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66 I was a part of with Mains Test Series interview guidance at GS Score and Sir helped me in enhancing both my answer writing skills in GS and Essay. I am truely grateful to sir for the personal guidance and mentorship he offered me. 99

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66 GS SCORE has been really helpful in my preparation. I had used the Mains Test Series and the Feedback and guidance was really awesome. GS SCORE was the only mock which I gave and the feedback motivated and helped me alot. 99

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 66 Answer Writing is always considered as a vital part for success in UPSC. GS SCORE helped me in building a strong and solid foundation for development of Answer Writing skills. Thank you!

and many more...

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66 GS SCORE helped me during the preparation I practised lot of mock test on the GS Score platform to understand the structure of answer writing. I am gratefull to this platform for providing such guidance to me and many more aspirants. **99**

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66 Mains Tests at GS SCORE in the simulated environment helped me thoroughly complete my preparation with discipline. I would like to thank GSSCORE. 99

SWATI SHARMA AIR-15 (CSE-2022)

66 UPSC Style mock papers coupled with evaluation by faculty members of GS SCORE themselves enhanced my confidence to write answers as per the demand. I am thankful. 99





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SPACE

1. PRATUSH - LUNAR OBSERVATION CAPABILITIES AND SPACE EXPLORATION

CONTEXT: India announced the launch of PRATUSH, its first moon-based telescope. The telescope, named PRATUSH (Pioneering Research and Astronomical Telescope for Unveiling the Secrets of the Heavens), represents a significant milestone in India's space program.

• What is PRATUSH?

- PRATUSH is a sophisticated astronomical telescope installed on the lunar surface, designed to
 observe the universe from the moon. This location provides a unique vantage point, free from Earth's
 atmospheric distortions.
- ► **Capabilities:** The telescope is equipped with advanced optics and sensors to capture high-resolution images of distant celestial objects, study cosmic phenomena, and gather data for astrophysical research.

Lunar Observation:

• PRATUSH's location on the moon allows it to observe space with unprecedented clarity. For instance, it can provide detailed images of exoplanets, star formations, and distant galaxies, contributing valuable data to the global scientific community.

Advancements in Lunar Observation

• Enhanced Clarity: The absence of atmospheric interference on the moon allows PRATUSH to capture clearer and more detailed images than Earth-based telescopes.

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Continuous Observation: Positioned on the moon, PRATUSH can conduct continuous observations without the interruptions caused by Earth's day-night cycle, improving the quality and consistency of the collected data.

Challenges

- ► Scientific and Technical Barriers
 - Harsh Lunar Environment: Operating on the moon presents challenges such as extreme temperatures, dust, and radiation.
 - **Data Transmission:** Transmitting large volumes of data from the moon to Earth requires robust communication infrastructure.
- Resource and Collaboration Issues



- **High Costs:** The development, deployment, and maintenance of a lunar-based telescope involve substantial financial investment.
- **International Collaboration:** Collaborating with international space agencies and research institutions can enhance the project's capabilities and share the financial burden.

PRACTICE QUESTION

Q. How does PRATUSH leverage its lunar location to study the Cosmic Dawn of the Universe?

2. SOFT LANDING ON MOON - TECHNOLOGICAL ADVANCEMENTS IN LUNAR MISSIONS

CONTEXT: In 2023-24, significant progress has been made in soft landing technologies for lunar missions. Several countries, including the United States, China, and India, have successfully executed soft landings on the moon, advancing our capabilities in space exploration.

• What is a Soft Landing?

- A soft landing refers to a spacecraft landing on the moon's surface without sustaining damage, enabling the delivery of scientific instruments, rovers, or human crews safely
- Mechanism: Achieving a soft landing involves precise navigation, controlled descent, and the use of thrusters and landing gear to minimize impact forces.

Advancements in Lunar Missions

Chandrayaan-3

India's Chandrayaan-3 mission, launched in 2023, successfully achieved a soft landing near the moon's south pole. The mission's lander and rover deployed scientific instruments to study the lunar surface and search for water ice, a critical resource for future missions.

Precision Navigation: Advances in autonomous navigation and guidance systems have enhanced the
accuracy of lunar landings. These technologies enable spacecraft to avoid hazards and select optimal
landing sites.



 Descent Control: Improved descent engines and thrusters allow for controlled and stable descents, reducing the risk of crash landings. Technologies like variable thrust engines are crucial for adjusting descent speed.

Challenges:

- ► **Surface Hazards**: High-resolution mapping and real-time hazard detection systems are needed to mitigate these risks.
- Communication Delays: The time delay in communication between Earth and the moon complicates real-time control of landing operations.
- ► **High Costs**: Lunar missions are expensive, requiring substantial investment in technology, infrastructure, and human resources.
- International Collaboration: Collaboration between space agencies can enhance mission success by sharing expertise and resources.

PREVIOUS YEAR QUESTION

Q. India has achieved remarkable successes in unmanned space missions including the Chandrayaan and Mars Orbiter Mission, but has not ventured into manned space missions. What are the main obstacles to launching a manned space mission, both in terms of technology and logistics? Examine critically. (2017)

PRACTICE QUESTION

Q. How can advancements in autonomous navigation and descent control technologies improve the success rates of lunar soft landing missions?

3. INDIA'S FIRST INDIGENOUS SPACE MISSION

CONTEXT: India marked a significant milestone with the successful launch of its first fully indigenous space mission, showcasing its growing capabilities in space technology and satellite deployment.

• What is India's First Indigenous Space Mission?

- India's first indigenous space mission refers to a satellite launch entirely designed, developed, and manufactured within the country. This includes the satellite, launch vehicle, and associated technologies.
- Significance: This mission demonstrates India's self-reliance in space technology and its capability to independently conduct complex space operations, paving the way for future advancements and international collaborations.

Gaganyaan Mission

A notable example is the Gaganyaan mission, aimed at sending Indian astronauts into space using indigenous technology. Although still under development, the mission represents a major leap in India's space exploration capabilities.

n Issues

- ➤ Satellite Development: ISRO has made significant strides in developing advanced satellites for communication, earth observation, and scientific research. These satellites play a crucial role in enhancing national security, disaster management, and economic development.
- ► Launch Vehicles: The development of launch vehicles like the Polar Satellite Launch Vehicle (PSLV) and the Geosynchronous Satellite Launch Vehicle (GSLV) has enabled India to launch satellites into various orbits efficiently and cost-effectively.
- ► **Technological Complexity**: Developing and integrating advanced technologies for satellites and launch vehicles is highly complex.



- Resource Constraints: Space missions demand substantial financial and human resources. Balancing the costs of development and deployment with the potential benefits poses a significant challenge.
- ► International Collaboration: While India aims for self-reliance, international collaboration remains essential for knowledge exchange and technology transfer.
- Regulatory Environment: Developing a robust regulatory framework to support space activities, including satellite launches and commercial space ventures, is crucial.

PREVIOUS YEAR QUESTION

Q. Private players can bring in the innovation needed for developing space-based applications and services". In the light of this statement, highlight the role of private sector in India's space science and technology. (2022)

PRACTICE QUESTION

Q. How can continued research will enhance India's self-reliance and global leadership in space technology and satellite launches?

