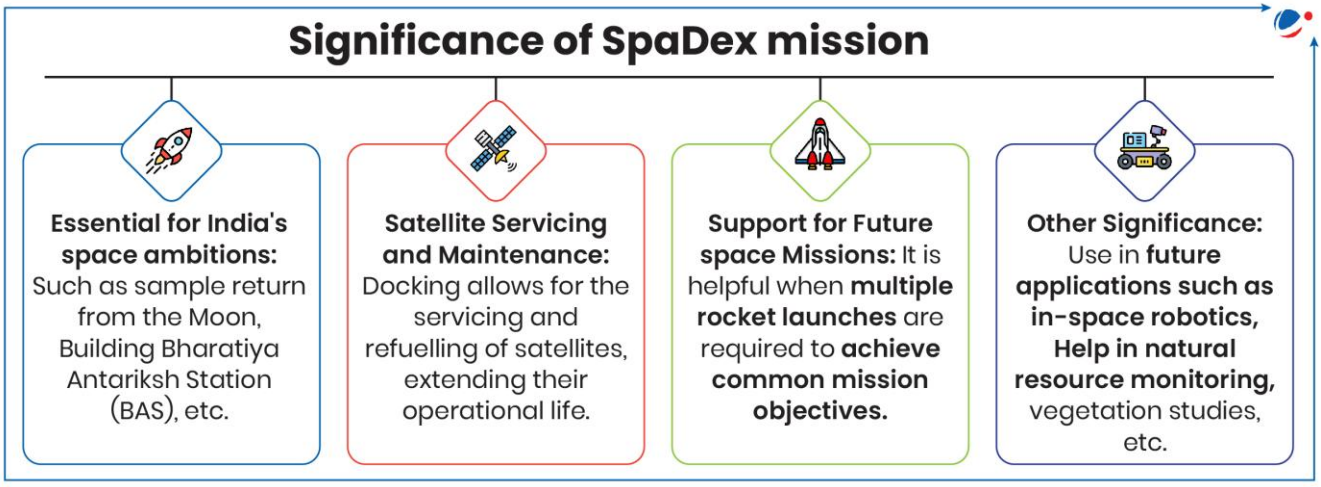
ISRO, successfully demonstrated the docking and undocking of two small satellites in orbit under the Space Docking Experiment (**SPaDeX).**

What is Space Docking?

- Space docking involves **precise connection of two spacecraft**, allowing those **to operate as a single unit for critical tasks** such as refuelling, repair, and crew exchange.
  - It enables the **construction of cutting-edge facilities like International Space Station** in orbit.
- Some spacecraft dock with the International Space Station and others berths with the station.
  - **In Docking,** the spacecraft can manoeuvre and attach to the station by itself.
  - **In Berthing,** an astronaut uses the station's robotic arm to capture the spacecraft. Then Mission Control on ground directs the arm to manoeuvre the spacecraft to the attachment site.

About Space Docking experiment (SPaDeX)

- **About**: Technology demo to master autonomous docking, a capability held only by the US, Russia, and China.
- **Satellites**: Chaser and Target launched by PSLV into different orbits to dock at ~700 km altitude. Docking at ~28,000 km/h to form a single entity.
- **Key Manoeuvres**:
  - **Autonomous Rendezvous and Docking**: Self-navigation and coordinated docking.
  - **Formation Flying**: Precise orbital control for future assembly and servicing.
  - **Remote Operations**: controlling one spacecraft using the Attitude Control System of the other in docked configuration.
  - **Robotic Arms**: Exploring in-space manipulation and servicing.
- **Indigenous Technologies**:
  - Inter-satellite communication link.
  - GNSS-based **Novel Relative Orbit Determination and Propagation (**RODP) processor for position and velocity.
  - Docking mechanism, sensors, and strategies.



Challenges

- **Complex Docking**: Precise coordination needed at ~8–10 km/s; navigation errors risk collision (e.g., Sunita Williams' incident).
- **Automation**: Real-time autonomous manoeuvres face dynamic challenges such as relative speeds and trajectories.
- **Sensor Reliability**: Cameras, LIDAR, and radar can fail in harsh space conditions.
- **Other Issues**: Space debris, microgravity, data transfer, and communication stability.

Conclusion

The development of advanced space technologies by India represents a significant leap forward in space exploration capabilities. Such advancements reflect the nation's commitment to scientific and technological self-reliance and its aspirations to be a frontrunner in global space research and development, in line with the Atmanirbhar Bharat vision.

3.6. THIRD LAUNCH PAD

Why in the News?

Union Cabinet approved the establishment of 'Third Launch Pad' (TLP) project at Satish Dhawan Space Centre of ISRO at Srihari Kota, Andhra Pradesh.

About TLP

- **Key Features:** Configured to support Launch of **Next Generation Launch Vehicles (NGLV)** and **Launch Vehicle Mark-3 (LVM3)** with Semi cryogenic stage as well as scaled up configurations of NGLV.
- **Timeline:** To be established within 4 years.

Significance of TLP

- **Capacity augmentation**: Enables **higher launch frequencies** and enhances the launch capacity for future human spaceflight & space exploration missions, etc.

- **Expanded vision of Indian Space Programme:** Bharatiya Antariksh Station (BAS) by 2035 and an Indian Crewed Lunar Landing by 2040 require a next generation of heavier launch vehicles with new propulsion systems.
- **Future Transportation:** It is highly essential so as to meet the evolving space transportation requirements for another 25-30 years.

Existing Launch pads in India

- **First Launch Pad**: It provides launch support for **Polar Satellite Launch Vehicle (PSLV)** and **Small Satellite Launch Vehicle** (**SSLV)**.
- **Second Launch Pad:** It was established primarily for **Geosynchronous Satellite Launch Vehicle (GSLV) & LVM3** and also functions as standby for PSLV.

Conclusion

The expeditious establishment of a Third Launch Pad to cater to a heavier class of Next Generation Launch Vehicles and as a stand by for SLP is highly essential so as to meet the evolving space transportation requirements.

Next Generation Launch Vehicles (NGLV) Programme

- **About**: New "Soorya Rocket" to launch satellites and payloads.
- **Features**:
  - 3-stage design with reusable first stage for low-cost access.
  - Semi-cryogenic boosters (using refined kerosene and Liquid Oxygen or LOX).
  - 3 times current payload capacity at 1.5 time the cost of LVM3.

Other ISRO Launch Vehicles

- **Polar Satellite Launch Vehicle (PSLV)**: 4-stage (solid-liquid-solid-liquid); third-generation vehicle.
- **Geosynchronous Satellite Launch Vehicle (GSLV)**: 3-stage with cryogenic third stage; launches communication satellites.
- **Small Satellite Launch Vehicle (SSLV)**: 3 solid stages and liquid Velocity Trimming Module for small satellites.
- **Geosynchronous Satellite Launch Vehicle Mk-III (LVM3)**: 3-stage with solid strap-ons, liquid core, and cryogenic upper stage.

3.7. ENGINE TECHNOLOGY IN SPACE SECTOR

3.7.1. SCRAMJET ENGINE

Why in the News?

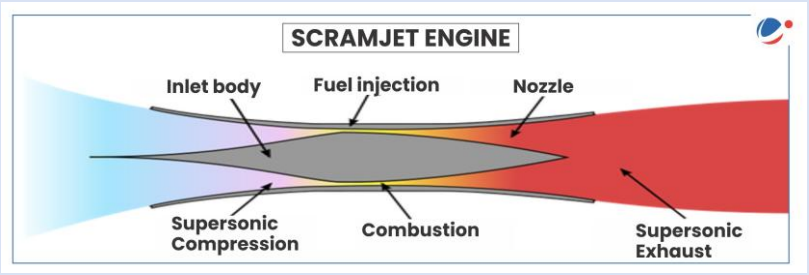
Defence Research and Development Laboratory (DRDL) successfully conducted a 120-seconds ground test of an active-cooled Scramjet combustor for the first time in India.

About Scramjet Engine

- A scramjet engine means a **Supersonic Combusting Ramjet engine**.
  - It is an improvement over the **ramjet engine** as it efficiently operates at **hypersonic speeds** and allows **supersonic combustion**.
    - > **Scramjet-powered vehicle** requires an **assisted take off** by a rocket to accelerate it to a speed where it begins to produce thrust.

How does the Scramjet engine work?

- **Air Intake:** Vehicle must already be moving at supersonic speeds (above Mach 3).
- **Compression:** Incoming air is compressed due to the high velocity of the aircraft.
- **Combustion:** Fuel (typically hydrogen) is injected into the compressed air and ignited while maintaining supersonic airflow.
- **Thrust Generation:** The expansion of hot gases produces thrust, propelling the vehicle at hypersonic speeds (based on **Newton's third law**).



Challenges in Scramjet Development

- **High-Energy Fuels**: Fuels that provide the necessary energy for sustained combustion.
- **High Initial Costs**: Significant financial investment required for development.
- **Integration Issues:** Require a launch mechanism to reach operational speeds.
- **Active Cooling Systems:** To maintain optimal temperatures during operation.
- **Heat-Resistant Materials**: Materials that can withstand extreme temperatures without degrading

Conclusion

Despite technological challenges, scramjet technology holds immense potential for defense and space applications, enhancing deterrence and reducing space access costs. Continued research and innovation will be crucial for overcoming limitations and realizing its full potential.

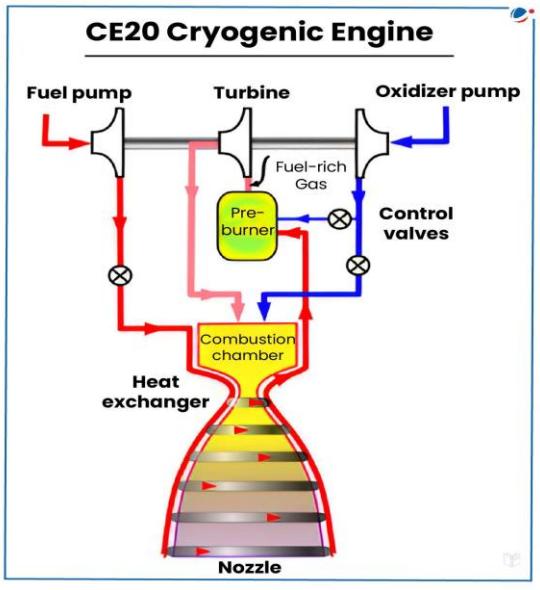
3.7.2. CE20 CRYOGENIC ENGINE

Why in the News?

The Indian Space Research Organisation's CE20 cryogenic engine passed a critical sea-level test, a breakthrough in its propulsion technology.

About CE20

- **Developed by:** The Liquid Propulsion Systems Centre (LPSC), Valiamala, Kerala.
- **Successful Mission:** It has demonstrated its capability by successfully operating in six successive LVM3 missions, including the **Chandrayaan-2, Chandrayaan-3, and two commercial OneWeb missions.**
- **Uses:** Cryogenic engines are the last stage (or upper stage) of a rocket.
  - A Cryogenic engine uses both cryogenic fuel and oxidizer, liquefied at a very low temperature.



How does a cryogenic engine work?

- **The working principle**: The thrust is produced by an **internal combustion/pressure difference**.
  - Like scramjet, this also follows **Newton's Third law of motion.**
- **Fuel:** The fuel and oxidizer used in a cryogenic engine are liquefied gases, stored at extremely low temperatures.

- Generally **liquid hydrogen liquefied at -253° Celsius** is used as fuel and liquid **oxygen liquefied at -183° Celsius** is used as oxidizer.

Advantages of cryogenic engine

- **Efficiency and Thrust**: With LOX+LH2 producing maximum energy and lightweight water vapor, resulting in higher performance.
- **Fuel Efficient**: ISRO's PSLV Vikas engine burns 3.4 kg/sec, while cryogenic engines need only 2 kg/sec for the same thrust.
- **Eco-Friendly Technology**: Hydrogen-oxygen combustion emits only steam.
- **Heavy Payloads & Space Missions:** Ideal for heavy payloads and long missions like Gaganyaan.

Challenges in Cryogenic engine technology

- **Complex Systems**: Extremely low-temperature propellants create thermal and structural issues.
- **Thermal Stress**: Risks of cracks, blockages, nozzle distortion, and stoppages.
- **High Pressure**: Requires strong superalloys to handle thrust and coolant pressures.
- **Temperature Control**: Balancing performance with coolant liner capability at low flows.

Conclusion

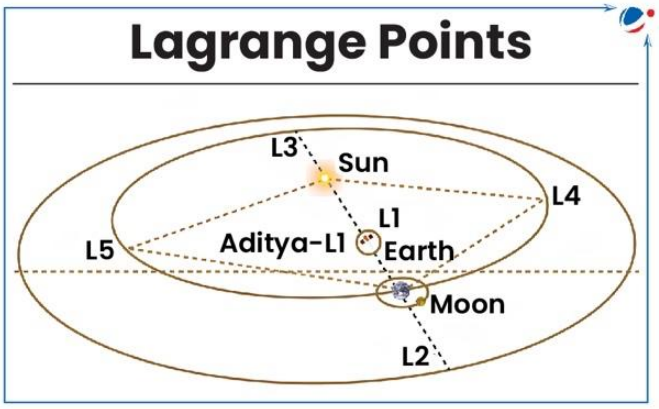
The CE20 Cryogenic engine marks a significant milestone in ISRO's progress with cryogenic technology. Advancing further, ISRO could explore start fuel ampules like Tri-ethyl-aluminium and Tri-ethyl-boron to enhance ignition reliability and efficiency.

3.8. ADITYA L1

Why in the News?

Aditya-L1 payload captures the first-ever image of a solar flare 'kernel'

About Aditya L1



- **First Indian space mission** to study the Sun.
- **Objectives:** Study the **Sun's corona**, **solar emissions**, solar winds and flares, and **Coronal Mass Ejections (CMEs)**, and will carry out round-the-clock imaging of the Sun.
- **Payload:** Carries 7 payloads (Visible Emission Line Coronagraph (VELC), Solar Ultraviolet Imaging Telescope (SUIT) etc.)
- Aditya-L1 was inserted in its **halo orbit** in early 2024 around the **Langrange L1** point.
  - At **Lagrange point**, the **gravitational pull** of the **two large bodies** equals the necessary **centripetal force** required for a small object to move with them.
- For two body gravitational systems, there are a total five **Lagrange points** denoted as L1, L2, L3, L4 and L5. Out of these L4 and L5 are stable.

What are halo orbits?

- These are **periodic** and **three-dimensional orbits** resulting from an interaction between the **gravitational pull** of the two planetary bodies and **centrifugal force** on a spacecraft.
  - Halo orbits exist in any **3-body system.** E.g., **Earth-Moon orbiting satellite system**.
  - Mainly linked to L1, L2 or L3.

Benefits of placing Aditya-L1 in Halo Orbit

- Ensuring a mission lifetime of 5 years
- **Reducing fuel consumption** (minimising station-keeping manoeuvres)
- Ensuring an **unobstructed view of the sun**

Other Solar Missions:

Parker Solar Probe (PSP) of NASA

- Launched in **2018,** the probe had flown through the **Sun's upper atmosphere (corona)** and sampled **particles and magnetic fields** there, making it the first spacecraft to touch the sun

PUNCH by NASA: First-of-its-kind solar mission that will study the solar corona — the outermost layer of the Sun's atmosphere.

Others Solar Observatories:

- Advanced Space-based Solar Observatory (ASO-s), China; Hinode (SOLAR-B), Japan; Solar and Heliospheric Observatory (SOHO) in collaboration with NASA, ESA, and AXA etc.

Significance of Solar Missions

- **Forecasting Space Weather: Solar radiation** and associated **energy and magnetic fields** can cause changes in the space weather impacting space technology and communications systems.
- **Understanding cosmic objects:** Sun being the closest star, its study can help in research about other stars.

Conclusion

The solar maximum is the best possible window available for physicists to both launch and observe the sun. This is precisely why there has been a spike in the missions to observe the star.

3.9. HYPERSPECTRAL IMAGING (HSI) SATELLITES

Why in the News?