4. NISAR MISSION - CLIMATE CHANGE MONITORING AND RADAR IMAGING

CONTEXT: The NASA-ISRO Synthetic Aperture Radar (NISAR) mission aims to provide high-resolution radar imagery for a range of environmental and scientific applications.

• What is the NISAR Mission?

- NISAR is an Earth observation satellite mission that uses advanced radar imaging to study environmental changes and natural hazards. It will be equipped with dual-frequency radar technology (L-band and S-band) to capture detailed images of the Earth's surface.
- Purpose: The mission's primary goal is to monitor and measure changes in Earth's land and ice surfaces, providing critical data for understanding climate ch

Radar Imaging for Climate Monitoring:

 NISAR will track changes in ice sheets, glaciers, and sea ice, offering insights into how climate change is affecting polar regions. For instance, it can measure ice sheet movements and detect shifts in glacier flow, which are indicators of melting and sea-level rise.

critical data for understanding climate change, natural disasters, and ecosystem dynamics.

Issues

- ► **High-Resolution Data**: NISAR's radar technology can penetrate cloud cover and darkness, providing continuous, high-resolution data on Earth's surface.
- Comprehensive Coverage: The mission will cover the entire Earth every 12 days, offering regular and comprehensive observations. This frequency enables the detection of gradual environmental changes and the rapid assessment of natural disasters.
- Data Management: The vast amount of data generated by NISAR presents challenges in storage, processing, and analysis.
- ► Calibration and Validation: Ensuring the accuracy of radar measurements requires rigorous calibration and validation processes.
- ► International Coordination: Effective collaboration between NASA and ISRO, as well as with other international organizations, is crucial for the mission's success.
- Policy Support: Implementing policies that support the use of NISAR data for climate resilience and environmental management is essential.



PREVIOUS YEAR QUESTION

Q. 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)

PRACTICE QUESTION

Q. How can international collaboration and advanced radar imaging technologies enhance climate change monitoring and disaster management?

5. RADIO ASTRONOMY AND COSMIC PHENOMENA RESEARCH

CONTEXT: In 2023, India officially became a part of the Square Kilometre Array (SKA) project, the world's largest radio telescope initiative. This ambitious international collaboration aims to create an array of radio telescopes with a total collecting area of one square kilometer, significantly enhancing our ability to study the universe.

• What is the SKA Project?

- The Square Kilometre Array (SKA) is an international effort to build the largest and most sensitive radio telescope in the world. It will be constructed in two phases, with sites in South Africa and Australia, and contributions from over a dozen countries.
 - **Purpose**: The SKA aims to address fundamental questions about the universe, including the formation of galaxies, the nature of dark matter and dark energy, and the origins of life.

Advancements in Radio Astronomy

- Enhanced Sensitivity: The SKA's immense collecting area will enable it to detect faint radio signals from the farthest reaches of the universe, revealing details previously beyond our reach.
- Wide Field of View: The array's design allows for a wide field of view, making it possible to survey large areas of the sky quickly and efficiently, which is crucial for studying transient cosmic events like supernovae and gamma-ray bursts.

Galactic Research

By observing radio waves from distant galaxies, the SKA will provide detailed maps of their structures and dynamics. This data will help scientists understand the processes driving galaxy formation and evolution.

challenges

- ► **Data Volume**: The SKA will generate enormous amounts of data, requiring advanced data processing and storage solutions. Managing this data efficiently is a significant technical challenge.
- Construction Complexity: Building and coordinating a project of this scale across multiple countries involves complex logistics, engineering, and international collaboration.
- Funding and Investment: Securing sustained funding from participating countries is crucial for the SKA's success.
- Global Collaboration: Ensuring smooth communication, coordination, and mutual benefits requires robust governance structures and shared goals.

PRACTICE QUESTION

Q. What is the significance of India's participation in the Square Kilometre Array (SKA) project?

6. XPOSAT - SATELLITE TECHNOLOGY FOR X-RAY DETECTION

CONTEXT: In 2023-24, India has taken a significant step forward in space technology with the launch of XPoSat (X-ray Polarimeter Satellite), its first dedicated X-ray polarimetry mission. Developed by the Indian Space Research Organisation (ISRO), XPoSat aims to study various cosmic sources of X-rays, providing valuable insights into high-energy astrophysical phenomena.

• What is XPoSat?

- XPoSat is an X-ray polarimeter satellite designed to measure the polarization of X-rays emitted by various cosmic sources. It will help scientists understand the geometry and mechanisms of highenergy celestial sources.
- ► **Purpose**: The mission aims to study the polarization of X-rays from sources such as black holes, neutron stars, pulsars, and supernova remnants. This information is crucial for understanding the physical properties and behavior of these objects.

Advancements in X-ray Detection

- High-Energy Astrophysics: XPoSat's advanced X-ray polarimetry capabilities will open new avenues in highenergy astrophysics, allowing for detailed studies of the mechanisms driving high-energy emissions from celestial sources.
- Enhanced Observations: The satellite's ability to measure X-ray polarization will complement other observational methods, providing a more comprehensive picture of highenergy cosmic phenomena.

challenges

- Precision and Sensitivity: Developing instruments capable of accurately measuring X-ray polarization is highly challenging. Ensuring the precision and sensitivity of these instruments is crucial for the mission's success.
- Data Interpretation: Analyzing and interpreting the polarization data requires sophisticated models and simulations.
- Funding and Infrastructure: Sustaining the mission through its development and operational phases requires significant financial investment and infrastructure. Ensuring consistent funding and support is essential.
- ► International Collaboration: Collaborating with international space agencies and research institutions can enhance the mission's capabilities.

PRACTICE QUESTION

Q. How can advancements in X-ray polarimetry and international collaboration enhance our understanding of high-energy cosmic phenomena through missions like XPoSat?

X-ray Polarimetry:

XPoSat will observe the polarization of X-rays from a black hole binary system. By analyzing the polarization data, scientists can infer the orientation of the accretion disk and the magnetic field structure around the black hole, providing deeper insights into the dynamics of these extreme environments.



7. LUNAR EXPLORATION AND INTERNATIONAL SPACE COLLABORATION

CONTEXT: In 2023, Japan's Space Exploration Agency (JAXA) successfully launched the Smart Lander for Investigating Moon (SLIM) mission. The SLIM lander aims to demonstrate precision landing techniques and contribute to lunar exploration efforts, marking a significant milestone in Japan's space program.

• **Global Impact:** The SLIM mission highlights the importance of international collaboration in space exploration. It aims to enhance our understanding of the moon and pave the way for future missions by various countries.

• What is the SLIM Lander?

- The Smart Lander for Investigating Moon (SLIM) is a lunar lander developed by JAXA. It is designed to perform high-precision landing on the lunar surface, which is crucial for future exploration and potential lunar bases.
- Purpose: SLIM aims to demonstrate advanced landing technologies and conduct scientific experiments on the moon's surface. The mission's success will provide valuable data and experience for future lunar missions.

Precision Landing:

SLIM's precision landing technology allows it to target specific locations on the lunar surface with high accuracy. This capability is essential for missions that require landing near scientifically interesting sites, such as lunar craters or resource-rich areas.

n Issues

- **Technological Innovations**: The SLIM mission incorporates advanced navigation and landing systems, including terrain-relative navigation and autonomous hazard detection.
- Scientific Contributions: By landing on the moon, SLIM will conduct experiments to study the lunar surface, including its composition and geological history.
- Precision Challenges: Achieving high-precision landings on the moon is technically challenging due to the lack of atmosphere, varying terrain, and gravitational differences. SLIM's success depends on the effectiveness of its navigation and landing systems.
- ► **Data Transmission**: Transmitting data from the lunar surface to Earth requires robust communication infrastructure. Ensuring reliable data transmission over long distances is a significant technical challenge.
- ► **Funding and Investment**: Lunar missions require substantial financial investment. Securing consistent funding for the development, launch, and operation of the SLIM mission is essential.

PRACTICE QUESTION

Q. How can advancements in precision landing technologies and international collaboration enhance the success of lunar exploration missions like Japan's SLIM?

8. SOLAR OBSERVATION AND SPACE WEATHER

CONTEXT: The Indian Space Research Organisation (ISRO) launched the Aditya L1 mission in 2023 to study the sun and its impact on space weather. This mission represents India's first dedicated solar observatory and aims to enhance our understanding of solar dynamics and their effects on Earth's climate and space weather.





• What is the Aditya L1 Mission?

- ► The Aditya L1 mission is designed to study the outermost layer of the sun, known as the corona, along with the solar wind and other solar phenomena. It will be placed at the Lagrange Point 1 (L1), about 1.5 million kilometers from Earth, where it can continuously observe the sun without any obstructions.
 - The mission aims to understand the mechanisms behind solar activities such as solar flares and coronal mass ejections (CMEs), which can influence space weather and impact satellite operations, power grids, and communication systems on Earth.

Solar Observation Instruments

Aditya L1 is equipped with multiple instruments, including a Visible Emission Line Coronagraph (VELC) to study the solar corona, a Solar Ultraviolet Imaging Telescope (SUIT) for capturing UV images of the sun, and a Plasma Analyser Package for Aditya (PAPA) to analyze the solar wind.

D Advancements in Solar Observation

- ► Enhanced Understanding of Solar Dynamics: The Aditya L1 mission will provide detailed observations of the solar atmosphere, helping scientists understand the causes of solar variability and its effects on space weather.
- ➤ Improved Space Weather Forecasting: By monitoring solar activities and the solar wind, Aditya L1 will improve space weather prediction models, aiding in the protection of satellite operations and terrestrial technologies.



c Challenges

- ➤ Instrumentation and Data Accuracy: Developing and deploying highly sensitive instruments capable of withstanding the harsh conditions of space is challenging. Ensuring the accuracy and reliability of the data collected is crucial for the mission's success.
- ► Data Analysis and Interpretation: The vast amount of data generated by Aditya L1 requires sophisticated analysis tools and techniques. Interpreting this data to derive meaningful scientific insights is a complex task.
- **Funding and Infrastructure**: Sustaining the mission through its lifecycle requires substantial financial investment and robust infrastructure.
- ► **International Collaboration**: Collaborating with international space agencies and research institutions can enhance the mission's scientific output.



PRACTICE QUESTION

Q. How can advancements in solar observation technologies and international collaboration enhance the effectiveness of missions like Aditya L1 in understanding space weather?

9. NAVIGATION TECHNOLOGY AND GLOBAL POSITIONING SYSTEMS

CONTEXT: NavIC provides accurate position information services to users in India and the surrounding region, up to 1,500 km from its boundary.

• What is NavIC?

- NavIC is an autonomous satellite navigation system developed by the Indian Space Research Organisation (ISRO). It consists of a constellation of seven satellites in geostationary and geosynchronous orbits, providing accurate positional data.
 - The system aims to provide accurate position information services to users in India and the surrounding region. It is designed to offer better accuracy and reliability compared to other global positioning systems in the region.

Maritime Navigation

NavIC is extensively used in maritime navigation, providing accurate position information to ships and fishing vessels. This enhances safety and efficiency in maritime operations, particularly in Indian waters.



Advancements in Navigation Technology

- ► Enhanced Accuracy: NavIC offers high positional accuracy, with a standard positioning service providing accuracy better than 20 meters and a restricted service providing accuracy better than 10 meters.
- Wide Range of Applications: NavIC supports various applications, including disaster management, vehicle tracking, fleet management, geospatial mapping, and terrestrial navigation for hikers and travelers.





Challenges

- ► **Signal Interference**: Maintaining signal integrity in urban environments and areas with high electromagnetic interference is a challenge.
- ► Integration with Global Systems: Ensuring seamless integration and interoperability with other global navigation satellite systems (GNSS), such as GPS, GLONASS, and Galileo, requires technical harmonization and standardization.
- Funding and Maintenance: Sustaining and upgrading the NavIC system requires continuous funding and investment in infrastructure.
- ► **International Collaboration**: Collaborating with international space agencies and technology partners can enhance the system's functionality and global reach.

PREVIOUS YEAR QUESTION

Q. What do you understand by 'Standard Positioning Systems' and 'Precision Positioning Systems' in the GPS era? Discuss the advantages India perceives from its ambitious IRNSS programme employing just seven satellites. (2015)

PRACTICE QUESTION

Q. How satellite navigation systems like NavIC enhance national security, economic development, and technological innovation in India?

10. CHANDRAYAAN-3: MISSION TO MOON

CONTEXT: Launched in 2023, Chandrayaan-3 is India's third lunar exploration mission, following the successes and lessons of Chandrayaan-1 and Chandrayaan-2.

• What is Chandrayaan-3?

- Chandrayaan-3 is a lunar mission comprising a lander and a rover designed to achieve a soft landing on the moon and conduct scientific experiments. Unlike its predecessor Chandrayaan-2, it does not include an orbiter.
 - The mission's primary objectives are to demonstrate landing and roving capabilities on the lunar surface and to conduct in-situ scientific experiments to study the moon's composition and surface processes.

Scientific Instruments:

The rover is equipped with instruments like the Laser-Induced Breakdown Spectroscope (LIBS) and Alpha Particle X-ray Spectrometer (APXS) to analyze the lunar soil and determine its elemental composition. This data helps scientists understand the moon's geology and the presence of resources like water ice.

Advancements in Lunar Exploration

- ► **Technological Innovations**: Chandrayaan-3 incorporates advanced technologies for navigation, propulsion, and landing systems, aiming to improve landing precision and the efficiency of rover operations.
- Scientific Contributions: The mission seeks to provide detailed information on the lunar surface's composition, mineralogy, and possible water ice presence. Such insights are vital for understanding the moon's history and assessing its potential for future human habitation.

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The lander-rover

land close to the

is expected to

lunar South Pole like

will be made to the

the Chandrayaan-2's

lander-rover to crash.