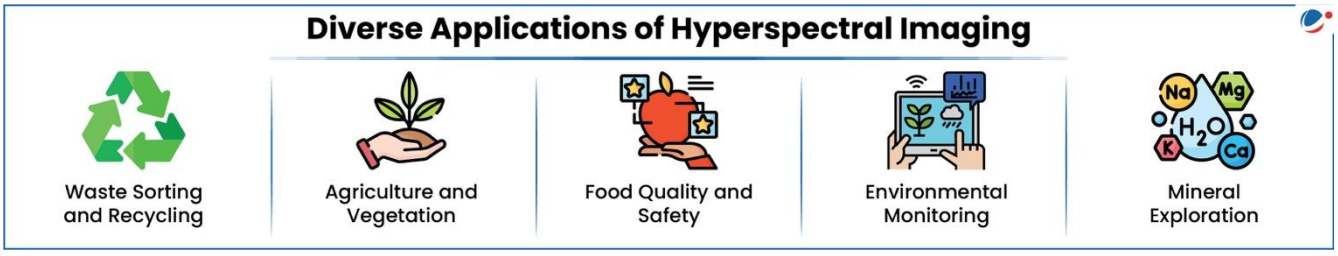
Indian private space-tech company Pixels launched India's first private satellite constellation 'Firefly'.

More on the News

- Firefly **is Pixxel's flagship Hyperspectral Imaging (HSI) satellite constellation**, featuring six of the highest-resolution commercial hyperspectral satellites to date.

About Hyperspectral Imaging (HSI) Satellites

- HSI **analyses a wide spectrum of light** instead of just assigning primary colours (red, green, blue) to each pixel, **effectively spectrally fingerprinting the Earth**.
- While a **typical satellite can identify a forest** from space, **HSI can distinguish between different types of trees** and determine health of each individual tree.



Conclusion

Hyperspectral Imaging captures the unique spectral fingerprint of materials, vegetation, and surfaces across Earth. By measuring reflected light across hundreds of narrow, contiguous spectral bands, it identifies patterns and anomalies that traditional sensors miss, enabling reliable analysis in even the most dynamic environments.

3.10. OUTER SPACE GOVERNANCE

Why in the News?

Norway becomes 55th nation to join NASA's Artemis Accords for lunar exploration.

About Artemis Accords

- **Established:** In 2020 by **NASA**, in coordination with the US Department of State, together with **seven other founding member nations** (Australia, Canada, Italy, Japan, Luxembourg, UAE, and UK).
  - Grounded in the **Outer Space Treaty of 1967** and other agreements including the Registration Convention, the Rescue and Return Agreement.
- **Objective:** It sets common **non-binding principles** to govern civil exploration and use of outer space, the moon, Mars, comets, and asteroids, for peaceful purposes.
- **India is also a signatory** to this Accord.

Key Principles of the Artemis Accords

- Conduct activities for **peaceful purposes**.
- Ensure **transparency** by sharing policies and plans.
- Join the Registration Convention and avoid **harmful interference**.
- Use and develop **international standards** for interoperability.
- Share scientific data **openly and promptly**.
- Preserve **outer space heritage** with historic value.

Need for Outer Space Governance Reform

- **Space Debris**: 130 million debris pieces exist; no global mechanism for monitoring or removal.
- **Resource Activities**: No agreed framework for exploring and using space resources.
- **Traffic Coordination**: Varying national standards hinder interoperability.
- **Conflict Prevention**: New norms needed to avoid weaponization and conflict in space.
- **Rising Launches**: Satellite numbers growing ~30% yearly (as of 2020).

What role can India play in improving Outer Space Governance?

- **Promoting better Implementation of Existing Framework:** India is a party to major international agreements, and it can act as a role model vis-à-vis adherence to these agreements.
- **Creating Space Doman Awareness (SDA): For instance**, India collaborates with various space-faring nations such as the United States, Russia, France, and others through partnerships in satellite launches, technology exchanges, and joint research initiatives.

Way Forward

United Nations in its policy brief document titled 'For All Humanity – the Future of Outer Space Governance' recommended:

- **New Treaty**: Negotiate a treaty to ensure peace and prevent an arms race in space.
- **Debris Removal**: Establish norms considering legal and scientific aspects.
- **Traffic Management**: Create a framework for coordination and situational awareness.
- **Resource Use**: Develop rules for sustainable exploration of celestial bodies.
- **Inclusiveness**: Involve commercial actors, civil society, and stakeholders in governance.

Conclusion

In the past decade, new actors, ambitions, and opportunities have transformed space exploration. The need is to ensure full implementation of international space law and establish effective governance to drive innovation and reduce risks.

3.10.1. SPACE DEBRIS

Why in the News?

SpaceX's Starship rocket faced a major setback when its eighth test flight ended in an explosion, dispersing debris over Florida and the Bahamas.

About Space Debris

- **It is defined** as all non-functional, man-made objects, including fragments and elements thereof, in Earth orbit or re-entering into Earth's atmosphere.
  - **Space debris** objects larger than **1 cm in size** (Large enough to be capable of causing catastrophic damage) is estimated to be over **1.2 million** (ESA Space Environment Report 2025).
- **Key Sources:** Majority of debris objects originate from on-orbit break-ups as well as on-orbit collisions.

Concerns related to Space Debris

- **Threat to space exploration:** E.g. **collision with a 10-cm object would cause catastrophic fragmentation of a satellite.**
- **Kessler syndrome:** Uncontrolled growth of debris can lead to self-sustained **cascading collisions creating a chain of reactions.**
- **Risk to life on Earth:** Large space debris that re-enter the atmosphere in an uncontrolled way can **create risks for the population** on the ground.
- **Rising cost of maintaining satellites in Space**: Space agencies have to undertake **Collision Avoidance Manoeuvres (CAMs)**.

Initiatives Taken

Global

- **Inter-Agency Debris Coordination Committee (IADC)** established in 1993.
- **UN Space Debris Mitigation Guidelines, p**repared by UN Committee on the Peaceful Uses of Outer Space (UN-COPUOS).
- **Zero Debris Charter:** Signed by **12 countries** - Austria, Belgium, Cyprus, etc.

Indian

- **Debris Free Space Missions (DFSM) 2030**
- **ISRO System for Safe and Sustainable Operations Management (IS4OM)**
- **Established Space Situational Awareness Control Centre (SSACC)**
- **Project Network for Space Object Tracking and Analysis (NETRA)**

Conclusion

Space debris poses an escalating threat to the safety and sustainability of outer space activities. As the number of satellites and missions grows, proactive measures—such as debris mitigation technologies, international regulations, and responsible space operations—are essential

3.11. SPACE-BASED SURVEILLANCE

Why in the News?

Cabinet Committee on Security (CCS) has approved the third phase of the Space-based Surveillance (SBS-3) project for better land and maritime domain awareness for civilian and military applications.

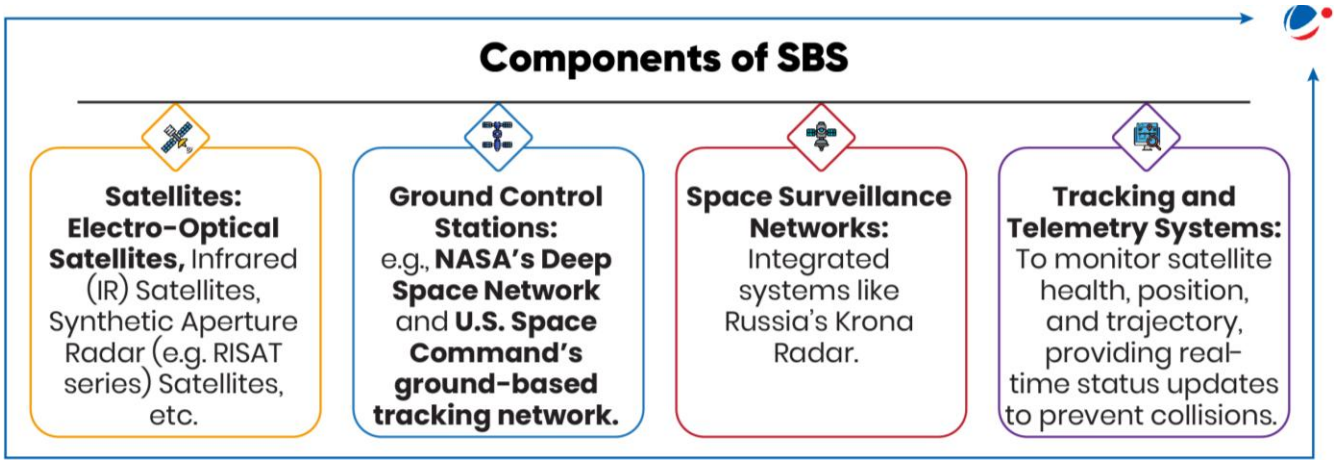
More on the News

- SBS-3 includes **52 satellites** in **Low Earth Orbit (LEO)** and **Geostationary Orbit (GEO)** for surveillance.
- The new fleet of satellites will be at different orbits **based on artificial intelligence (AI)** and will be able to **"interact with each other in space to gather geo-intelligence"** on the Earth.

India's SBS Projects		
SBS-1 (approved in 2001)	**SBS-2 (approved in 2013)**	**SBS-3**
Focused on basic surveillance capabilities.	Focused on enhanced surveillance for maritime domain awareness.	Proposes to utilize both LEO and GEO satellites for comprehensive coverage for land, sea and air-based missions.

About Space-based Surveillance (SBS)

- **It** involves the **use of satellites and other space assets** to monitor and collect data on objects and activities in space and on Earth.



Significance of Space-based Surveillance (SBS)

- **National Security:** Track threats like missiles and military activity (e.g., EMISAT provides for intercepting signals).
- **Space Traffic Management:** Monitor debris (e.g., ISRO's NETRA).
- **Asset Protection:** Defend satellites (e.g., Mission Shakti ASAT test).
- **Environmental Monitoring:** Track disasters, climate change, and ecosystems.
- **Scientific Research:** Study cosmic phenomena like solar flares, asteroids and Earth observations.

Concerns with Space-based Surveillance (SBS)

- **Dual-Use Risks**: Hard to distinguish peaceful and military use owing to difficulties in verification of regulatory compliances.
- **Militarization**: Arms race risk (e.g., US Space Force, Russian Aerospace Forces).
- **Privacy Issues**: Satellites can intrude on individual and national privacy.
- **Collision Risks**.

Conclusion

Space-based surveillance can transform disaster response, planetary understanding, and scientific collaboration. To ensure responsible use, global frameworks must promote transparency, prevent misuse, and uphold space as a shared domain for progress.

3.12. NAVIC (NAVIGATION WITH INDIAN CONSTELLATION)

Why in the News?

During Operation Sindoor, India used NavIC (Navigation with Indian Constellation) across several layers of combat operations such as Missile guidance, Drone navigation, Battle Damage Assessment, etc.

More on the News

- Additionally, ISRO has launched 100th mission from Sriharikota placing NVS-02 satellite into Geosynchronous Transfer Orbit for NavIC regional navigation system.

About NavIC

- **Developed** by **ISRO**
  - It was erstwhile officially known as **Indian Regional Navigation Satellite System (IRNSS)**.
  - India is the **only country** in the **developing** world to deploy such a system.
- **Coverage:** Provides accurate **Position, Velocity and Timing (PVT) service** up to region extending about **1500 km beyond** the **Indian landmass**.
- **Satellite Constellation:** Consists of **7 satellites** and a **network of ground stations** operating 24 x 7.
  - **3 satellites** are placed in **geostationary orbit** and **4** in inclined **geosynchronous orbit.**
  - These satellites are equipped with **dual-band signals (L5 and S-band)**.
  - The **L5 signal** is encrypted for **military use.**
- **Key services: Standard Position Service (SPS)** for civilian users and **Restricted Service (RS)** for strategic users.

Strategic advantages of NavIC

- **Independence from GPS:** India could strike deep without relying on any **foreign-owned navigation signals.** (In 1999 Kargil War, USA denied use of GPS).
- **Encrypted Military Channel:** Prevents jamming or spoofing during missile and drone missions.
- **Faster Signal Lock:** Provides higher accuracy over the **Indian subcontinent than even GPS in some regions**.
- **Tactical Depth:** With NavIC's expansion to include **NVS (NavIC Second Generation Satellite) series** satellites, India **aims** to cover the I**ndian Ocean Region** more comprehensively.

India's vision for NavIC includes:

- **Hypersonic Weapon Integration:** Guiding future **hypersonic glide vehicles (HGVs)**.
- **Space Command Network:** Serving as the **digital backbone for India's Defence Space Agency**, **Intelligence, Surveillance, And Reconnaissance (ISR) satellites**, and **kinetic space response units**.

Conclusion

NavIC's successful deployment demonstrates India's determination to achieve strategic autonomy in critical technologies. By providing reliable, accurate, and secure navigation capabilities independent of foreign systems, NavIC strengthens India's military readiness, enhances civilian applications, and reinforces its position as a major space power.

3.13. SATELLITE INTERNET SERVICES

Why in the News?

IN-SPACe has granted Starlink the licence to commercially operate in India for the next five years.

About Satellite Internet

- **Definition:** It is a **wireless internet connection** provided through communication satellites **orbiting the Earth.**
- **Difference:** Unlike land-based internet services such as fiber, cable, or DSL, it **doesn't rely on wires to transmit data.**
- **Infrastructure:** Includes three segments:
  - **Space Segment: Composed of several communication satellites**, which is responsible for receiving and forwarding satellite signals and providing satellite signal coverage to users.
  - **Ground segment:** Includes satellite measurement and **control networks, gateway stations,** etc., and mainly plays the role of connecting the satellite Internet and ground communication networks.
  - **User segment:** Includes various **communication terminals used by users**.

Various prominent Satellite Internet projects in the world

- **Project Kuiper**: **By Amazon** aiming to deploy over 3,200 LEO satellites to deliver affordable, high-speed broadband globally.
- **OneWeb:** By French satellite operator Eutelsat, and currently operates the world's second-largest satellite constellation fleet after SpaceX.
- **Qianfan constellation:** Qianfan is a planned **Chinese low-Earth orbit satellite internet megaconstellation** to create a system of worldwide internet coverage.

Significance of Satellite Internet services

- **Bridges Digital Divide**: Connects rural areas lacking internet.
- **Disaster Connectivity**: Provides service in emergencies and mobile locations.
- **Supports Digital Economy**: Enables platforms, trade, and infrastructure.
- **Strategic Autonomy**: Less vulnerable to cuts and tensions.
- **Military Use**: Use in conflicts (e.g., Starlink in Ukraine).

Issues about Satellite Internet services

- **Concerns for internal security:** In the wake of the Pahalgam attack, NIA suspect that terrorist **may have used satellite phones**.
- **Satellite Latency:** Satellite internet typically has **higher latency compared to traditional wired connections** due to the distance data must travel to and from the satellite.
- **Atmospheric changes:** Alumina produced in satellites is known to cause ozone depletion and could alter atmosphere's ability to reflect heat.
- **Other Issues:** Weather can affect satellite internet, high cost associated with its deployment and operation, increase in **space junk**, etc.

Conclusion

Prioritizing integration of underserved regions and embracing innovative hybrid models will not only bridge the digital divide but also drive inclusive socio-economic growth and strengthen India's global technological leadership.

3.14. GEOSPATIAL TECHNOLOGY AT A GLANCE

Geospatial Technology

- It is a collection of **various technologies** that provide information about the earth and aid decision-making capability towards earth's resource management and sustainable development.
- **Includes:** Remote sensing, Global Positioning System (GPS) and Geographic Information System (GIS).

Applications related to Geospatial Technology

Agriculture: **E.g.,** Krishi-Decision Support System (Krishi-DSS) to provide real-time information on crop conditions, weather patterns, and soil health.	**Land Records Management:** **E.g.,** NAKSHA (National Geospatial Knowledge-based Land Survey of Urban Habitations)	**Water Resource:** **E.g.,** India-WRIS Web GIS provides all water resources & related data and information.	**Mineral Mapping:** **E.g.,** GSI has initiated surface mineral mapping using ASTER multispectral remote sensing data.	**Environment:** **E.g.,**M-STrIPES uses GIS tools for effective patrolling of triggers.