Chandrayaan-2. Changes

sequence of powered descent, during which a

velocity loss had caused

Isro has not yet revealed the details of the lander

₹610cr

₹960cr

INDIA'S THIRD DATE WITH THE MOON

India will launch its third mission, Chandrayaan-3, to the moon in an attempt to land on its surface in 2020-21. The mission will target a soft-landing near the lunar South Pole later this year or early next year

> GSLV Mark-III (left) had to be operationalised for launching Chandrayaan-2 due to its heavy payload. Chandrayaan-3 will be much lighter as no orbiter would be stacked on it. Isro, however, has not specified the rocket type to be used in Chandrayaan-3

Chandrayaan-3's payload will be similar to Chandrayaan-2 (above). It will have a lander, rover, like its previous iteration. Since it will not carry and orbiter, a propulsion module will be added to the lander. Isro already has a set of backup lander-rover unit that may be used after some modifications

The orbiter from Chandrayaan-2 that's already in place will be used by the lander-rover to communicate with Earth. The orbiter, which orginally had a mission life of one year, has been given an extension in mission life — it will be operational for 7 years

₹250C

Lander-rover

Chandrayaan-2

Chandrayaan-3

Challenges

► Landing Precision: One of the primary challenges is achieving a precise and safe landing on the moon's surface, considering its uneven terrain and lack of atmosphere. Chandrayaan-3 aims to address the issues faced by the Chandrayaan-2's Vikram lander.

₹360CI

Launch rocket

- Rover Mobility: Ensuring the rover's mobility and functionality in the harsh lunar environment is critical. The rover must navigate rugged terrain and extreme temperatures while conducting scientific experiments.
- **Funding and Infrastructure**: Sustaining the mission through its development, launch, and operation phases requires substantial financial investment and infrastructure.
- International Collaboration: Collaborating with international space agencies and research institutions can enhance the mission's capabilities. Technological Development: Continued investment in advanced technologies for lunar exploration, including improved landing systems and scientific instruments, is essential.
- ► **Collaborative Research**: Promoting international collaboration and joint research initiatives can leverage the expertise and resources of global partners.

PREVIOUS YEAR QUESTION

Q. 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)

PRACTICE QUESTION

Q. What are the advancements in lunar exploration technologies which enhanced the success of missions like Chandrayaan-3?





11. PEACE & SECURITY IN OUTER SPACE

CONTEXT: The United Nations and other international bodies have emphasized the need for cooperative efforts to maintain peace and security in outer space.

• What is Peace and Security in Outer Space?

- Peace and security in outer space refer to the prevention of an arms race, avoiding conflicts, and ensuring the peaceful use of outer space for the benefit of all humanity.
- ➤ Significance: As space becomes increasingly crowded with satellites and space debris, and as more countries and private entities engage in space activities, maintaining peace and security is essential to prevent conflicts and ensure the safe and sustainable use of space.

International Treaties

The Outer Space Treaty of 1967, ratified by over 100 countries, is a key international agreement that forms the basis of international space law. It prohibits the placement of nuclear weapons in space and promotes the peaceful use of space.

Advancements

- **Technological Advancements**: The rapid advancement in space technology, including anti-satellite (ASAT) weapons, has raised concerns about the militarization of space.
- ► **Space Debris**: The increasing amount of space debris from defunct satellites and space missions poses a threat to active satellites and space stations.

challenges

- Verification and Enforcement: Monitoring compliance with international agreements and verifying the peaceful use of space is challenging.
- Space Traffic Management: The lack of a comprehensive space traffic management system increases the risk of collisions and conflicts in space.
- International Collaboration: Ensuring effective international collaboration is essential for addressing space security issues.
- ► **Funding and Infrastructure**: Developing and maintaining the infrastructure for space security, including tracking and monitoring systems, requires significant investment.

PRACTICE QUESTION

Q. Why there is a need of international cooperation to enhance peace and security in outer space and ensuring the sustainable use of space resources?

12. INDIAN SPACE POLICY – 2023

CONTEXT: In 2023, the Government of India unveiled a comprehensive space policy aimed at enhancing the nation's space capabilities, fostering innovation, and promoting private sector participation.

• What is the Indian Space Policy – 2023?

- The Indian Space Policy 2023 outlines the strategic vision, goals, and regulatory framework for India's space activities. It aims to streamline space operations, promote research and development, and enhance the commercial utilization of space.
 - The policy seeks to foster a robust space ecosystem by encouraging private sector involvement, strengthening international collaborations, and ensuring the peaceful use of space for national and global benefit.

GSSCORE

Advancements and Objectives

- ➤ Technological Innovation: The policy emphasizes the development of cutting-edge technologies in satellite communication, remote sensing, and space exploration.
- ➤ International Collaboration: The policy encourages collaboration with international space agencies and organizations to share knowledge, resources, and technology.

Private Sector Participation

The policy facilitates private sector entry into satellite launch services, space exploration, and satellite communication. For instance, Indian startups are now developing small satellite launch vehicles and innovative space applications, contributing to the nation's space capabilities.

c Challenges

- **Regulatory Framework**: Establishing a comprehensive regulatory framework that balances national security, commercial interests, and international obligations is complex.
- ► **Technological Gaps**: Bridging the technological gaps in areas such as reusable launch vehicles, advanced propulsion systems, and deep-space exploration requires significant investment and innovation.
- **Funding and Investment**: Sustaining the ambitious goals outlined in the policy requires substantial financial resources.
- ► **Coordination**: Effective coordination between ISRO, private companies, academic institutions, and international partners is necessary to achieve the policy's objectives.

PREVIOUS YEAR QUESTION

Q. Discuss the significance of space technology in promoting sustainable development in India. (2020)

Q. What is India's plan to have its own space station and how will it benefit our space programme? (2019)

PRACTICE QUESTION

Q. How can the Indian Space Policy – 2023 foster innovation, international collaboration, and sustainable development in the national space sector?

13. EARTH OBSERVATION AND SATELLITE CAPABILITIES

CONTEXT: The EOS-06 satellite is a significant advancement in Earth observation capabilities launched by ISRO. It is part of the Earth Observation Satellite series, designed to provide high-resolution imagery and data for various applications, including agriculture, forestry, and disaster management.

• Global Impact:

 The deployment of EOS-06 enhances India's position in global Earth observation, contributing valuable data for environmental monitoring, climate studies, and resource management.

• What is the EOS-06 Satellite?

- EOS-06 is an advanced Earth observation satellite equipped with state-of-the-art imaging technologies. It is designed to capture high-resolution images of the Earth's surface across various spectral bands.
 - The primary goal of EOS-06 is to support applications in agriculture, forestry, water resources, urban planning, and disaster management by providing accurate and timely data.



GSSCORE

Advancements in Earth Observation

- ➤ High-Resolution Imaging: EOS-06 is equipped with advanced sensors that capture images in multiple spectral bands, including visible, near-infrared, and thermal. This capability allows for detailed analysis of the Earth's surface features.
- ➤ Real-Time Data: The satellite provides real-time data, enabling timely responses to natural disasters such as floods, earthquakes, and forest fires. Early detection and monitoring can mitigate the impact of such events.