Initiatives taken related to Geospatial Technology

National Geospatial Policy 2022: Position India as global leader in geospatial sector.	**Operation Drona Giri (2022):** To enhance citizen services, business efficiency, and governance.	**Integrated Geospatial Data Sharing Interface (GDI):** Supports applications in urban planning, environmental monitoring, and disaster management.	**National Geospatial Data Repository:** Developed to serve as a centralized platform for geospatial data management and access.

Concerns related to Geospatial Technology

Limited Availability of High-Resolution Data: Due to lack of detailed land use and cadastral maps.	**High Cost : E.g.,** LiDAR, drones, and high-resolution satellites are expensive	**Low Awareness and Adoption:** **E.g.,** Local Panchayats rarely use GIS for resource management.	**Surveillance Concerns:** E.g., use of drones and location tracking during COVID-19 lockdowns sparked debates on individual privacy.	**Low Penetration:** North-Eastern states, poor internet connectivity and lack of GIS labs.

Way Forward to enhance use of Geospatial Technology

Integration with Emerging Technologies Combine with AI, IoT, and Big Data for smarter decision-making and real-time applications.	**Enhance Data Availability** Develop and share **open-access high-resolution maps** and land records to support rural development and planning.	Conduct **training programs for local bodies, Panchayats** to increase adoption of geospatial tools.	**Invest in low-cost indigenous** alternatives such as Miniaturized Satellites (e.g., Cartosat series) for smaller organizations and local governments.

3.15. SPACE EXPLORATION AND OBSERVATORIES AT A GLANCE

Space Telescope and Observatories

Space observatories are **scientific instruments** that are designed **to study celestial objects and phenomena including Universe expansion.**

- **They allow astronomers** to access the entire electromagnetic spectrum, ranging from radio waves to high-energy gamma rays.

Key Concepts related to Space Explorations

Hubble Constant: It says that universe is **expanding at a rate of 67-68** Km per second per megaparsec.	**Dark matter:** It is a **hypothesised form of matter** that is invisible but is inferred to exist based on its gravitational effects.	**Dark energy:** It's a hypothetical form of energy to explain why the universe is not just expanding but is doing so at an accelerating rate.	**Redshift of galaxies:** **Light** from distant galaxies is redshifted, meaning their wavelengths are stretched, indicating they are moving away from us.

Important Space Telescopes

Hubble Space Telescope (1990): Understand the Universe.	**Chandra X-ray Observatory (1999):** It detects X-ray emissions from very hot regions of the universe such as exploded stars, clusters of galaxies, and matter around black holes.	**NASA's Fermi Gamma-ray (2008):** Detects gamma rays, the most energetic form of light.	**Imaging X-ray Polarimetry Explorer (2021):** It studies targets including active galactic nuclei, microquasars, pulsars etc.	**James Webb Space Telescope (JWST) (2022):** It studies every phase of Universe (first luminous glows after the Big Bang, formation of solar systems capable of supporting life on planets like Earth, evolution of Solar System etc.).

Significance of Space Telescope and Observatories

Studying Universe Expansion: E.g., Recently JWST confirms the Hubble Space Telescope's earlier finding that the rate of the universe's expansion is faster by about 8%. This discrepancy with Hubble Constant is called the '**Hubble Tension**'.	**Exoplanets:** **E.g.,** NASA's **Hubble and Spitzer space telescopes** opened a window on the atmospheres of far distant worlds, capturing early evidence of the gases present.	**Galaxy Formation and Evolution:** E.g., Hubble have captured images of majestic spiral galaxies, like NGC 3344.	**Life Cycle of a Star** **E.g.,** NASA's Hubble and Webb Telescopes Reveal Two Faces of a Star Cluster Duo.

Conclusion

Space telescopes have revolutionized astronomy by providing clear, detailed observations beyond Earth's atmosphere. Despite challenges like high costs, limited servicing, data limitations they continue to deepen our understanding of the universe and hold great promise for future discoveries.

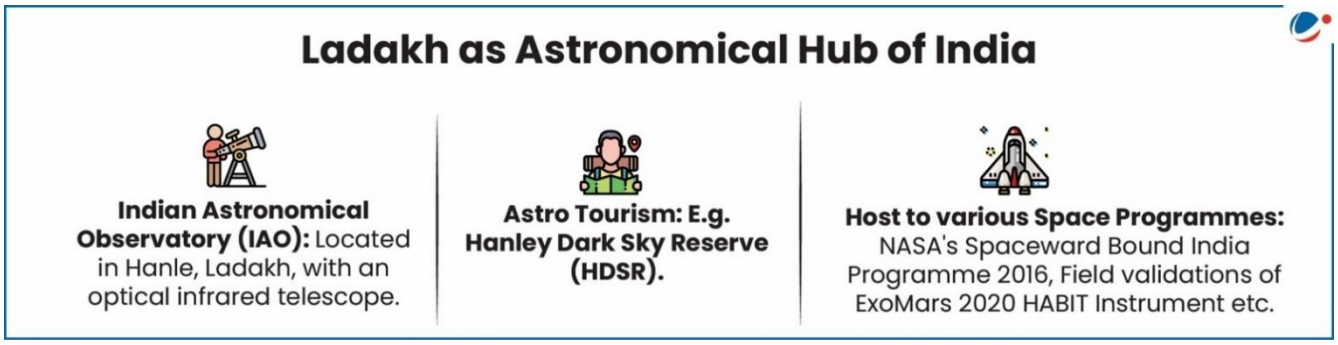
3.16. LADAKH AS OBSERVATORY HUB

Why in the news?

Department of Atomic Energy (DAE) inaugurated the **Major Atmospheric Cherenkov Experiment (MACE) Observatory at Hanle, Ladakh.**

More on the News

- Scientists also identify Ladakh as potential site for Martian or Lunar analogue research station.
- Presently, there are **33 analogue research stations** with none being in Indian sub-continent.
  - These include BIOS-3 (Russia), HERA and Biosphere 2 (USA), Mars One (Netherlands) and D-MARS (Israel).



About MACE Observatory

- It is largest imaging **Cherenkov telescope in Asia** and **2nd largest in the world.**
- **Objective:** Observe **high-energy gamma rays** to understand the most energetic phenomena in the universe (such as supernovae, black holes, and gamma-ray bursts).
    - **Gamma rays** have the smallest wavelengths and the most energy of any wave in the electromagnetic spectrum.

Why Ladakh is chosen for observatory?	Why is Ladakh ideal as Martian/Lunar Analogue?
• **Hanle Valley** of Changthang (4250m above msl), the site is a dry, cold desert with sparse human population. • **Cloudless skies** and **low atmospheric water vapour** make it one of the best sites in the world for optical, infrared, sub-millimetre, and millimetre wavelengths.	• **Geomorphological similarities to an early Mars and Moon:** ○ **Dry, cold, arid desert**, with abundant rocky ground. ○ **Vast flat land devoid of vegetation**, **dunes**, and drainage networks. ○ Segregated **ground ice and permafrost**, and rock glaciers. • **Geochemical similarities to Martian surface:** Volcanic rocks, saline lakes, and hydrothermal systems. • **Exobiological similarities:** Permafrost (evidence of water in past), increased UV and cosmic radiation flux, reduced atmospheric pressure, hot springs (rich in boron).

Conclusion

Identifying Ladakh as a site for research station underscores India's growing role in advancing planetary science and space exploration. Ladakh offers an unparalleled opportunity for testing technologies, studying human factors, and strengthening India's preparedness for ambitious interplanetary missions.

3.17. BLACK HOLES

Why in the News?

Scientists have reported the discovery of gravitational waves from the merger of two black holes that are the biggest to have been observed in such an event.

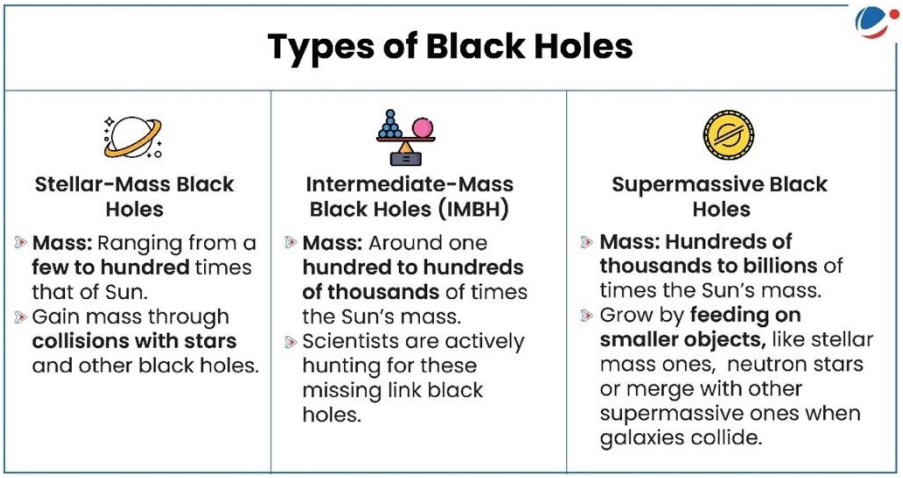
More on the News

- Earlier, Devasthal Optical Telescope (DOT) detected and measured the properties of an IMBHs (Intermediate-Mass Black Holes).
- Discovery was made by the scientists from **Aryabhata Research Institute of Observational Sciences (ARIES),** autonomous institute under **Department of Science and Technology (DST).**
- The **3.6m DOT** (commissioned in 2016) is the **largest** telescope for studying celestial objects at optical wavelengths in India.
    - Located in **Nainita**l and is maintained and operated by **ARIES.**

About IMBH Detected

- **Location:** About **4.3 million light-years away** in a faint galaxy.
- **Finding**: **A gas cloud** orbiting the black hole at a distance of around **2.25 billion kilometres** with a **velocity dispersion of 545 km per second** was found.
- **Significance of the discovery:** So far IMBH have **remained evasive** due to their **faint nature** and **location** in small galaxies.
    - Unlike their larger counterparts, they generally **do not generate bright emissions.**

About Black Holes



- **About:** Regions in space where an **enormous amount of mass** is packed into a **tiny volume** creating a **gravitational pull** so strong that **not even light can escape.**
    - They **neither emit nor reflect light**, making them **invisible** to telescopes.
    - They are created when **giant stars collapse** and are surrounded by a boundary called an **Event Horizon.**
- **Detection:** Based on their impact on surroundings through **Accretion disks** (ring of gas and dust surrounding black holes) and **Gravitational waves** (ripples created when very massive objects accelerate through space), etc.
- **Significance of Studying Black Holes:** Testing fundamental theories of Universe like the **General Theory of Relativity** and **Quantum Physics, understanding universe and its origin, gravitational waves,** etc.

Conclusion

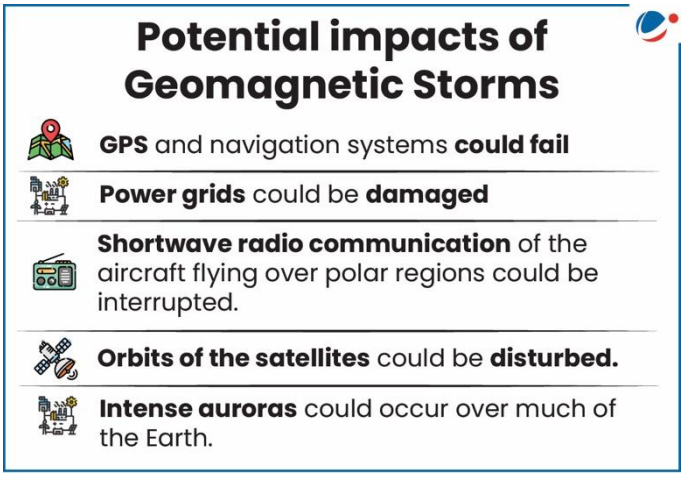
As we observe more black hole mergers with gravitational wave detectors like LIGO and Virgo, it becomes ever clearer that black holes exhibit diverse masses and spins, suggesting they may have formed in different ways.

3.18. GEOMAGNETIC STORMS

Why in the News?

After two decades, Earth has been struck by the G-5 Level Geomagnetic Storm.

Geomagnetic Storms



- **Definition:** Geomagnetic or Solar storms are **disturbances in Earth's magnetosphere** (Earth's magnetic field).
- **Classification**: Depending on the intensity, they are classified from **G1** (Minor) **to G5** (extreme).
- **Caused by:** These disturbances arise from the **interaction of charged particles from Sun with Earth's magnetic fields**, which is triggered by following solar explosions:
    - **CMEs:** Primary drivers of the **most severe geomagnetic storms.**

- They are **large expulsions of plasma and magnetic fields from the Sun's corona** (the outermost part of the Sun's atmosphere).
- They usually **take place around sunspot groups**, which are **cooler, highly magnetized** areas on the Sun's surface.
- They typically take **1 to 3 days to reach Earth.**

- **Solar Flares:** An **intense burst of radiation** coming from the release of **magnetic energy associated with sunspots.**
  - **Largest explosive events** in our Solar system that can **last from minutes to hours.**
  - They travel at the speed of light, which takes approximately **8 minutes to reach Earth.**

Conclusion

As our dependence on technology grows, understanding and forecasting these storms has become more critical. Strengthening early warning systems, investing in resilient infrastructure, and fostering global collaboration will be essential to mitigate their impacts and safeguard modern society.

3.19. METEORITE

Why in the News?

Scientists have confirmed a meteorite fall in a village in Beed (Maharashtra).

Difference between Meteoroid, Meteor and Meteorite

Stage	Meteoroid (In Space)	Meteor (In Atmosphere)	Meteorite (On Earth)
Definition	Space rocks broken from larger bodies.	Meteoroids burning in atmosphere ("shooting stars").	Meteoroids that reach Earth's surface.
Features	Rocky/metallic, smaller than asteroids.	High-speed entry, burn up, meteor showers.	Stony, iron, or stony-iron types; impact craters.
Examples	From planets, asteroids, comets.	Seen as streaks of light.	Lonar Lake crater, dark burned surfaces.

Significance of studying Meteorites

- **Understanding Solar Systems:** They contain in themselves past records of **our solar system's history.**
- **Geological composition**: They provide insights into **geochemistry and mineral composition** of the planets and solar system.
- **Helps in understanding evolution of terrestrial planets** including Earth and probe origin and evolution of life.

Exploration Initiatives

- **NASA All Sky Fireball Network:** It is a network of cameras to observe **meteors** in the sky **brighter than Venus**, which are called **fireballs**.
- **Canada's CMOR (Canadian Meteor Orbit Radar)**: It aims to detect the speed, direction, and location of meteoroids.

Conclusion

Meteorites carry clues about the origins and evolution of our solar system and life itself. By studying these celestial objects, scientists can deepen our understanding of planetary formation, geochemical processes, and cosmic history.

3.20. KEY WORDS

Keywords				
SPaDeX (Space Docking Experiment)	Kessler Syndrome	ISRO's NETRA	CE20 Cryogenic Engine	Scramjet Engine
NavIC	Bharatiya Antariksha Station	Hyperspectral Imaging	ISRO and Private Participation	TRISHNA Mission
Mars Orbiter Mission 2	Third Launch Pad	IN-SPACe	AXIOM-4	Artemis Accords

3.21. PRACTISE QUESTION

Answer Canvas

What is space debris and why is it a growing concern for global space activity? Highlight the initiatives taken at both global and national levels to tackle the issue.

Introduction	Body Part: 1	Body part: 2	Conclusion
Explain Space debris	Concerns related to Space debris	Steps taken both Global and Indian to tackle space debris.	Suggestive Conclusion mentioning mitigation technologies etc.

4. HEALTH

4.1. TRADITIONAL MEDICINE AT A GLANCE

Traditional Medicine

- It is **sum total of the knowledge, skill, and practices based on the theories, beliefs, and experiences indigenous to different cultures** used in the prevention, diagnosis, improvement or treatment of physical and mental illness (WHO).
- It composes of **Ayurveda, Yoga and Naturopathy, Unani, Siddha, and Homoeopathy (AYUSH).**

Significance of Traditional Medicine

Addresses gaps in health services: About 80% of the global population use some form of traditional medicine (WHO).	**Medical value travel:** Countries can provide unique resources and services that may be unavailable, unaffordable, or inaccessible elsewhere.	**Pharmaceutical:** Approx. 40% of pharmaceutical products have a natural product basis **(E.g., Aspirin).**	**Accessibility & Affordability:** Easily available and cost-effective compared to modern medicine for the poor.	**Effective in managing conditions like Chronic Back pain**

Initiatives taken to promote Traditional Medicine

Traditional Knowledge Digital Library (TKDL): To protect Indian traditional medicinal knowledge and prevent its misappropriation at International Patent Offices.	**National Ayush Mission:** To enhance the quality of Ayush healthcare services across India.	**Ministry of Ayush:** It has recently completed 10 years of its formation, aims to revive ancient medical knowledge	**Ayush Mark Certification Scheme:** Introduced the **Ayush Mark** and **Ayush Premium Mark** certification programs for Ayush products.	**WHO Global Centre for Traditional Medicine:** It is being established in Jamnagar (Gujarat) as a knowledge hub.

Challenges related to Traditional Medicine

Lack of Scientific Evidence: Claims about certain herbal treatments for cancer remain unproven due to insufficient research.	**Limited collaboration** between traditional and allopathic medicine practitioners can indeed hinder the delivery of holistic healthcare.	**Standardization:** Definition and categorization of herbal medicines vary from one country to another.	**Biopiracy:** E.g., traditional knowledge is patented without due recognition or compensation to the communities.	**Other:** Unethical herbal drug training, a shortage of qualified practitioners, etc.

Way forward to enhance Traditional medicine

Use of Artificial Intelligence (AI): WHO has recognized India's efforts in integrating AI with traditional medicine, particularly Ayush systems.	**Enhance Integration:** Build referral links with allopathy and streamline care.	**Ensure Quality & Safety:** Upgrade labs, enforce strict testing and surveillance.	**Enhance data collection:** Enabling the global tracking of traditional medicine usage, ensuring comprehensive reporting of its application.	**Pharmacovigilance** in the herbal sector to find the toxicological data and adverse drug reactions of herbal drugs.

4.2. TRANS-FAT ELIMINATION

Why in the News?

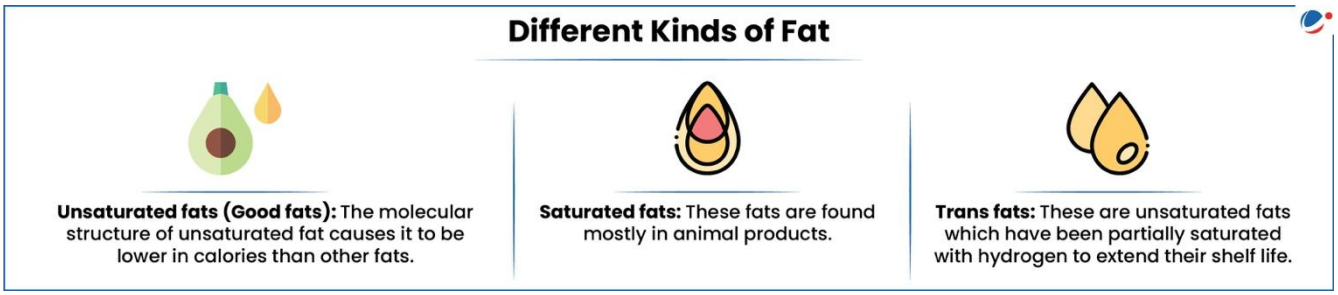
World Health Organisation (WHO) has published the fifth milestone report on progress towards global trans-fat elimination covering the period from 2018–2023.

Key Finding of the report

- **The policies** have improved the food environment for **46% (it was only 6% in 2018) of the world's population.**
- **WHO's ambitious target** to fully eliminate trans-fat from the global food supply by the end of 2023 has **not been fully met.**

About Fat

- **Fatty acids,** which are the building blocks of fat, are long chains of **carbon and hydrogen atoms.**
- **Essential fatty acids** are those needed by the **human body** that can only be obtained through food.



About Trans-fat (or Trans-fatty acids (TFA))

- **They are considered** as the worst type of fats (bad fat).
- **Types of Trans-fat**
  - **Natural** (ruminant trans fats): Occur naturally in meat and dairy and are not considered harmful.
  - **Artificial:** They are formed in an industrial process that adds **hydrogen** to **vegetable oil**, converting the liquid into a solid and resulting in partially hydrogenated oil (PHO).
- **Health Impacts**:
  - **Raises the level of the bad cholesterol** and **lowers the good cholesterol**.
  - It also **linked to inflammation, overweight/obesity, high blood pressure, diabetes etc.**

Steps taken to regulate Trans fat

- **Initiative of FSSAI:** Trans-fat free logo, Heart Attack Rewind**,** Eat Right India Movement etc.
  - **FSSAI capped** the amount of trans fatty acids (**TFA) in oils and fats** to **3% for 2021 and 2%** by 2022
- **REPLACE action framework by WHO (2018)**: Provides a strategic approach to eliminating industrially produced trans-fat from national food supplies.

Challenges in Eliminating Trans fat

- **High demand in Food Industry**: Trans-fat is cheaper in comparison to its alternatives.
- **Poor enforcement of policies**: Many unregistered firms are using them in different ways.
- **Consumer preferences:** Growing inclination towards processed food is a looming challenge towards governments as well as health regulators.

Way Forward to reduce use of Trans fats

- **Policies**: Countries must strengthen enforcement mechanisms to qualify for the WHO Validation Certificate.
- **Healthier Alternative**: Partially Hydrogenated Oils (PHOs) in foods can be replaced by oils rich in **Polyunsaturated Fatty Acids (PUFA)**. E.g. safflower, corn, sunflower, soybean, peanut etc.

- **Awareness and nudge:** Educating consumers regarding the ills of trans fat and associated foods like warnings and images used in cigarette packets.

Conclusion

Eliminating trans fats is vital to reduce heart disease and improve public health. With strong regulations, industry reform, and public awareness, a trans fat-free world is an achievable and urgent goal.

4.3. OBESITY

Why in the News?

Prime Minister stated that in 2022, one in eight people globally is living with obesity with cases among children and adolescents (5 to 19 years) has quadrupled.

About Obesity

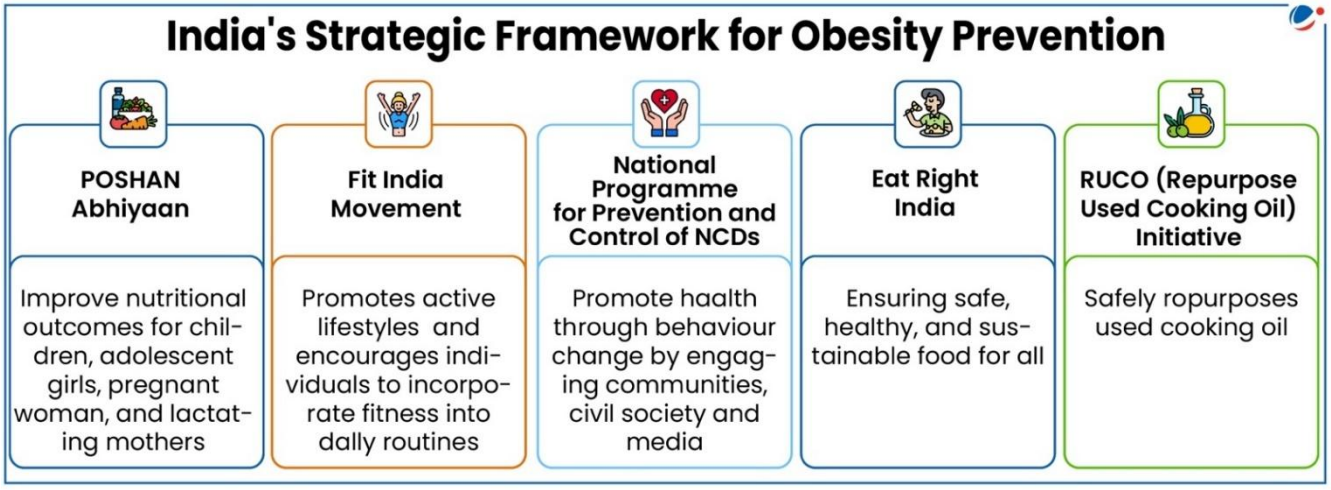
- Defined as an **abnormal or excessive fat accumulation** that presents a risk to health (World Health Organization).
  - **Body Mass Index (BMI)** is used to classify obesity. **BMI 30 or above** is classified as **obese.**

Status of obesity in India as per NFHS-5 (2019-2021)

- Overall, **24% of women** and **23% of men** are overweight or obese.
- **Child (under 5 years**) overweight rates **increased from 2.1% to 3.4% between 2015-16 and 2019-21.**

Factors Driving obesity in India

- **High-Calorie, Low-Nutrient Diets:** Increased consumption of refined carbohydrates, saturated fats and **easy access to processed foods**.
- **Sedentary Lifestyles:** Long sitting hours, excessive screen time, minimal movement in daily routines etc.
- **Use of Genetically modified crops:** Altered food composition, impacting metabolism and weight gain.



Conclusion

Addressing obesity requires a balanced approach combining lifestyle changes, supportive policies, and community engagement. With collective action and strong political will, we can reduce obesity and build a healthier society.

4.4. ANTI-MICROBIAL RESISTANCE (AMR)

Why in the News?

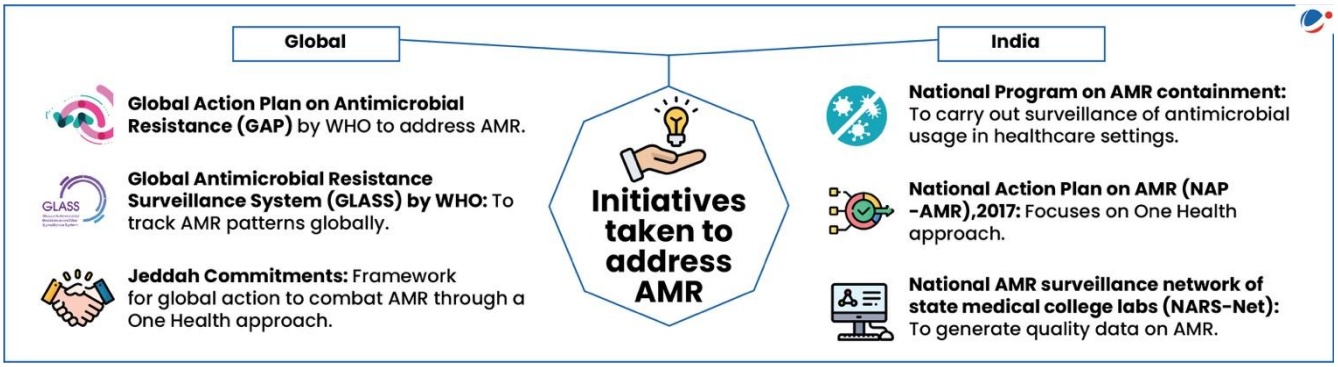
United Nations General Assembly (UNGA) High-Level Meeting on Antimicrobial Resistance (AMR) have approved a political declaration on antimicrobial resistance (AMR).

More on the News

- The declaration aimed at reducing the **human deaths** linked to bacterial **AMR by 10% by 2030**.
- Declaration also calls for an **additional US$100 million in catalytic** funding to combat AMR.

What is AMR?

- It is a **condition when microorganisms** such as bacteria, viruses, fungi, and parasites change in ways that render the **medications** used to cure the infections they cause ineffective.
- **Scenario of AMR:** ~39 million deaths estimated from antibiotic-resistant infections by **2050,** with **2 million annual deaths** projected in India alone. (The Lancet study).
- **Major factors contributing to AMR**:
  - **Pharmaceutical Manufacturing**: Industrial waste from production of Active Pharmaceutical Ingredients (APIs) for antibiotics.
  - **Agriculture**: Overuse of antibiotics for growth in sectors like livestock, aquaculture, etc.
  - **Healthcare Facilities**: Improper management of unused medications, patient excretion, and disposal of expired drugs.
  - **Waste Management**: Landfill leachate, untreated wastewater, and sewage effluents.



Why AMR is a Global Health threat?

- **Economic cost**: According to the World Bank, AMR could add **US$ 1 trillion** to healthcare costs by 2050.
- **Gains of modern medicine at risk**: It makes infections harder to treat and increases the risks of surgeries and treatments like chemotherapy.
- **Impact on Vulnerable Populations:** Individuals with weakened immune systems, the elderly, and children are particularly vulnerable to AMR-related infections.
- **Limited R&D for alternatives**: There is an inadequate research and development pipeline for alternative treatments in the face of rising levels of resistance.

Way Forward

WHO Guidance on Wastewater and Solid Waste Management for Antibiotic Manufacturing:

- **Regulations**: Implement Environment (Protection) Amendment Rules, 2019, which impose stringent limits on residues of 121 antibiotics in treated effluents from drug production units.
- **Agriculture Operations**: Sustainable farming practices such as organic farming can be promoted to limit the use of antibiotics in livestock and aquaculture.
- **Promoting Responsible Use**: Healthcare facilities should implement antibiotic stewardship programs for responsible antibiotic use.

Conclusion

Strengthening regulations, promoting responsible antibiotic use, investing in research, and raising public awareness are key to slowing its spread. Coordinated global and local actions are vital to safeguard the effectiveness of antibiotics for current and future generations.

4.5. ZOONOTIC DISEASES

Why in the News?

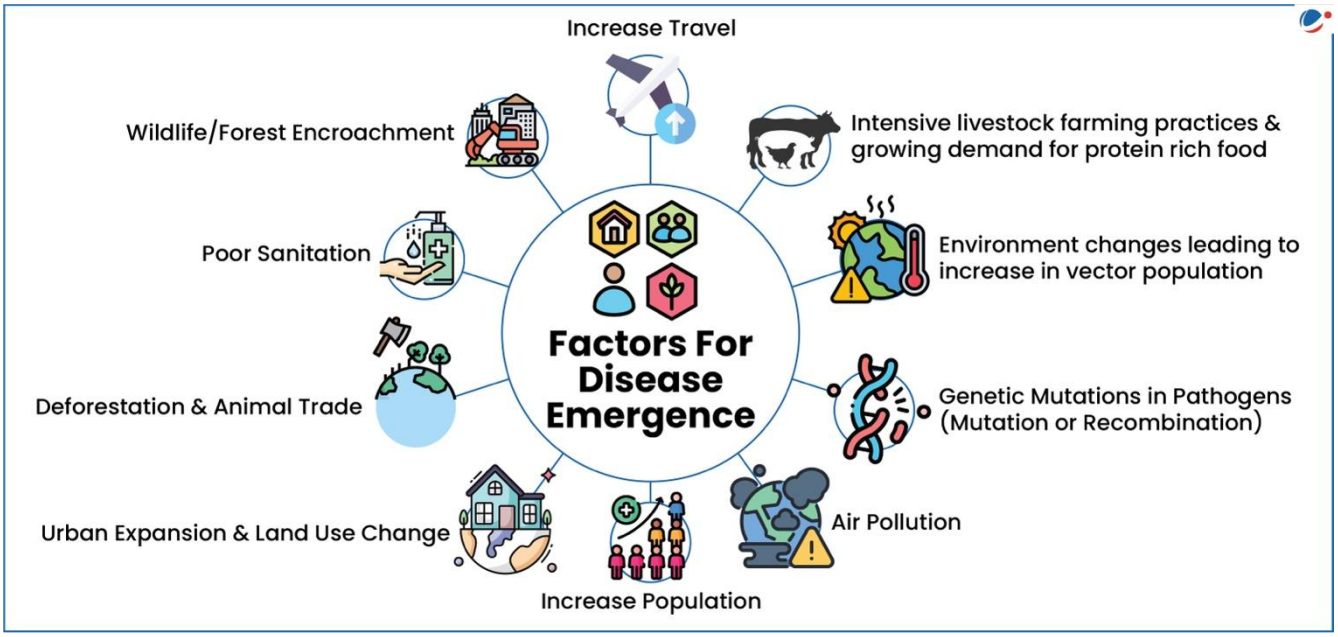
India's Integrated Disease Surveillance Programme (IDSP), 2018–2023 reported Zoonotic disease outbreaks.