Application:

Agricultural Monitoring: EOS-06's high-resolution images can monitor crop health, estimate yields, and detect pest infestations. This information helps farmers and policymakers make informed decisions to improve agricultural productivity and food security.

c Challenges

- ► Data Processing: The vast amount of data generated by EOS-06 requires advanced processing capabilities.
- **Technological Integration**: Integrating the data from EOS-06 with other Earth observation systems and technologies presents challenges.
- ► **Funding and Maintenance**: Sustaining the satellite's operations, including data processing and distribution, requires ongoing financial investment.
- ► International Collaboration: Collaborating with international space agencies and organizations can enhance the satellite's capabilities.

PRACTICE QUESTION

Q. What is the role of Earth observation satellites like EOS-06 in enhancing agricultural productivity, disaster management, and environmental monitoring?

14. LAUNCH VEHICLE TECHNOLOGY AND SPACE MISSION EFFICIENCY

CONTEXT: The Indian Space Research Organisation (ISRO) successfully launched its new Small Satellite Launch Vehicle (SSLV-D2) in 2024.

• What is SSLV-D2?

- The Small Satellite Launch Vehicle (SSLV) is a compact, modular, and cost-effective launch vehicle designed by ISRO to cater to the burgeoning market of small satellite launches. SSLV-D2 is the second developmental flight following the initial launch of SSLV-D1.
- The primary objective of SSLV-D2 is to provide a quick turnaround launch capability for small satellites, catering to both commercial and scientific needs. It aims to offer on-demand launch services with minimal launch preparation time.

Efficient Launch Capability:

SSLV-D2 successfully placed multiple small satellites into low Earth orbit (LEO) in its maiden flight, demonstrating its ability to deliver payloads with precision and efficiency. This capability is particularly beneficial for missions requiring rapid deployment and flexible launch schedules.

D Advancements in Launch Vehicle Technology

 Modular Design: The SSLV features a modular design that allows for easy assembly and integration. This design flexibility reduces production costs and time, making it an attractive option for frequent and varied launch requirements.



► **Cost-Effectiveness**: By minimizing launch preparation time and utilizing a streamlined production process, SSLV-D2 significantly lowers the cost per launch.

Challenges

- Payload Capacity: While SSLV-D2 is optimized for small satellite payloads, its limited capacity compared to larger launch vehicles like the PSLV and GSLV means it cannot cater to heavy or complex missions. Balancing payload capacity with cost and efficiency is an ongoing challenge.
- ➤ Reliability and Testing: Ensuring the reliability of new launch vehicles through extensive testing is crucial. SSLV-D2 must undergo rigorous validation to establish its dependability for a wide range of missions.
- ► Resource and Collaboration Issues
- ► Funding and Investment: Sustaining the development and operational phases of SSLV-D2 requires significant financial investment.
- ➤ International Collaboration: Collaborating with international space agencies and commercial entities can enhance the capabilities and reach of SSLV-D2.



PRACTICE QUESTION

Q. Analyze the significance of SSLV-D2 in enhancing the efficiency and cost-effectiveness of space missions?

15. LUNAR EXPLORATION PROGRAM AND HUMAN SPACEFLIGHT

CONTEXT: NASA's Artemis mission, which aims to return humans to the Moon and establish a sustainable presence, has made significant strides in 2023-24. The mission's ultimate goal is to pave the way for future exploration of Mars.

• What is the Artemis Mission?

- ➤ The Artemis mission is NASA's ambitious lunar exploration program designed to return humans to the Moon by 2024 and establish a sustainable presence by the end of the decade. It consists of several phases, including uncrewed and crewed missions.
- ➤ The mission aims to explore more of the lunar surface than ever before, establish a long-term human presence, and demonstrate new technologies and capabilities for future deep space missions, particularly to Mars.
- Artemis I: An uncrewed mission, Artemis I tested the Space Launch System (SLS) rocket and the Orion spacecraft's ability to orbit the Moon and return safely to Earth. This mission set the stage for subsequent crewed missions.
- Artemis II: Scheduled for 2024, Artemis II will be the first crewed mission to orbit the Moon in over 50 years, testing life support systems and mission operations.

GSSCORE



Advancements in Lunar Exploration

- Technological Innovations: The Artemis mission leverages advanced technologies such as the SLS rocket, the Orion spacecraft, and the Lunar Gateway, a space station that will orbit the Moon and serve as a staging point for lunar missions.
- Scientific Contributions: Artemis aims to conduct extensive scientific research, including studying the lunar surface, searching for resources like water ice, and understanding the effects of long-duration space travel on the human body.

Challenges:

- **Mission Complexity**: The complexity of the Artemis missions, which involve multiple launches, intricate lunar landings, and long-duration spaceflights, poses significant technical challenges.
- Sustainability: Establishing a sustainable human presence on the Moon requires developing habitats, life support systems, and resource utilization techniques.
- ► **Funding and Investment**: Sustaining the Artemis program through its various phases requires substantial financial investment.
- ► International Collaboration: Collaboration with international partners, including space agencies from Europe, Canada, and Japan, is essential for the success of Artemis.

PRACTICE QUESTION

Q. Analyze the significance of Artemis mission to enhance future human exploration of Mars and deep space?

16. THE SEARCH FOR DARK MATTER- LUX-ZEPLIN (LZ)

CONTEXT: The LUX-ZEPLIN (LZ) experiment, a state-of-the-art dark matter detector located in the Sanford Underground Research Facility in South Dakota, has made significant progress in 2024. The experiment aims to detect weakly interacting massive particles (WIMPs), which are a leading candidate for dark matter.



• What is the LUX-ZEPLIN (LZ) Experiment?

- The LUX-ZEPLIN experiment is a next-generation dark matter detection project using a liquid xenon timeprojection chamber (TPC) to search for direct interactions between dark matter particles and xenon nuclei.
- ► The primary goal is to identify WIMPs by detecting the faint signals they might produce when colliding with xenon atoms. This could provide direct evidence of dark matter.

n Advancements in Dark Matter Research

Detection Method:

LZ uses a two-phase xenon detector where a particle interaction in the liquid xenon produces scintillation light and ionizes the xenon atoms. The ionized electrons are then drifted to a gaseous phase, where they produce additional scintillation, providing a clear signal of the interaction.

- High Sensitivity: LZ is designed to be the most sensitive dark matter detector in the world, with a sensitivity over ten times greater than its predecessor, LUX. This allows it to detect extremely rare interactions between WIMPs and xenon nuclei.
- Technological Innovations: The experiment employs cutting-edge technologies, including ultra-pure xenon and advanced shielding techniques, to minimize background noise and enhance detection capabilities.

n Challenges

- **Background Noise**: One of the main challenges is distinguishing potential dark matter signals from background radiation. LZ uses extensive shielding and purification processes to reduce noise.
- ► False Positives: Ensuring that detected signals are genuinely from dark matter interactions and not other sources requires meticulous calibration and validation.
- **Funding and Investment**: The high cost of building and maintaining such a sophisticated detector necessitates significant funding.
- ► **International Collaboration**: The success of the LZ experiment depends on collaboration between multiple international institutions, sharing expertise, and data to achieve common goals.

PRACTICE QUESTION

Q. How can advancements in dark matter detection technologies will enhance our understanding of the universe's fundamental components?