Key-findings

- **Outbreaks reported**:8.3% were zoonotic, with a median of **seven monthly zoonotic outbreaks**.
  - **Japanese encephalitis accounted for 29.5% of zoonotic outbreaks**, followed by **leptospirosis** and scrub typhus.
- **Northeast region** contributed to around **one-third** of zoonotic disease outbreaks, followed by Southern region.

About Zoonotic Diseases

- Zoonoses are defined as those diseases and infections which are **naturally transmitted between vertebrate animals and people** (WHO).
- Zoonotic pathogens may be **bacterial, viral or parasitic**, and can spread to humans.
- Globally, **60% of reported emerging infectious diseases globally are zoonoses**.
- According to 1st State of the World's Animal Health Report, infectious animal diseases are expanding into **new geographical areas**, with nearly **47% having zoonotic potential.**



Initiatives taken to reduce Zoonotic diseases

- **Integrated Disease Surveillance Programme (IDSP):** IDSP monitors data on six zoonotic diseases of human health importance i.e.
  - Anthrax
  - Crimean-Congo haemorrhagic fever (CCHF)
  - Rabies
  - Kyasanur Forest Disease (KFD)

- Leptospirosis
- Scrub typhus.

- **National One Health Programme for Prevention and Control of Zoonosis:** Aims to institutionalize one health at national, state and district level, integrated surveillance, integrated community outreach program.
- **Disease Specific Programs:** National Rabies Control Program, Program for Prevention and Control of Leptospirosis and National Programme for Prevention and Control of Snakebite Envenoming.

Conclusion

Lack of comprehensive analysis and reporting delays in zoonotic disease surveillance hinder effective response. Strengthening disease-specific surveillance, especially in hotspot regions, is essential for timely, evidence-based interventions.

4.6. DRUG QUALITY IN INDIA

Why in the news?

Central Drugs Standard Control Organisation (CDSCO) directed manufacturers of 49 medicines to recall their products after samples were found to be "not of standard quality".

Regulation of drugs in India

- **CDSCO:** It regulates **quality, safety and efficacy of Drugs, Medical Device and Cosmetics** in India **Drugs & Cosmetics Act, 1940** and Drugs and Cosmetics Rules, 1945.
- **Drugs and Cosmetics Act (DCA), 1940:** It regulates import, manufacturing, sale and distribution of drugs in India.
- **State Drug Regulatory Authorities (SDRAs):** Responsible for licensing of manufacturing establishments, surveillance over sale of spurious drugs.
- **National Pharmaceutical Pricing Authority (NPPA):** It revises the prices of controlled bulk drugs and also monitors the availability of drugs, identifies shortages.

Issues with drug quality in India

- **State-Level Authorities (SLAs):** SLAs face challenges like ill-equipped testing labs, paucity of drug inspectors, poor understanding of rules etc.
- **Non-Compliance with Standards:** In 2023, just about 2,000 out of 10,500 manufacturing units were found to be compliant with WHO- **Good Manufacturing Practices (**GMP) standards.
- **Information Asymmetry:** Due to non-mention of time frame for completion of regulation stages, no centralised record keeping, absence of national database of manufacturers etc.
- **Limited reach of Pharmacovigilance:** Limited outreach among patients as well as healthcare professionals, with little or no information about measures taken after adverse drug reports.

Measures taken to ensure quality of Drugs

- **'Strengthening of States' Drug Regulatory System (SSDRS):** It envisages to strengthen the laboratory infrastructure and up-gradation of existing State Drug Controller offices in States.
- **Amendment to DCA 1940:** Drugs & Cosmetics (Amendment) Act 2008 provides stringent penalties for manufacture of spurious and adulterated drugs.
- **Amendments to Drugs and Cosmetics Rules, 1945:** Making inspection of manufacturing establishment mandatory by Central and State Drug Inspectors before the grant of manufacturing license.
- **Revamping Pharmaceuticals Technology Upgradation Assistance Scheme (PTUAS):** Government has extended eligibility to all pharmaceutical manufacturing units with turnover below ₹500 crore.

Conclusion

Improving drug regulation in India requires uniform standards, stronger **CDSCO-SDRA** collaboration, better infrastructure, financial autonomy, and use of digital tools to enhance drug quality and patient safety.

4.7. FIXED DOSE COMBINATION DRUGS

Why in the News?

CDSCO prohibited the manufacture, sale or distribution of 35 **fixed-dose combination (FDC)** medicines**.**

What are FDCs Drugs?

- **Definition**: FDCs refer to **products containing two or more active ingredients** also referred as cocktail drugs used for a particular indication (as per **Drugs & Cosmetics Rule 1945).**
  - **Active Ingredient** is the biologically active component of a drug product (tablet, capsule, cream, injectable) that produces the intended effects.
- Mostly FDCs are in **combinations** of **cough, cold, and fever preparations**; **antimicrobials; vitamins and minerals** etc.

Rationale for Usage of FDCs	Issues associated with FDCs
• **Enhanced efficacy**. • **Cost-effectiveness.** • **Reduced pill burden** and patient compliance. • They have a **pharmacokinetic** advantage. ○ **Pharmacokinetics** is defined as the study of absorption, distribution, metabolism, and excretion of drugs by the body.	• **Lack of individual dose flexibility** may not be suitable for all patients. • **Unapproved and Banned FDCs** accessible in countries like India. • **Increased risk of Anti-microbial Resistance (AMR)** due to potential overuse. • **Ethical concern as** there is no ban on same drugs being exported to African or SAARC countries.

Way forward

- **Strong punitive action:** As suggested by **Mashelkar Committee** (for regulatory infrastructure and problem of spurious/substandard drugs) against those involved in drug-related cases of corruption.
- **Evidence-Driven Authorization:** Require robust scientific evidence of **FDC efficacy** and safety to prevent unjustifiable combinations and enhance regulatory scrutiny.
- **Surveillance Systems:** Establish vigilant post-market monitoring mechanisms for prompt detection and resolution of FDC-related adverse effects, prioritizing public safety.
- **Export Control Stringency**: Harmonize export policies with domestic regulations to prohibit the overseas export of domestically banned or restricted FDCs.

Conclusion

Ensuring drug quality and rational use in India requires a multi-pronged strategy. Periodic surveys of manufacturers and retailers can help assess existing challenges, while establishing a National Drug Authority through legislation can strengthen oversight.

4.8. CHIMERIC ANTIGEN RECEPTOR (CAR) T-CELL THERAPY

Why in the News?

India's first homegrown gene therapy (CAR-T cell therapy) for cancer has been launched.

About CAR T-cell therapy

- **It modifies immune cells, specifically T-cells,** by turning them into potent cancer fighters known as CAR-T cells.
  - **T-cells are special cells** (types of white blood cells) whose primary function is cytotoxic, meaning killing other cells.
- **T cells** are taken from patient blood and are changed in lab by **adding a gene for a man-made receptor (called CAR).**
  - CARs are proteins that assist the T-cells to **recognise and attach to a specific protein present on cancer cells.**
- CAR-T cells are then given back to the patient.

Benefits of the CAR T Cell therapy

- **Can treat cancer** for an extended period.
- **It has the potential to cure** specific cancers completely.
- **Short treatment time** is needed and more rapid recovery.

Challenges: CAR T cell therapy for one cancer won't work for another type of cancer, can have negative effects on the nervous system, risk of infection, etc.

Conclusion

At present, CAR-T cell therapy is mainly applied in the treatment of certain hematological tumors. However, the future development direction aims to expand the range of applications, improve the therapeutic effects, reduce the serious side effects and lower the cost of treatment.

4.9. ORAL REHYDRATION THERAPY (ORT)

Why in the News?

Richard Cash, physician and global health scholar, died who was instrumental in the development of Oral Rehydration Therapy (ORT).

About Oral Rehydration Therapy (ORT).

- **ORT** is the **administration of appropriate solutions** (glucose, sodium chloride, sodium bicarbonate, and potassium chloride or citrate) by mouth to prevent or correct dehydration.
- **ORT consists of**:
  - **Rehydration**: Water and electrolytes are administered to replace losses.
  - **Maintenance fluid therapy** to take care of ongoing losses once rehydration is achieved (along with appropriate nutrition).
- **Treatment for:**
  - **Diarrhoea:** ORT has significantly reduced deaths from diarrheal diseases, with child mortality declining by two-thirds since 1990.
  - **Cholera**: ORT is highly effective in reducing mortality from over 50% to less than 0.2% in cholera patient.
- **Efficacy in Adults**: The patients receiving the oral solution required **80% less intravenous fluids** for cure in comparison to other techniques.
  - It demonstrated that this **low-cost intervention could effectively and safely reduce intravenous fluid needs.**

How ORT works?

- ORT works because of the **molecular mechanisms that govern sugar and sodium absorption inside the gut.**

- The cells that make up the lining of the gut have **special receptors on their surfaces that allow them to actively absorb sugar molecules.**
- The increase in sugar and sodium inside the cells leads to **increased absorption of water and chloride ions.**

Indian Initiatives:

- **National Oral Rehydration Therapy Programme (1985):** Launched to promote the use of ORT to combat child mortality due to diarrhoea.
- **National Health Mission (NHM):** ORT is a critical component of NHM programs targeting childhood illnesses like diarrhoea and dehydration.
- **STOP Diarrhoea Campaign**

Global Initiatives:

- **Oral rehydration solution (ORS) and zinc are recommended by the WHO and UNICEF** to be used collectively to ensure the effective treatment of diarrhoea**.**
- **Global Task Force on Cholera Control (GTFCC):** Roadmap 2030.
- **GAVI, the Vaccine Alliance**: GAVI supports initiatives to prevent and treat diarrheal diseases, including the promotion of ORT.

Conclusion

Oral Rehydration Therapy stands as one of the most cost-effective and life-saving public health innovations. Its ability to reduce mortality from diarrheal diseases, especially in children, has made it a cornerstone of global health strategies.

4.10. PANDEMIC AGREEMENT

Why in the News?

World Health Assembly (WHA) Adopted World's First Pandemic Agreement.

Key Highlights of the Agreement

- **Pandemic Prevention**: Aligned with International Health Regulations (IHR, 2005) to manage global disease spread.
- **Global Supply Chain**: Ensures access to health products during health emergencies.
- **Sustainable Financing**: IHR's Financial Mechanism to support implementation.
- **Pathogen Access and Benefit Sharing system (PABS) System**:
  - Facilitates timely sharing of pathogen data.
  - Pharma firms to give WHO access to 20% of real-time production.
  - Outcome to be reviewed at next WHA.
- **Enforcement**: Agreement opens for ratification post-PABS; enforced after 60 ratifications.

Existing Framework for Epidemic/Pandemic Management

- **'Public Health and Sanitation'** under Entry 6 of the State list (Seventh Schedule).
- **Entry 29 of Concurrent List** empowers center and State both to legislate for prevention of infectious or contagious diseases from one state to another.
- **International Health Regulation (2005)** provides legal framework for States in handling public health emergencies.
- **EDA 1897** is main legislation on subject matter.

Conclusion

Agreement's adoption follows three years of intensive negotiation launched due to gaps and inequities identified in national and global COVID-19 response. It boosts global collaboration to ensure stronger, more equitable response to future pandemics. Next steps include negotiations on Pathogen Access and Benefits Sharing system.

4.11. DISEASES

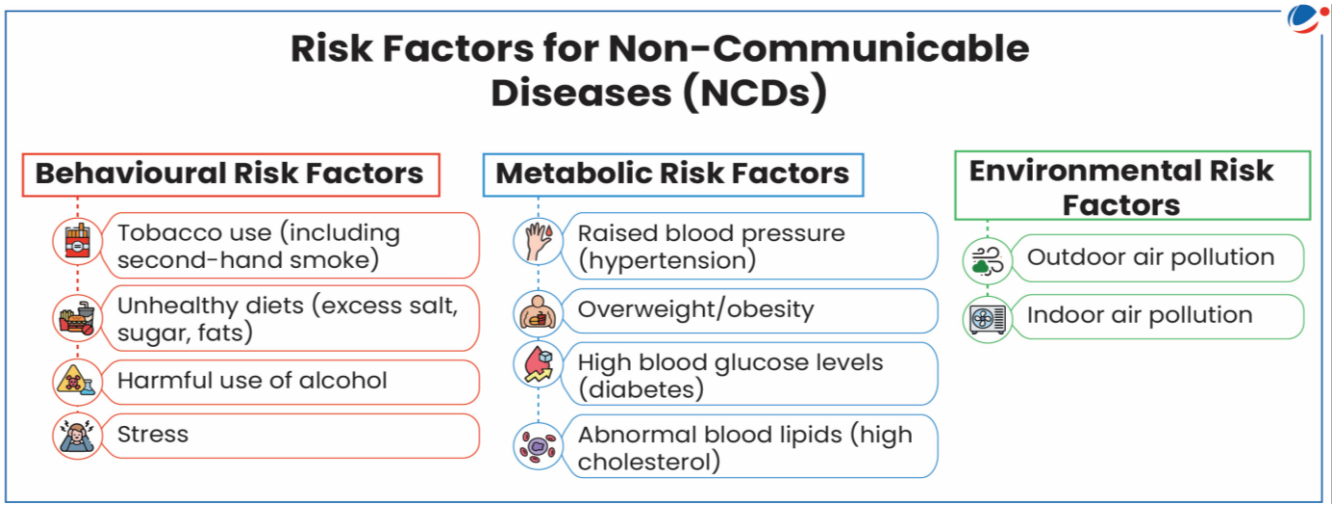
4.11.1. NON-COMMUNICABLE DISEASES (NCD)

Why in the News?

Ministry of Health & Family Welfare launched the Intensified Special NCD Screening Drive.

About Non-Communicable Diseases (NCDs)

- **NCDs** are **chronic diseases that are not transmissible** from one person to another.
- **Types**: **Cardiovascular diseases, cancers, chronic respiratory diseases** and **diabetes.**
- **Scenario:** NCDs accounts for **74% of all deaths globally** and **63%** of all deaths in India.



Initiatives for Controlling NCDs

Global

- **SDG target 3.4** aims to reduce premature NCD mortality by **one-third by 2030.**
- **WHO Global Action** Plan for the Prevention and Control of NCDs **2023-2030**

India

- **Affordable Medicines and Reliable Implants for Treatment (AMRIT)** to provide affordable medicines for the treatment of cancer, cardiovascular diseases etc.
- **National Tobacco Control Programme (NTCP):** To reduce production and supply of tobacco products etc.
- **National Programme for Prevention and Control of Cancer, Diabetes, Cardiovascular Diseases and Stroke (NPCDCS)** focuses on NCD prevention.

Recommendations for Prevention and Control of NCDs:

- **NCD Management**: Early detection, treatment, and palliative care via primary healthcare.
- **Digital Health**: Invest in low-cost tools (e.g., chatbots).
- **Fiscal Measures**: Use taxes on tobacco, salt, and sugar to reduce risk factors.
- **Life-Course Approach**: Integrate NCD policies with labour, social protection, and long-term care reforms.

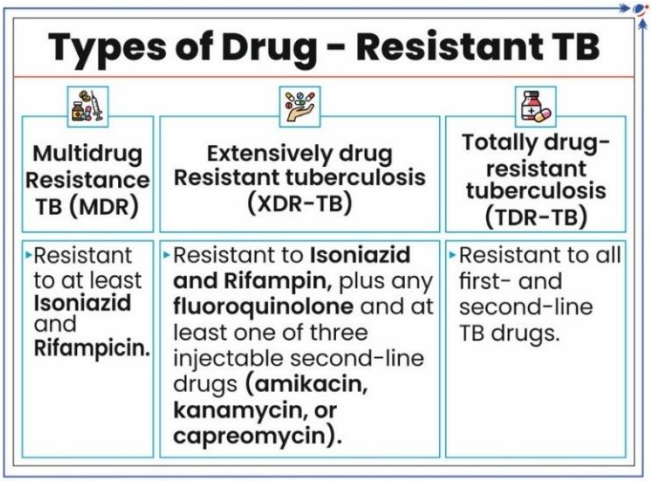
Conclusion

Non-communicable diseases are a major global health challenge but largely preventable through lifestyle changes, consuming food low in Glycemic Index, early detection, and strong public health measures. A collaborative approach is essential to reduce their impact and ensure better health outcomes.

4.11.2. TUBERCULOSIS (TB)

Why in the News?

Ministry of Health and Family Welfare approved new BPaLM regimen consisting of four drugs: Bedaquiline, Pretomanid, Linezolid and Moxifloxacin.



About BPaLM regimen

- Introduced **under National TB Elimination Programme** to achieve goal of **ending TB** in India by 2025.
- BPaLM regimen can cure the drug-resistant TB in just **6 months** with high treatment success rate.
    - **Traditional MDR-TB treatments** can last up to 20 months.

About Tuberculosis (TB)

- An infectious disease that most often **affects lungs**.
- Caused by **bacillus Mycobacterium tuberculosis bacteria.**
- **Bacillle Calmette-Guerin (BCG) vaccine provides immunity** against TB.
- There were **25.52 lakh notified TB patients** in 2023 **(India TB Report 2024)**.

Other Key initiatives of TB

- **Pradhan Mantri TB Mukt Bharat Abhiyan:** It provides additional patient support, augment community involvement.
- **Ni-kshay Mitra** ensures additional diagnostic, nutritional, support to those on TB treatment.
- **Nikshay Poshan Yojana** provides financial support to TB patients for their nutrition.

Challenges in Tuberculosis Eradication

- **Sub-optimally regulated private healthcare** leading to irrational use of first-line and second-line anti-TB drugs.
- **Diagnosis based on conventional methods** such as sputum culture is time-taking and less reliable**.**
- **Presence of comorbidities** such as HIV, diabetes, silicosis, etc, enhances the vulnerability to TB.
- **Social stigma** such as reluctance to disclose infection of family members.

Conclusion

An integrated, patient-centred approach with nutritional, financial, and psychological support is vital for TB control. Collaborations with pharmaceutical and AI firms can boost early detection and treatment efficiency. Community involvement, social media outreach, and advocacy efforts can further promote timely diagnosis and care-seeking behaviour.

4.11.3. NEGLECTED TROPICAL DISEASES (NTDS)

Why in the News?

World Health Organization has recently published report titled **Global report on Neglected Tropical Diseases 2024.**

Key-highlights

- **Target: Reduce the percentage of people requiring interventions against NTDs by 90% by 2030**.
    - In 2022, 1.62 billion people required interventions against NTDs, a **26% decrease from 2010.**

Neglected Tropical Diseases (NTDs)

- **These are a diverse group** of diseases caused by a **variety of pathogens** (including viruses, bacteria, parasites, fungi and toxins).
- **It is** called **Neglected** because they are almost absent from the global health agenda, Low global funding and associated with stigma and social exclusion.
- **India:** It has the world's largest **absolute burden of at least 10 major NTDs** (hookworm, dengue, lymphatic filariasis etc.)**. About 40%** of people requiring interventions against NTDs in India.

Why eliminating NTDs is important?

- **Affecting large Population:** NTDs affect over **1 billion** people globally, with **80%** of the burden in low- and middle-income countries.
- **Socio-economic Impact:** WHO estimates that eliminating NTDs by 2030 would save affected individuals over **$342 billion** in healthcare costs.
- **Affecting Gender Equality:** For E.g. Female genital schistosomiasis affects an estimated 56 million women, increasing HIV risk and causing organ damage.
- **NTD control yields high returns:** An NTD investment case for ending NTDs published in 2017 estimated that preventive chemotherapy treatments yield $25 in benefits per $1 invested.

Challenges in handling NTDs

- **Knowledge gaps** hinder development of better NTD diagnostics, treatments, and vaccines.
- **Weak health systems** struggle to restore NTD services to pre-COVID-19 pandemic levels.
- **Limited surveillance** led to NTD underdiagnosis and underreporting, hampering strategic planning.
- **Unpredictable funding** disrupts medicine distribution, hindering demand forecasting and supply planning
- **Rising temperatures** and changing weather patterns are altering the spread of vector-borne diseases (WHO).

Steps Taken to control NTDs

Global

- **Global NTD Annual Reporting Form (GNARF):** Standardized document used by countries participating in the Global NTD Programme.
- **Global vector control response (GVCR) 2017–2030:** Provides a new strategy to strengthen vector control worldwide through increased capacity, improved surveillance.
- **Kigali declaration on NTDs** (2022).

India

- **National Vector Borne Disease Control Programme (NVBDCP):** for control of Dengue and elimination of Kala-azar and Lymphatic Filariasis.
- **National Programme for Control of Blindness: services are provided for the control of Trachoma.**

Key recommendations of Global report on neglected tropical diseases 2024

- **Pillar 1: Accelerate Action:** Reduce disease burden (incidence, disability, death).
- **Pillar 2: Cross-Cutting Approaches:** Integrate and mainstream NTD services across programmes.
- **Pillar 3: Transform Models:** Promote country ownership and realign stakeholder roles.
- **Reposition NTDs**: Link with global health/emergency efforts, One Health, and climate priorities.

Conclusion

Overall, need a comprehensive approach that includes veterinary public health, improved water and sanitation, expanded vaccine access, food safety measures, vector control, and effective communication strategies to eliminated NTDs.

4.11.4. RARE DISEASES

Why in the News?

India's Central Drugs Standard Control Organisation (CDSCO) approves **first anti-complement therapy for rare diseases.**

What are Rare Diseases?

- **WHO** defines rare disease as often debilitating lifelong disease or disorder with **a prevalence of 1 or less, per 1000 population.** For E.g. Fanconi Anemia, Osteopetrosis etc.
- **India:** 63 Rare Diseases **are listed under National Policy for Rare Disease 2021 (NPRD, 2021).**

Classification of Rare Diseases in India (as per NPRD 2021)		
Group 1: **Amenable to one-time curative treatment**	**Group 2** **Long-term treatment needed with relatively lower costs and documented benefits**	**Group 3** **Definitive treatment is available but challenges in optimal patient selection for benefit, very high cost and lifelong therapy**
E.g., **Urea cycle disorders, Fabry disease** etc.	E.g., **Phenylketonuria, Homocystinuria etc**.	E.g., **Gaucher Disease, Pompe Disease** etc.

Initiatives taken to tackle rare diseases in India

- **National Policy for Rare Diseases, 2021**: Aims to lower incidence and prevalence of rare diseases.
- **Rashtriya Arogya Nidhi:** Provides financial assistance for poor patients suffering from rare disease.
- **Exemption on GST and Basic Customs Duty** on drugs imported for Rare Diseases for individual use.
- **Drugs and Clinical Trials Rules, 2019, CDSCO** has waived off local clinical trials for new drugs for rare diseases that have already been approved in countries like the United States, United Kingdom, Japan, etc.

Issues in managing Rare Diseases in India

- **Limited clinical trials**: Less than 0.1% of global clinical trials have site in India.
- **Lack of definition:** India currently lacks sufficient epidemiological data for a **standard definition.**
- **Underutilization of funds by Centre of Excellences (CoEs)**: Over ₹47 crore of the ₹71 crore allocated for financial assistance to 11 CoEs remains unused.
- **Limited treatment options:** 95% rare diseases have no approved treatment.

Way forward

- **Establish National Fund for Rare Diseases (NFRD)** with ₹974 crore allocation **for FY 2024-25 and FY 2025-26**.
- **Create dedicated Fast Track approval process** for rare disease drugs and therapy.
- **Enable Corporate Social Responsibility (CSR) contribution** by companies, including Public Sector Undertakings by adding Donations for rare diseases in Schedule VII of the Companies Ac.
- **Need a** hospital-based National Registry to collect epidemiological data on rare diseases across India has been initiated.

Conclusion

Rare diseases demand greater awareness, early diagnosis, and equitable access to care. Through policy support, research, and global collaboration, we can improve outcomes and bring hope to affected individuals and families.

4.12. KEY WORDS

Keywords				
Non-Communicable Diseases (NCDs)	Ayushman Bharat Digital Mission	CAR-T Cell Therapy	Rare Diseases	Neglected Tropical Diseases (NTDs)
Oral Rehydration Therapy (ORT)	Public Health Infrastructure	Pandemic Agreement	Zoonotic Diseases	Fixed Dose Combinations
Antimicrobial Resistance (AMR)	Glycemic Index	Trans-fat Elimination	Body Mass Index	BPaLM regimen

4.13. PRACTISE QUESTION

Answer Canvas

What are Neglected Tropical Diseases (NTDs) and why eliminating NTDs is important? Highlight global and India's steps to address NTDs.

Introduction	Body Part: 1	Body part: 2	Conclusion
Define NTDs	Importance of eliminating NTDs	Steps taken both Global and Indian level in reducing NTDs.	Highlighting important report recommendations and Conclusion.

5. MISCELLANEOUS

5.1. NUCLEAR ENERGY IN INDIA AT A GLANCE

Nuclear Energy in India

- India's installed nuclear energy capacity is **8.78GW.** The government plans to increase this 3 times **by 2031-32.**

Significance of Nuclear Energy

Medical **Radioactive iodine (I-131)** is used to treat thyroid cancer and other conditions affecting the thyroid gland.	**Low-Carbon Energy Source:** Essential for achieving India's **Net Zero by 2070 target** under the Paris Agreement.	**Agriculture:** **Fallout radionuclide (FRN) technique** analyses soil radionuclide concentrations to measure erosion patterns.	**Industry: Radiotracers** have wide application to provide valuable methods for the measurement and investigation of industrial process systems

Initiatives taken to promote Nuclear Energy

Atomic Energy (Amendment) Act, 2015: It enables NPCIL to form **joint venture with other Indian PSUs** to meet funding requirements for expansion of nuclear power programme.	**Three-Stage Nuclear Power Programme:** It comprises **Pressurised Heavy Water Reactors (PHWR)** in the first stage, **Fast Breeder Reactor** in the second stage and **thorium-based systems** in the third stage.	**Nuclear Energy Mission:** To achieve 100 GW of nuclear power capacity by 2047.	**World's first thorium based nuclear plant "Bhavni"** using Uranium-233 is being **set up at Kalpakkam in Tamil Nadu.**	**First two units of the indigenous** 700 MWe PHWR at Kakrapar, Gujarat **(KAPS - 3 & 4)** have **started commercial operation** in FY 2023-24

Challenges related to Nuclear Energy

Safety concern: **E.g.** Chernobyl (1986), Fukushima Daiichee accident (2011).	**Land requirements:** Protests against government plans of land acquisition.	**Import dependency on fuel requirements:** Uranium requirement is fulfilled through import.	**High upfront cost:** High capital costs as compared to energy sources like coal and natural gas.

Way Forward to Increase adoption of Nuclear Energy

Structured plan for effective management of radioactive wastes.	**Building societal awareness** and decoding negative connotations around nuclear power generation.	**Optimal regulatory regime:** To assess the safety requirements and compliances.	**Public-private partnership :** Policy support, free flow of authentic information and careful impact assessment on different stakeholders.

5.2. PRESSURIZED HEAVY WATER REACTOR (PHWR)

Why in the News?

North India's first nuclear power project will be established in Gorakhpur, Haryana.

More on the news

- Gorakhpur project consists of two twin units, each with a **Pressurized Heavy Water Reactor (PHWR)**, for a **total capacity of 2800 MW**

About PHWR

- A **PHWR** uses **Heavy Water (D_2O)** as both coolant and moderator, with **natural uranium** as fuel.
  - Heavy water is **water that contains heavy hydrogen** (also known as deuterium) in place of regular hydrogen.
  - Heavy water is used because it **slows down neutrons** effectively and also has **a low probability of absorption of neutrons.**
- **India's PHWR Development**
  - Introduced through **Indo-Canadian nuclear cooperation** in the 1960s.
  - First **220 MW reactor** built at **Rajasthan Atomic Power Station (RAPS-1)**.
  - After **Pokhran-1 (1974)**, Canada withdrew support, leading India to **indigenously develop and standardize** the 220 MW PHWR design.

Fast Breeder Reactor (FBR)

India's first Fast-Breeder Nuclear Reactor (500 MWe) set for commissioning by 2026

Located at **Kalpakkam in Tamil Nadu,** this will mark the beginning of the **second stage of India's three-stage nuclear power programme**.

About Fast Breeder Reactor

- **Genesis**: In 2003, government established **Bharatiya Nabhikiya Vidyut Nigam Limited (BHAVINI)** to construct and operate **Prototype Fast Breeder Reactor (PFBR)**.
  - Earlier **first stage** was implemented by **Nuclear Power Corporation of India Limited (NPCIL).**

Significance of FBR

- **Paves way for third stage:** It also marks use of **Thorium-232 (a non-fissile material),** which creates **fissile Uranium-233** to be used as fuel in **third stage**.
- **Technological Advancement:** India becomes **second country after Russia** with a commercial FBR.
- **Reduced Nuclear Waste:** Uses **spent fuel from Stage-I**,
- **Utilization of Thorium Reserve:** Paves the way for the **full utilization of India's abundant thorium reserves**.

5.3. THORIUM BASED REACTOR

Why in the News?

World's first thorium molten salt nuclear power station will be launched in Gobi Desert by China in 2025. Instead of Uranium, this nuclear power station uses **thorium as fuel.**

More on the News

- Its reactor **does not need water** for cooling because it **utilizes liquid salt or carbon dioxide** to transfer heat and make electricity.
- Unlike the water-cooling model, this design **significantly reduces the chances of meltdowns.**

Thorium as a Fuel

- Thorium, a **naturally occurring element with radioactivity**, is found at trace levels in soil, rocks, water, plants and animals.
- Due to its physical characteristics, thorium **cannot be used directly to produce nuclear energy**. It has to be first converted to **U-233 in a nuclear reactor**.

Significance of Thorium based reactors

- **Abundant Supply** unlike Uranium. In India, **Kerala and Odisha** have rich reserves of **monazite**, which contains **about 8 – 10% thorium.**
  - Monazite is also prominent in **Andhra Pradesh, Tamil Nadu, West Bengal and Jharkhand**.

- **Chemically safe,** due to higher melting point, better thermal conductivity, better fuel performance characteristics, chemical inertness and stability.
- **Environmentally safe,** generates lesser toxic and short-lived radioactive wastes.

Conclusion

The development of thorium-based molten salt reactors marks a significant shift towards safer, cleaner, and more sustainable nuclear energy. With abundant thorium reserves and superior safety features, these reactors present a promising alternative to traditional uranium-based systems.

5.4. SMALL MODULAR REACTORS (SMRS)

Why in the News?

Union Budget 2024-25 announced that **Centre will partner with private sector** to develop **Bharat Small Reactors (BSRs).**

More on the News

- This announcement marks a historic **shift in India's nuclear policy,** as the **Atomic Energy Act of 1962** did not permit private sector participation in nuclear energy generation.
- BSRs are aligned with global trends where **Small Modular Reactors (SMRs)** are gaining attention.
  - Unlike **SMRs,** which are an entirely new concept involving **factory-made, easily assembled reactors, BSRs** are based on India's existing **Pressurized Heavy Water Reactor technology.**
  - They can enhance the contribution of **nuclear energy in India's energy basket** (current share of **nuclear energy is 1.6%).**

What are Small Modular Reactors (SMRs)?

- **Definition:** Small modular reactors (SMRs) have a power capacity of **up to 300 MW (e) per unit,** which is about one-third of the generating capacity of traditional nuclear power reactors. SMRs are:
  - **Small**: Physically a fraction of the size of a conventional nuclear power reactor.
  - **Modular:** Making it possible for systems and components to be factory-assembled and transported.
  - **Reactors:** Harnessing nuclear fission to generate heat to produce energy.

Significance of SMR Nuclear Energy

- **Compact & Safe**: Passive safety systems reduce reliance on external power and pumps.
- **Versatile Use**: Suitable for electricity and thermal needs like seawater desalination (e.g., South Korea's SMART).
- **Factory-built**: Modular design allows easy transportation and quicker site assembly (e.g., NuScale).
- **Remote Operation**: Can be placed underground or on floating platforms (e.g., Russia's Akademik Lomonosov).
- **Scalable**: Multiple modules can be installed at a single site for flexible power generation.