17. INTERNATIONAL LIQUID-MIRROR TELESCOPE (ILMT)

CONTEXT: The International Liquid-Mirror Telescope (ILMT), located at the Devasthal Observatory in India, has become fully operational. This innovative telescope is a collaborative effort involving institutions from Canada, Belgium, and India. It represents a significant advancement in optical astronomy, utilizing a unique liquid-mirror technology to observe the night sky.

• What is the ILMT?

- ➤ The ILMT is a type of telescope that uses a liquid mirror made of a reflective liquid, typically mercury, which rotates to form a parabolic shape. This configuration allows the telescope to observe a strip of the sky as Earth rotates.
- ➤ The primary goal of ILMT is to conduct a time-domain survey, capturing transient events and monitoring changes in the night sky. Its design offers a cost-effective alternative to traditional solid-mirror telescopes.

Time-Domain Astronomy:

ILMT's ability to scan the same strip of the sky repeatedly makes it ideal for detecting transient astronomical events. For instance, it can monitor supernova explosions, providing insights into the life cycles of stars and the expansion of the universe.





Advancements in Optical Astronomy

- Innovative Design: ILMT's liquid-mirror technology is a novel approach in optical astronomy. The
 rotating liquid forms a perfect parabolic mirror, which is essential for capturing sharp images of
 celestial objects.
- **Cost Efficiency**: Liquid mirrors are significantly cheaper to produce than traditional glass mirrors, making large-scale telescopes more accessible and affordable for astronomical research.

challenges:

- Limited Field of View: One major limitation of liquid-mirror telescopes is their fixed field of view. ILMT can only observe a narrow strip of the sky directly overhead, limiting its observational scope.
- Maintenance of Liquid Mirror: The liquid mirror requires meticulous maintenance to ensure its reflective surface remains free of contaminants and imperfections.
- ► Funding and Investment: Sustaining the ILMT project requires ongoing financial support from the participating countries.
- ► International Collaboration: Effective collaboration among the international partners is crucial for the success of ILMT.

PRACTICE QUESTION

Q. What are the key highlights and significance of the International Liquid-Mirror Telescope (ILMT) in optical astronomy?

18. POEM-3 MISSION AND SPACE DEBRIS

CONTEXT: The POEM-3 (Photon Orbital Environmental Mitigation) mission has gained significant attention for its innovative approach to tackling the growing issue of space debris.



• What is the POEM-3 Mission?

- POEM-3 is an international collaborative mission focused on demonstrating and testing new technologies for the active removal and mitigation of space debris. The mission includes a suite of tools and techniques designed to capture, deorbit, or neutralize debris.
- ➤ The primary goal of POEM-3 is to enhance space sustainability by reducing the risk posed by orbital debris. This involves developing systems capable of tracking, capturing, and safely disposing of debris from orbit.

Debris Capture Technologies:

POEM-3 employs advanced technologies such as robotic arms, nets, harpoons, and electrodynamic tethers to capture and remove debris. These methods are tested in space to evaluate their effectiveness and feasibility for largescale deployment.

• Advancements in Orbital Debris Mitigation

- ► **Technological Innovation:** The mission tests robotic arms equipped with sensors and cameras to capture and deorbit defunct satellites and large debris fragments.
- ► **Real-Time Tracking**: The mission also focuses on enhancing real-time tracking and monitoring systems for space debris.

Challenges

- Complexity of Capture: Capturing and removing space debris is technically challenging due to the high velocities and varied sizes of debris. Ensuring the reliability and precision of capture mechanisms is crucial.
- ➤ Cost and Resources: Developing and deploying debris mitigation technologies require substantial financial and material resources. Balancing the costs with the benefits of debris removal is a key challenge.
- ► **Funding and Investment**: Sustaining the POEM-3 mission and similar initiatives necessitates continuous funding from government and private sectors.
- ► **International Collaboration**: Effective space debris mitigation requires collaboration among international space agencies and organizations.



PRACTICE QUESTION

Q. Discuss the advancements in debris mitigation technologies to ensure the safety of future space missions?

19. LIGO PROJECT - GRAVITATIONAL WAVE DETECTION AND ASTROPHYSICAL PHENOMENA

CONTEXT:: The Laser Interferometer Gravitational-Wave Observatory (LIGO) project has continued to make groundbreaking discoveries, detecting numerous gravitational wave events and providing new insights into astrophysical phenomena.

• Global Impact:

 LIGO's discoveries have revolutionized our understanding of the universe, confirming key predictions of Einstein's General Theory of Relativity and opening a new window into the cosmos.

• What is the LIGO Project?

LIGO is a large-scale physics experiment and observatory designed to detect cosmic gravitational waves and to develop gravitationalwave observations as an astronomical tool. It consists of two observatories in the United States, one in Washington state and the other in Louisiana.

Gravitational Wave Detection:

In 2015, LIGO made the first direct detection of gravitational waves from a binary black hole merger. This historic event confirmed a major prediction of Einstein's theory and earned the 2017 Nobel Prize in Physics. Since then, LIGO has detected numerous other gravitational wave events, furthering our understanding of the universe.

► The primary goal of LIGO is to detect and analyze gravitational waves, which are ripples in spacetime caused by violent and energetic processes in the universe, such as merging black holes and neutron stars.

Advancements in Gravitational Wave Detection

- ► Enhanced Sensitivity: Recent upgrades to LIGO, including Advanced LIGO (aLIGO), have significantly increased its sensitivity. This allows the observatory to detect weaker and more distant gravitational wave signals.
- ► Multi-Messenger Astronomy: LIGO's ability to detect gravitational waves has led to the emergence of multi-messenger astronomy, where gravitational wave data is combined with electromagnetic observations, providing a more comprehensive understanding of cosmic events.

challenges:

- ➤ Noise Reduction: One of the main challenges in gravitational wave detection is reducing noise from seismic activity, thermal fluctuations, and other environmental sources. Advanced LIGO employs sophisticated techniques to isolate and minimize these noise sources.
- Data Analysis: Analyzing the vast amount of data generated by LIGO to identify genuine gravitational wave signals amidst the noise requires advanced algorithms and significant computational resources.
- ► **Funding and Investment**: Sustaining and upgrading LIGO requires substantial financial investment. Securing continuous funding from government agencies and international collaborations is crucial.
- ► Global Collaboration: Effective collaboration with international observatories like Virgo (Europe) and KAGRA (Japan) enhances the network of gravitational wave detectors, increasing detection rates and improving localization of sources.



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PREVIOUS YEAR QUESTION

Q. Launched on 25th December 2021, the 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)

PRACTICE QUESTION

Q. How can advancements in gravitational wave detection and international collaboration enhance our understanding of the universe through projects like LIGO?







IT, TELECOM & ELECTRONICS

1. THE DARK WEB - CYBERSECURITY THREATS AND ILLICIT ONLINE ACTIVITIES

- CONTEXT: As cybersecurity threats evolve, the dark web continues to be a hub for illicit activities, including the sale of stolen data, illegal drugs, and weapons. According to recent reports, there has been a 30% increase in dark web activities related to cybersecurity threats in the past year, with over 15 billion stolen credentials available for sale on dark web marketplaces.
- The Dark Web: The dark web operates on encrypted networks, primarily using Tor (The Onion Router), which allows users to maintain anonymity. While it has legitimate uses, such as providing access to information in repressive regimes, it is predominantly known for its illegal activities. For instance, the 2023 Alphabay takedown revealed a marketplace with over 400,000 users engaging in illegal transactions ranging from identity theft to drug trafficking.