Concerns with SMRs

- **Commercial Risks**: Profit-driven private sector may compromise on safety.
- **Passive System Limitations**: Safety features may fail post-accident (U.S. Nuclear Regulatory Commission caution).
- **High Costs**: Smaller plants less cost-effective per MW than larger ones.
- **Waste Management**: Generates same level of radioactive waste per unit as large reactors.
- **Fuel Efficiency**: No better than large reactors; some need expensive high-assay low enriched uranium or HALEU fuel.

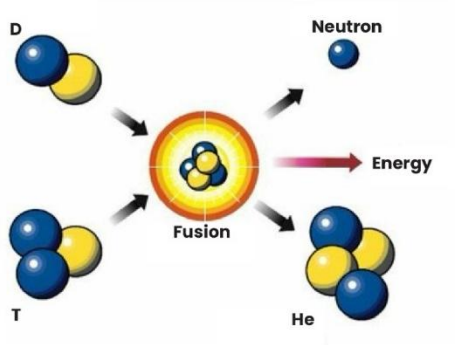
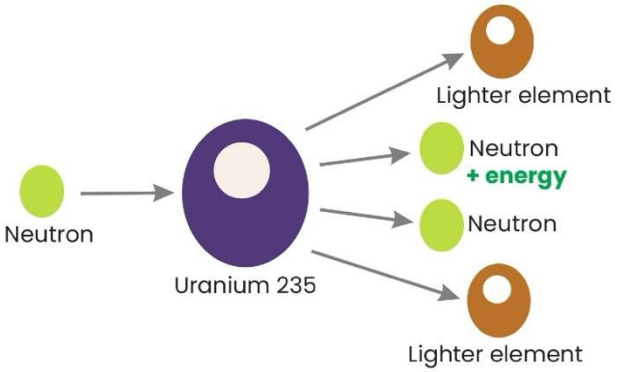
Conclusion

Small Modular Nuclear Reactors hold significant promise as a flexible, safer, and more cost-effective alternative to traditional large nuclear plants. By offering scalable clean energy solutions with enhanced safety features, SMRs can play a vital role in meeting growing energy demands and reducing carbon emissions.

5.5. NUCLEAR FUSION AT A GLANCE

Nuclear Fusion

Difference Between Nuclear Fusion and Fission

Nuclear Fusion	Nuclear Fission
›Fusion occurs when two atoms slam together to form a heavier atom, like when two hydrogen atoms fuse to form one helium atom.  ›**Fuel used:** Generally, two hydrogen (H) isotopes- deuterium (D) and tritium (T).	› Fission occurs when a neutron slams into a larger atom, forcing it to excite and split into two smaller atoms.  › **Fuel used:** Uranium, plutonium etc.

Initiatives taken to promote Nuclear Fusion

ADITYA: Institute of plasma research, Ahmedabad **indigenously built and operated the first Indian Tokamak.**	**Steady State Superconducting Tokamak (SST-1)** for developing an experimental facility to study plasmas in steady state in thermo-nuclear fusion devices.	**Indus Synchrotron Radiation Facility:** INDUS-1 and INDUS-2 share a common injector system consisting of a microtron and a booster synchrotron.	**China's Experimental Advanced Superconducting Tokamak (EAST):** It maintained a steady-state high-confinement plasma.	**Other Global: Joint European Torus (JET)** in UK, **Korea Superconducting Tokamak Advanced Research (KSTAR)** in South Korea.

Challenges related to Nuclear Fusion

High temperature required: Temperatures of over 100 million °C are required to make deuterium and tritium fuse (IAEA).	**Magnetic Confinement:** The plasma must be suspended within a confined space using strong magnetic fields to prevent contact with reactor walls.	**Neutron radiation** during the reaction can travel tens of centimetres out into containment structure which can cause structural damage.	**Technology and Application:** Still at the experimental stage.

Way forward for Nuclear Fusion technology

International cooperation: It can play key role in achieving the net Energy Gain (NEG).	**Invest in R&D:** To develop radiation-resistant and heat-tolerant materials for reactor walls and components.	**Accurately evaluate** the plasma confinement magnetic field using AI technology that solves optimization problems.	**Incorporating private sector players into fusion research** can emulate success stories from other critical sectors, such as defence and space.

5.6. TOKAMAK REACTORS

Why in the News?

World's biggest nuclear fusion project, ITER has completed its central magnet system, with **India playing a critical role in building several key components**.

About Tokamak reactor

- **Origin of term:** The term "tokamak" comes from a Russian acronym that stands for **"toroidal chamber with magnetic coils".**
- **Purpose:** The **tokamak** is an experimental machine designed to harness the energy of fusion.
- **Working:** Inside a tokamak, fusion plasma is created and confined by strong magnetic fields.
  - **Plasma** is a **fundamental state of matter** along with **solids, liquids and gases.**
- **Energy to electricity:** The energy produced through the **fusion of atoms in the plasma** is absorbed as heat in the walls of the vessel.
  - **Just like a conventional power plant,** a fusion power plant will use this heat to produce steam and then electricity **by way of turbines and generators.**
- **Key components of Tokamak reactor**
  - **Torus:** A donut shape chamber that confines a plasma using magnetic fields is called a torus.
  - **Magnetic coils:** Two sets of magnetic coils - toroidal and poloidal acts as a magnetic 'cage' to hold and shape the plasma.
  - **A central solenoid:** (A magnet that carries electric current) creates a second magnetic field.

About International Thermonuclear Experimental Reactor (ITER)

- It is an international collaboration of **more than 30 countries**, located in **Southern France.**
- **ITER Members:** 27 member countries of the European Union plus China, India, Japan, Korea, the Russian Federation, and the United States.
- **Objective:** To **demonstrate the viability of fusion** (the power of the sun and star) as an abundant, safe, carbon-free energy source for the planet.
- **Contributions:** European Union contributes 45% of construction cost while rests of the parties contribute 9% each.
- **India's Membership:** India joined the ITER project in 2005.
  - **Institute for Plasma Research in Ahmedabad** is lead institution from India participating in the project.

Conclusion

Tokamak reactors, **using magnetic confinement,** remain at the forefront of fusion research, offering a path to clean and abundant energy. However **alternative laser fusion based on inertial confinement** is emerging as a viable alternative. In Toto global pursuit of practical nuclear fusion, possess unique advantages toward **achieving sustainable energy.**

5.7. BATTERY ENERGY STORAGE SYSTEM (BESS) AT A GLANCE

Battery Energy Storage System (BESS)

- It refers to an **electrochemical device** which enables **renewable energy like solar energy, wind energy to be stored and released when needed.**
- **Types Of Energy Storage System: Mechanical** (Pumped Storage Hydro, Flywheel etc.), **Electrochemical** (Lead acid, Zinc-bromine etc.), **Chemical** (Fuel Cells, etc.)

Significance of BESS

Minimizes greenhouse gas emissions: Aid in achieving Panchamrit target of **net zero emission** by 2070.	**Reduce Energy Costs:** Stored energy can be used during **peak hours,** when energy prices are highest.	**Reduce Grid Dependency and Improves Grid Stability:** By sourcing and storing power, and by balancing supply and demand.	**Cater to Future needs:** As per National Electricity Plan, 236 GWh BESS would be required by 2031-32.

Initiatives taken to promote BESS

Viability Gap Funding (VGF) scheme: For development of 4,000 MWh of BESS projects by 2030-31.	**Legal status for ESS as a** Generator, Transmission or Distribution element, issued by Ministry of Power (MoP) in 2022.	**Production Linked Incentive Scheme** for National Programme on Advanced Chemistry Cell Battery Storage.	**National Framework for Promoting Energy Storage Systems** by Ministry of Power in 2023.

Concerns related to BESS

Extremely low reserves of Raw materials like lithium, cobalt, nickel and battery-grade graphite.	**Policy uncertainty:** such as discontinuation of tax holidays, reduction of accelerated depreciation benefit, etc.	Increased **need for maintenance** and monitoring.	**Other challenges:** Lack of high-quality R&D infrastructure, Absence of EV and storage policies, financing and cheaper imports.

Way forward to enhance use of BESS

Demand creation: Implementation of a soft loan facility for Discoms/transmission companies to deploy energy storage and battery solutions.	**Phased manufacturing programme:** Incentivising advanced cell manufacturing, supported adequately by states to encourage investors	**Taxation: Re-design GST** rates to discourage imports and encourage domestic procurement of batteries.	**Recycling and sustainability:** Ensure effective implementation of Extended Producer Responsibility (EPR) and digitize waste management to move from 'End-of-Life' approach to 'circular economy' in BESS.

5.7.1. SODIUM-ION BATTERY

Why in the News?

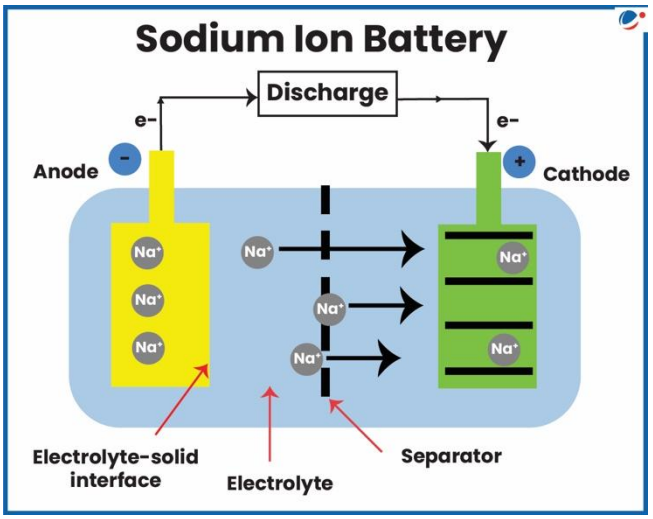
Research team working under Department of Science and Technology has developed a **super-fast charging sodium-ion battery (SIB)** that can charge up to **80% in just six minutes** and last over **3000 charge cycles.**

About Sodium-Ion Battery (SIB)

- **Definition**: SIBs are a **type of rechargeable battery** similar to lithium batteries, but carry the charge using sodium ions (Na+) instead of lithium ions (Li+).

How Sodium-Ion Batteries (SIBs) Work?

- **During discharge**: Sodium ions move from **anode** (negative electrode) to **cathode (positive electrode)**, which hosts ions and undergoes **reduction**.
- **These ions travel through an electrolyte** (an electrical conductor) that enables the flow of current by creating a potential difference.
- **During Recharge:** Sodium ions return to the anode.



Advantages of Sodium-Ion Batteries (SIBs) Compared to Lithium-Ion Batteries (LIBs)

Parameter	Sodium-Ion Batteries (SIBs)	Lithium-Ion Batteries (LIBs)
Cost	15–20% lower; sodium is cheaper	Higher due to expensive lithium compounds
Supply Chain	Decentralised; sodium is abundant worldwide	Concentrated; e.g., China processes 60% lithium
Temperature Range	Better suited for wider temperature variations	Less tolerant to extreme temperatures
Safety	Can be shipped at zero voltage; lower fire risk	Requires precautions due to fire hazards

Conclusion

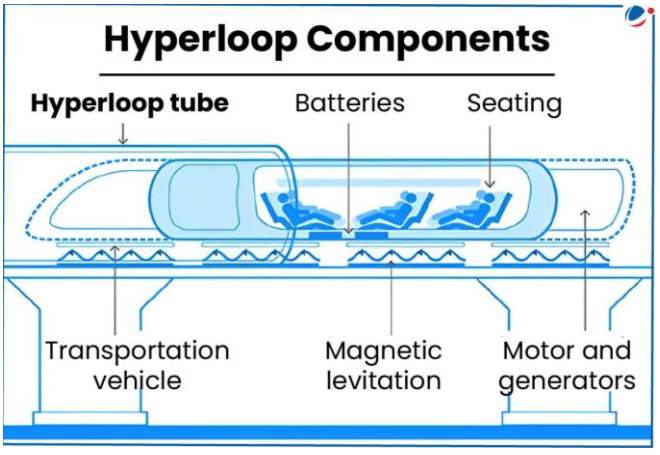
Sodium-ion batteries present a promising alternative to lithium-ion technology, especially in terms of cost, safety, and global resource accessibility. With advancements like ultra-fast charging and long cycle life, SIBs are emerging as strong contenders for applications in energy storage and electric mobility.

5.8. HYPERLOOP TECHNOLOGY

Why in the News?

IIT Madras in collaboration with TuTr (an startup) has recently completed a 410-meter Hyperloop test track, the first such experiment in Hyperloop technology in India.

What is Hyperloop Technology?



- **Genesis:** In 2013, the CEO of SpaceX, Elon Musk, proposed a concept of **ultra-high-speed rail (UHSR)** called hyperloop and open-sourced it.
  - The technology significantly builds on **"gravity vacuum tube," "gravity vacuum transit," or "high-speed tube transportation,"** which dates back to **1865.**
- **Functioning:**
  - Hyperloop is essentially a **magnetic levitation (maglev) train system** that uses one set of magnets to **repel** cars so that they hover above a track and another set of magnets to **propel** them forward over the track.
  - The track in hyperloop technology is a **low-pressure tube** with built-in vacuums that remove nearly all air from the steel tube.
  - **It enables** the theoretical speed of **1,200 km/h.**

- **Accessibility**: The technology has an ambitious goal to result in a **time-space shrinkage,** which will increase the accessibility of cities through very low travel times over long distances.

Advantages of Hyperloop

- **High Speed**: Over 1000 km/h, 3 times faster than high-speed rail.
- **Driverless**: Eliminates human error.
- **On-Demand**: 10–30 sec intervals, no collision risk.
- **Weatherproof**: Less affected by weather, no track buckling.
- **Less Invasive**: Easier tunnels, smaller stations.
- **Reshapes Logistics**: Carries large containers, cuts truck emissions.
- **Cuts Emissions**: 2–3 times more efficient, uses maglev and low-pressure design, stores electricity.

Issues with Hyperloop technology

- **High Costs**: ~$25–$27 million per mile (excluding land costs) as per NASA.
- **Safety Concerns**: Fire inside pods is a major risk despite fire-resistant tubes.
- **Vacuum Maintenance**: Energy-intensive and challenging over long distances.
- **Acceleration Impact**: Lateral/vertical acceleration >2 m/s^2 can cause motion sickness.
- **Infrastructure Demand**: Needs long, straight, stable tracks are difficult to construct.

Conclusion

As India enters the global Hyperloop race with initiatives like the IIT Madras test track, fostering collaboration between academia, startups, and policymakers will be key to realizing its full potential.

5.9. DESALINATION TECHNOLOGIES

Why in the News?

IIT Bombay scientists developed a lotus leaf-inspired hydrophobic graphene-based solar evaporator for efficient water desalination, offering a breakthrough solution to the global freshwater crisis.

Status of Fresh water crisis

- While 71% of its surface is covered by water, the world population depends on **only the 3% available fresh water.**
  - Out of which **only 0.06% can be easily accessed** as the rest comprises the frozen polar ice cap or glaciers, groundwater, and swam.

Desalination Technologies and Processes

Aspect	Thermal Technology	Membrane Technology
Concept	Heats water, collects vapor; for seawater desalination to pure water	Filters through membranes; for brackish water
Processes	Flash, Multi-Effect, Vapor Compression	Electrodialysis, Reverse Osmosis
Merits	Cuts high salinity; uses less electricity	Eco-friendly, smaller footprint
Demerits	Costly, uses fossil fuels, scaling issues	Fouling, high maintenance, incomplete TDS removal
Example	**Low Temperature Thermal Desalination** in Lakshadweep	Nemmeli RO Plant, Tamil Nadu

Conclusion

Moving forward, scalable deployment, supportive policy frameworks, and continued research will be crucial to ensure equitable access to clean water across regions.

5.10. LIGHT SUPERSOLID

Why in the News?

For the first time scientists of Italy's National Research Council have **made supersolid from light.**

About Supersolid

- **Definition:** It is a **rare state of matter** that **exhibits both solid-like structure and frictionless flow.**
  - It is **defined by quantum mechanics** where **particles condense into an orderly, crystalline solid** but **also move like a liquid** that has no viscosity (thus, zero friction exist in their movement).
- **Initial Research: First predicted in the 1960s**, Supersolid were demonstrated in **2017** using **ultracold Bose–Einstein Condensates (BEC)**.
  - So far Supersolid **required extremely low temperatures** usually very **close to absolute zero** (0 Kelvin or -273.15°C) where **quantum effects appear.**
  - At this temperature, **atoms have minimal energy**, and matter behaves in unusual ways, such as forming the **fifth state of matter** also termed as **BECs.**
  - While scientists **cannot reach absolute zero exactly**, they can get extremely close in laboratory conditions.
- **Current Research:** The new research used a **novel mechanism** that relies on the properties of **"polariton" systems**.
  - **Polaritons** are formed by **coupling light and quasiparticles like excitons** through strong electromagnetic interactions.
  - **Quasiparticles** are mathematical construct which **treat elementary excitations in solids**, like spin waves, **as particles**.
    - As the particles do not consist of matter, they **are called quasi particles.**

What is the Significance of Converting Light into Supersolid?

- Supersolid light could play a **crucial role in developing more stable quantum bits (qubits)**, which are essential for the advancement of quantum computing.
- The **ability to manipulate light** in this way could **revolutionize optical devices, photonic circuits, and even fundamental quantum mechanics research.**
- The ability to **manipulate light at this level allows researchers to explore new realms of material science** and could lead to advancements in how we understand and use energy.

Conclusion

The creation of a light-based supersolid marks a remarkable breakthrough in quantum physics, opening new pathways in the manipulation of light and matter.

5.11. VIGYAN DHARA SCHEME

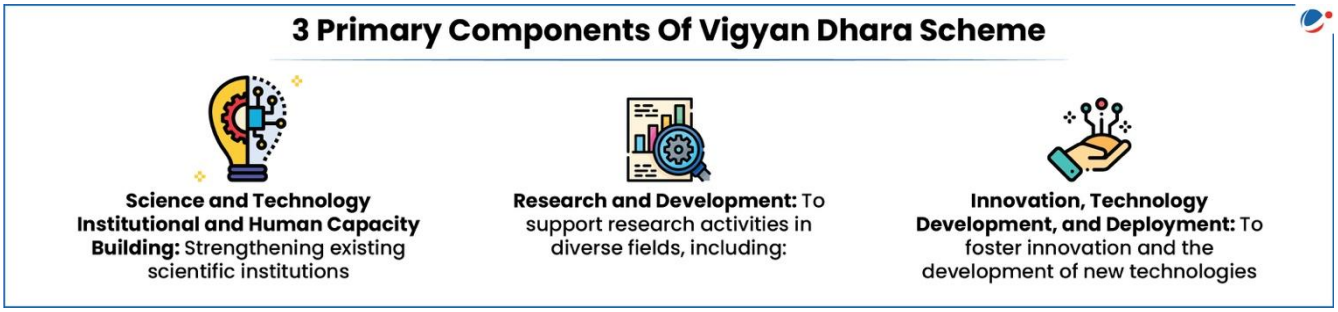
Why in the news?

Union Cabinet has approved continuation of three umbrella schemes, into a unified scheme **'Vigyan Dhara'** to enhance India's R&D ecosystem.

About Vigyan Dhara Scheme

- **Nodal Ministry:** Ministry of Science and Technology
- **Key objective:** To promote **S&T capacity building** as well as **research, innovation and technology development** towards strengthening the Science, Technology and Innovation ecosystem in the country.
- **Type:** Central Sector Scheme
- **Tenure:** From 2021-22 to 2025-26 (15th finance Commission period)
- **Potential benefits**:
  - **Building critical human resource pool** to strengthen the science and technology landscape

- Expand the **R&D base of the country** towards improving the Full-Time Equivalent (FTE) researcher count.
- Focused **interventions** to **enhance the participation of women** in the field of Science and Technology (S&T) for bringing **gender parity.**



Conclusion

The Vigyan Dhara Scheme represents a strategic step toward strengthening India's scientific and technological capabilities. Its focus on gender parity, international partnerships, and indigenous innovation further reinforces India's vision of becoming a global leader in science and technology.

5.12. KEY WORDS

Keywords				
Tokamak Reactors	Nuclear Fusion	Hyperloop Technology	Desalination Technologies	Deep Ocean Mission
Sodium-Ion Batteries	Battery Energy Storage Systems (BESS)	Computational protein design (CPD)	Hyperloop technology	Light Supersolid

5.13. PRACTISE QUESTION

Answer Canvas

Nuclear fusion is considered a clean energy alternative. Briefly discuss key initiatives, major challenges, and suggest measures for its development.

Introduction	Body Part: 1	Body part: 2	Conclusion
Define Nuclear Fusion.	Write national and international initiatives.	Challenges associated with nuclear fusion.	Suggestive way forward like international collaboration and Conclusion.

6. PREVIOUS YEAR QUESTIONS 2013-2024 (SYLLABUS-WISE)

GS-III: Technology

Developments and their applications and effects in everyday life

- What is the technology being employed for electronic toll collection on highways? What are its advantages and limitations? What are the proposed changes that will make this process seamless? Would this transition carry any potential hazards? **(2024 10 marks)**
- The world is facing an acute shortage of clean and safe freshwater. What are the alternative technologies which can solve this crisis? Briefly discuss any three such technologies citing their key merits and demerits. **(2024 15 marks)**
- How does e-Technology help farmers in production and marketing of agricultural produce? Explain it. (**2023 10 Marks)**
- Discuss several ways in which microorganisms can help in meeting the current fuel shortage. **(2023, 10 Marks)**
- What is the basic principle behind vaccine development? How do vaccines work? What approaches were adopted by the Indian vaccine manufacturers to produce COVID-19 vaccines? (**2022, 15 Marks**)
- Elucidate the relationship between globalization and new technology in a world of scarce resources, with special reference to India. (**2022, 15 Marks**)
- What is cryptocurrency? How does it affect global society? Has it been affecting Indian Society also? (**2021, 15 Marks**)
- How is science interwoven deeply with our lives? What are the striking changes in agriculture triggered off by the science-based technologies? **(2020, 10 Marks)**
- COVID-19 pandemic has caused unprecedented devastation worldwide. However, technological advancements are being availed readily to win over the crisis. Give an account of how technology was sought to aid management to the pandemic. **(2020, 15 Marks)**
- Describe the benefits of deriving electric energy from sunlight in contrast to the conventional energy generation? What are the initiatives offered by our government for this purpose? **(2020, 15 Marks)**
- What are the areas of prohibitive labour (whereby law prohibited ex manual scavenging) that can be sustainably managed by robots? Discuss the initiatives that can propel research in premier research institutes forsubstantive and gainful innovation. **(2015 15 Marks)**
- Can overuse and the availability of antibiotics without doctor's prescription, the contributors to the emergence of drug-resistant diseases in India? What are the available mechanisms for monitoring and control? Critically discuss the various issues involved. **(2014 12.5 Marks)**
- What do you understand by Fixed Dose Drug Combinations (FDCs)? Discuss their merits and demerits. **(2013 10 Marks)**
- What do you understand by Umpire decision review in cricket? Discuss its various components. Explain how silicon tape on the edge of a bat may fool the system? **(2013 10 Marks)**

Achievements of Indians in science & technology

- Discuss the work of 'Bose-Einstein Statistics' done by Prof. Satyendra Nath Bose and show how it revolutionized the field of Physics. **(2018, 10 Marks)**
- Discuss India's achievements in the field of Space Science and Technology. How the application of this technology has helped India in its socio-economic development? **(2016 12.5 Marks)**

Indigenization of technology and developing new technology

- What is the main task of India's third moon mission which could not be achieved in its earlier mission? List the countries that have achieved this task. Introduce the subsystems in the spacecraft launched and explain

the role of the Virtual Launch Control Centre' at the Vikram Sarabhai Space Centre which contributed to the successful launch from Sriharikota. **(2023, 15 marks)**

- How is S-400 air defence system technically superior to any other system presently available in the world? (**2021 10 Marks**)
- How have digital initiatives in India contributed to functioning of education system in country? Elaborate your answer **(2020 15 Marks)**
- What is India's plan to have its own space station and how will it benefit our space programme? **(2019 10 Marks)**
- With growing energy needs should India keep on expanding its nuclear energy programme? Discuss the facts and fears associated with nuclear energy. **(2018, 15 Marks)**
- Why is IRNSS needed? How does it help in navigation? **(2018, 15 Marks)**
- India has achieved remarkable successes in unmanned space missions including the Chandrayaan and Mars Orbiter Mission, but has not ventured into manned space mission, both in terms of technology and logistics? Explain critically. **(2017, 10 Marks)**
- Give an account of the growth and development of nuclear science and technology in India. What is the advantage of fast breeder reactor programme in India? **(2017 15 Marks)**
- What do you understand by 'Standard Positioning Systems' and 'Protection Positioning Systems' in the GPS era? Discuss the advantages India perceives from its ambitious IRNSS programme employing just seven satellites. **(2015 12.5 Marks)**

Awareness in the fields of IT, Space, Computers, robotics, nanotechnology, bio-technology

- What are asteroids? How real is the threat of them causing extinction of life? What strategies have been developed to prevent such a catastrophe? **(2024 15 Marks).**
- Describe the context and salient features of the Digital Personal Data Protection Act,2023 **(2024 10 Marks)**
- Introduce the concept of Artificial Intelligence (AI). How does AI help clinical diagnosis? Do you perceive any threat to privacy of the individual in the use of AI in healthcare? **(2023, 10 Marks)**
- Launched on 25th December 2021, James Webb Space Telescope has been much in the news since then. What are its unique features which make it superior to its predecessor Space Telescopes? What are the key goals of this mission? What potential benefits does it hold for the human race? **(2022 15 Marks)**
- What are the research and development achievements in applied biotechnology? How will these achievements help to uplift poorer section of the society? **(2021 15 Marks)**
- The Nobel Prize in Physics of 2014 was jointly awarded to Akasaki, Amano and Nakamura for the invention of Blue LEDs in 1990s. How has this invention impacted the everyday life of human beings? **(2021 15 Marks)**
- What do you understand by nanotechnology and how is it helping in health sector? **(2020, 10 Marks)**
- How can biotechnology help to improve the living standards of farmers? **(2019, 15 Marks)**
- Why is there so much activity in the field of biotechnology in our country? How has this activity benefitted the field of biopharma? **(2018 15 Marks)**
- Stem cell therapy is gaining popularity in India to treat a wide variety of medical conditions including Leukaemia, Thalassemia, damaged cornea and several burns. Describe briefly what stem cell therapy is and what advantages it has over other treatments? **(2017 10 Marks)**
- How does the JUNO mission of NASA help to understand the origin and evolution of earth? **(2017 10 Marks)**
- Why is nanotechnology one of the key technologies of the 21st century? Describe the salient features of Indian Government's Mission on Nanoscience and Technology and the scope of its application in the development process of the country. **(2016 12.5 Marks)**
- Scientific research in Indian universities is declining, because a career in science is not as attractive as our business operations, engineering or administration, and the universities are becoming consumer oriented. Critically comment. **(2014 12.5 Marks)**
- How does the 3D printing technology work? List out the advantages and disadvantages of the technology. **(2013 5 Marks)**
- What is an FRP (fiber reinforced plastic) composite material? How are they manufactured? Discuss their applications in aviation and automobile industries. **(2013 5 marks)**

Issues relating to intellectual property rights

- How is the Government of India protecting traditional knowledge of medicine from patenting by pharmaceutical companies? **(2019, 15 Marks)**
- India's Traditional Knowledge Digital Library (TKDL), which has a database containing formatted information on more than 2 million medicinal formulations is proving a powerful weapon in country's fight against erroneous patents. Discuss the pros and cons of making this database publicly available under open-source licensing. **(2015 12.5 Marks)**
- In a globalized world, Intellectual Property Rights assume significance and are a source of litigation. Broadly distinguish between the terms—Copyrights, Patents and Trade Secrets. **(2014 12.5 Marks)**
- Bringing out the circumstances in 2005 which forced amendment to the section 3(d) in Indian Patent Law, 1970, discuss how it has been utilized by the Supreme Court in its judgement in rejecting Novratis' patent application for 'Glivec'. Discuss briefly the pros and cons of the decision. **(2013 10 Marks)**

7. APPENDIX

Appendix: Indian Scientist and their Contribution

Scientist	Contribution/Key Work
Satyendra Nath Bose 	⇒ **He was an Indian physicist one** of the fathers of **quantum mechanics.** ⇒ **He developed** theory **of Bose–Einstein Statistics** and the concept of the **Bose–Einstein Condensate.**
Prafulla Chandra Ray 	⇒ **Established** first Indian research school in chemistry. ⇒ **He is known** as **Father of Indian Chemistry.** ⇒ **Important Research:** Platinum, Iridium and Sulphides of organic substances.
Srinivasa Ramanujan 	⇒ **He was an exceptional Indian mathematician** renowned for his substantial contributions to various branches of mathematics. **These are:** ⇒ **Mathematical concepts:** Complex analysis, number theory, infinite series, continued fractions, game theory, etc. ⇒ **Ramanujan sum:** Sum of all natural numbers till infinity is -1/12. ⇒ **Ramanujan number:** 1729 (It is the smallest number that could be expressed as sum of two cubes in two different ways, i.e., 10^3+9^3 and 1^3+12^3.)
C. V. Raman 	⇒ He was **Indian Physicist** known for discovery of the **'Raman Effect'** in 1928. • **Raman Effect** is a phenomenon when a stream of light passes through a liquid, a fraction of light scattered **by liquid is of a different colour.** ⇒ **He Won Nobel Prize** in Physics in **1930 (for Raman Effect).**
Homi Jehangir Bhabha 	⇒ First chairman of the **Atomic Energy Commission of India** (Known as **Father of Indian Nuclear Power)** ⇒ Founded and directed **Tata Institute of Fundamental Research (TIFR)** and **Atomic Energy Establishment,** Trombay, later renamed the **Bhabha Atomic Research Centre (BARC).** ⇒ **Pioneered** the use of thorium to extract uranium from it rather than relying on the meagre reserves of uranium in India.
Meghnad Saha 	⇒ He was Indian astrophysicist noted for his development in 1920 for **thermal ionization equation.** ⇒ He established the **National Academy of Sciences** in 1930.

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Scientist	Contribution/Key Work
Vikram Sarabhai 	⊕ He was regarded as the **father of the Indian space programme.** ⊕ Founded the **Physical Research Laboratory (PRL) in Ahmedabad in 1947.** ⊕ Played key role in setting up **Thumba Equatorial Rocket Launching Station** in Thiruvananthapuram. ⊕ Worked on India's first satellite **'Aryabhata'.** ⊕ He received the **Shanti Swarup Bhatnagar Medal in 1962.**
A.P.J. Abdul Kalam 	⊕ Project director of India's **first Satellite Launch Vehicle (SLV-III)** which successfully deployed the **Rohini satellite.** ⊕ Worked on **Integrated Guided Missile Development Programme (IGMDP) .** ⊕ He led to the **weaponisation of strategic missile** systems and the **Pokhran-II nuclear tests** in collaboration with Department of Atomic Energy.
Subrahmanyan Chandrasekhar 	⊕ **Played an important role** in notable contribution of **'Chandrasekhar Limit' (1.4 of solar masses).** ⊕ **Chandrasekhar limit** determines if a star dies as a white dwarf, or has the mass to exceed this, launching a supernova to create a black hole or neutron star. ⊕ **He was awarded the Nobel Prize in Physics in 1983** for his work on the physical processes involved in the structure and evolution of stars.
Prasanta Chandra Mahalanobis 	⊕ Founded the **Indian Statistical Institute.** Established the **National Sample Survey** (1950) and set up **Central** ⊕ **Statistical Organisation** to coordinate statistical activities. ⊕ **Shaped India's second Five-year Plan (1956-61),** also called the **Mahalanobis Plan.**
C.N.R. Rao 	⊕ Main research interests are in **solid state and materials chemistry.** ⊕ Also, worked on **metal oxides, carbon nanotubes, and other materials and two-dimensional systems,** including graphene, boron-nitrogen-carbon hybrid materials etc.
Gagandeep Kang 	⊕ **Known for her inter-disciplinary research** studying the transmission, development and prevention of enteric infections and their sequelae in children in India. ⊕ **She has worked on the development and use of vaccines** for rotaviruses, cholera and typhoid, conducting large studies to define burden, test vaccines.

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