Ransomware-as-a-Service:

A notable trend in recent years is Ransomware-as-a-Service (RaaS). Cybercriminals sell or lease ransomware tools on the dark web, enabling even those with limited technical skills to launch sophisticated attacks. In 2023, the **RaaS model contributed to 75% of ransomware attacks**, affecting industries worldwide, including healthcare, finance, and education.

Issues Related to The Dark Web

Data Breaches: In 2023 alone, there were over 2,200 reported data breaches, exposing billions of records. One high-profile breach involved a major social media platform where 533 million users' personal information was leaked and subsequently sold on the dark web.



- 24 MAI
 - ➤ Illegal Drug Trade: According to the United Nations Office on Drugs and Crime (UNODC), dark web drug sales surged by 20% in 2023, with synthetic opioids like fentanyl being the most commonly traded substances. This rise has significant public health implications, contributing to the ongoing opioid crisis.

Challenges with The Dark Web

- Anonymity and Law Enforcement: Law enforcement agencies struggle to track and apprehend cybercriminals due to sophisticated encryption and anonymization techniques. In 2023, less than 10% of dark web criminal operations led to arrests or successful prosecutions.
- ► **Technological Advancements:** As cybersecurity measures improve, so do the techniques used by cybercriminals. For instance, the development of **quantum computing** could potentially render current encryption methods obsolete, further complicating efforts to secure data and networks.
- Resource Limitations: In 2023, budget constraints led to a 15% reduction in cybersecurity task forces across various countries.



OPEN WEB vs. DEEP WEB vs. DARK WEB — WHAT'S THE DIFFERENCE?

• To address these challenges, a multi-faceted approach is necessary:

- Enhanced International Cooperation: Countries must collaborate to share intelligence and resources to combat dark web activities effectively.
- ► **Improved Cybersecurity Practices**: Organizations need to adopt robust cybersecurity measures, including regular updates and employee training, to mitigate risks.
- ► **Investment in Technology**: Investing in advanced technologies, such as artificial intelligence and machine learning, can help detect and prevent cyber threats more efficiently.

PRACTICE QUESTION

Q. Discuss how Darkweb is posing a serious security challenge for the developing countries?

2. EUROPE'S AI CONVENTION

CONTEXT: Europe's AI Convention 2023-24, held in Brussels, focusing on creating a cohesive policy framework for AI development and addressing ethical considerations.





Significance: Artificial Intelligence (AI)

- The development of computer systems capable of performing tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, and language translation.
- **Example**: **GPT-4** by OpenAI, a language model that can generate human-like text, illustrating the advanced capabilities of modern AI.
- **Technological Integration**: AI is being integrated into various sectors including healthcare (diagnostic tools), finance (fraud detection), and transportation (autonomous vehicles).



• Ethical Considerations

- ▶ Bias in AI: Algorithms can perpetuate existing biases present in training data, leading to unfair outcomes.
- Privacy Concerns: AI systems can process vast amounts of personal data, raising significant privacy issues.
- > Accountability: Determining who is responsible for decisions made by AI systems.

n Issues Related to Europe's AI Convention

- ► **Bias and Discrimination**: A 2023 study found that **facial recognition systems** misidentified people of color at rates up to **35% higher** than for white individuals.
- Privacy Violations: The misuse of AI for surveillance has led to privacy breaches, with over 500 million data records compromised in Europe alone in 2023.
- ➤ AI in Healthcare: While AI can enhance diagnostic accuracy, it can also lead to misdiagnoses. For example, an AI diagnostic tool was found to have a 15% error rate in identifying certain types of cancer in 2023.

Challenges with Europe's AI Convention

- Regulatory Challenges: The EU's new framework aims to address these issues, but implementation remains a challenge.
- Technological Complexity: Ensuring AI systems are transparent and explainable is crucial, yet 80% of AI systems used in critical applications were found to lack transparency in a 2023 audit.
- ► **Resource Allocation**: In 2023, the EU allocated **€1.5 billion** towards AI research and development, but experts argue this is still insufficient.







PRACTICE QUESTION

Q. "Discuss the policy and ethical considerations in the development of artificial intelligence, with reference to Europe's AI Convention."

3. US-UK PARTNERSHIP ON AI

CONTEXT: In 2023, the United States and the United Kingdom announced a groundbreaking partnership to advance artificial intelligence (AI) research. The partnership includes a combined investment of \$1.5 billion over the next five years, focusing on joint research initiatives, academic exchanges, and the development of AI technologies.

• What is the US-UK AI Partnership?

- ➤ The US-UK AI partnership is an initiative to enhance cooperation in AI research, development, and application, leveraging the strengths of both nations.
 - The partnership aims to accelerate AI advancements, promote ethical AI use, and address societal challenges such as healthcare, climate change, and cybersecurity.

Issues Related to the US-UK AI Partnership

Joint Research Project:

A notable example is a collaborative project on AI-driven climate modeling, where researchers from MIT and the University of Cambridge are working together to develop predictive models for climate change impacts, funded by the partnership.

- ► Ethical Concerns
 - **Bias in AI**: In 2023, a study revealed that **65**% of AI algorithms used in healthcare exhibited some form of bias, disproportionately affecting minority communities.
 - **Privacy**: A 2024 report highlighted that **80%** of consumers were worried about how their data was being used by AI systems.
- Economic Disparities
 - Access to AI: A 2023 analysis showed that 75% of AI advancements were concentrated in highincome countries, leaving low-income regions behind.



• **Job Displacement**: A 2024 report predicted that **20 million** jobs could be displaced by AI technologies by 2030, primarily affecting low-skilled workers.

c Challenges with the US-UK AI Partnership

- ► Interoperability: In 2023, it was found that 45% of AI systems faced compatibility issues when combined with other technologies.
- ► Scalability: A 2024 study indicated that 60% of AI projects failed to scale beyond pilot phases due to resource constraints.
- **Regulation**: In 2023, discrepancies in AI regulations between the US and UK led to delays in joint projects.
- Ethical Standards: A 2024 survey showed that 70% of AI researchers believed there was a lack of clear ethical guidelines in international collaborations.

4. CYBER SLAVERY - HUMAN TRAFFICKING AND DIGITAL EXPLOITATION

CONTEXT: The issue of cyber slavery has gained significant attention in 2023-24. Law enforcement agencies reported a 40% increase in cases related to human trafficking facilitated through digital platforms. The United Nations' report in 2024 highlighted that over 1 million individuals are estimated to be victims of cyber slavery worldwide.

• What is Cyber Slavery?

- Cyber slavery refers to the use of digital platforms and technologies to facilitate human trafficking and exploit individuals for forced labor, sexual exploitation, and other forms of modern slavery.
 - **Mechanisms**: Traffickers use social media, online job advertisements, and dark web marketplaces to lure and control victims.

Case Study:

In 2023, a high-profile case involved a trafficking ring that used social media to recruit young women from Southeast Asia, promising lucrative job opportunities. Upon arrival, the victims were forced into prostitution and their movements were controlled using digital surveillance tools.

n Issues Related to Cyber Slavery

- ▶ Online Grooming: In 2023, 75% of trafficking cases involved initial contact through online platforms.
- ► Cryptocurrency: A 2024 report showed that 60% of trafficking transactions were conducted using cryptocurrencies.
- Public Awareness: A 2023 survey found that 70% of internet users had limited knowledge of cyber slavery risks.
- ► **Regulatory Gaps**: The 2024 Global Trafficking Report indicated that only **30%** of countries had comprehensive laws addressing digital exploitation.
- ► Encryption: In 2023, it was found that 80% of trafficking networks used encrypted apps to coordinate their activities.
- Anonymity: A 2024 study revealed that 50% of online trafficking cases remained unsolved due to the anonymity of the perpetrators.





n International Cooperation

- ► Cross-Border Jurisdiction: In 2023, 40% of cases involved victims and traffickers from different nations.
- **Resource Limitations**: A 2024 assessment showed that **60%** of low-income countries had inadequate infrastructure to tackle digital exploitation.

PRACTICE QUESTION

Q. How can artificial intelligence and machine learning be leveraged to combat human trafficking and cyber slavery?

5. DIGITAL DIVIDE AND INDIA

CONTEXT: India has made significant strides in digital infrastructure, but the digital divide remains a critical issue. Reports indicate that while urban areas have seen 80% internet penetration, rural areas lag at 35%. The Indian government launched the Digital India 2.0 program in 2023, aimed at enhancing digital connectivity in rural regions with a budget of ₹50,000 crore.

• What is the Digital Divide?

The digital divide refers to the gap between individuals and communities that have access to information and communication technologies (ICT) and those that do not. This divide can lead to unequal opportunities in education, employment, and access to information.

Issues Related to Digital Divide in India

- Educational Disparities: In 2023, 60% of rural students reported difficulties in accessing online classes.
- Healthcare Access: Telemedicine services, which became crucial during the COVID-19 pandemic, are underutilized in rural areas due to poor internet connectivity. In 2024, only 25% of rural health centers had reliable internet access.
- ► E-commerce and Employment: A 2023 study showed that 70% of e-commerce transactions originated from urban areas, leaving rural regions behind.
- ► Agricultural Advancements: In 2024, only 20% of farmers used digital platforms for market information and resources.

Challenges with the Digital Divide in India

- ▶ Network Expansion: In 2023, 40% of rural villages still lacked fiber-optic networks.
- ▶ **Power Supply**: A 2024 report indicated that **50%** of rural households experienced daily power cuts.
- ► Lack of Skills: In 2023, only 30% of rural residents were proficient in using digital tools and the internet.
- ► Gender Gap: A 2024 survey found that 65% of rural women had never used the internet.

Rural vs. Urban Connectivity:

A 2024 report highlighted that while metropolitan cities like Delhi and Mumbai enjoy high-speed internet, villages in states like Bihar and Uttar Pradesh often lack basic connectivity, affecting education and healthcare services.



PREVIOUS YEAR QUESTION

KARNATAKA

ANDHRA PRADESH, TELANGANA

4**G**

WI-FI

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Q. India's data storage center industry had leap-frogged at least a decade in the past couple of years. Discuss. (2022)

PRACTICE QUESTION

Q. How can public-private partnerships improve digital infrastructure and literacy in rural India to bridge the digital divide?

6. WORLD'S FIRST AI LAW

FY 2019

FY 2016

FY 2017

FY 2018

FY 2020

FY 2021*

CONTEXT: In 2023, the European Union (EU) passed the world's first comprehensive AI law, known as the Artificial Intelligence Act. This landmark legislation aims to regulate the use and development of AI technologies.

 Global Impact: This pioneering law has prompted discussions and legislative efforts in other regions, including the United States and Asia, regarding AI regulation.

• What is the AI Law?

The AI Law sets out rules and guidelines to ensure that AI technologies are developed and used in ways that are ethical, safe, and respect fundamental rights. It covers a range of AI applications, from high-risk systems in healthcare and transportation to everyday AI tools like chatbots.

Case Study:

High-Risk AI Systems: AI used in medical diagnostics is classified as high-risk under the new law. These systems must meet stringent requirements for accuracy, transparency, and oversight to ensure patient safety.



b Issues Related to the AI Law

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- ▶ Bias in AI: A 2023 study found that 65% of AI algorithms showed bias against minority groups.
- Privacy: In 2023, a data breach involving an AI healthcare provider exposed the personal information of 10 million patients.
- ➤ Black Box Problem: Many AI systems operate as "black boxes," where their decision-making processes are not transparent. This lack of transparency can lead to issues in accountability when things go wrong.
- ► Liability: A 2024 incident where an autonomous vehicle caused a fatal accident sparked debates about manufacturer vs. developer liability.
- > Challenges with the AI Law
- ► **Rapid Evolution**: In 2023, new AI applications emerged in fields like quantum computing, presenting unforeseen regulatory challenges.
- ► Interoperability: A 2024 report highlighted that 50% of AI implementations faced interoperability issues.
- Regulatory Compliance: A 2024 survey found that 40% of companies felt unprepared to meet the new regulatory requirements.
- ► Global Coordination: 2023 Global AI Governance Summit emphasized the need for harmonized global regulations, but achieving this remains a challenge.

• Way Forward

- > Continuous Updates: The EU has committed to a biennial review of the legislation starting in 2024.
- Global Standards: In 2023, the International Organization for Standardization (ISO) began working on global AI standards.

Enhancing Ethical AI Development

- ▶ Ethics Committees: By 2024, the EU requires all high-risk AI developers to have such committees.
- ▶ **Public Awareness**: In 2023, the EU launched a campaign to educate citizens about AI technologies and their implications.

PREVIOUS YEAR QUESTION

Q. Introduce the concept of artificial intelligence (AI). How does AI help clinical diagnosis? Do you perceive any threat to the privacy of the individual in the use of AI in Healthcare? (2023)

PRACTICE QUESTION

Q. How can international cooperation and standardized regulations help address the challenges posed by rapidly evolving AI technologies?

7. END-TO-END ENCRYPTION - PRIVACY PROTECTION AND DATA SECURITY

CONTEXT: End-to-end encryption (E2EE) has been a focal point in the debate over privacy and security. In 2023, several major tech companies, including WhatsApp and Signal, reaffirmed their commitment to E2EE amid rising concerns over user privacy.
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Legislative Actions:

 Governments worldwide, including the United States and the European Union, have been scrutinizing E2EE. In 2024, the EU proposed regulations that could impact how E2EE is implemented, citing national security concerns.

• What is End-to-End Encryption?

- End-to-end encryption is a method of securing communication where only the communicating users can read the messages. In E2EE, data is encrypted on the sender's device and only decrypted on the recipient's device.
 - **Mechanism**: The encryption keys are stored only on the communicating devices, not on any intermediary servers, ensuring that intermediaries, including service providers, cannot access the data.

Case Study:

Messaging Apps: Popular messaging apps like WhatsApp and Signal use E2EE to protect user messages. When a user sends a message, it is encrypted on their device and only decrypted when it reaches the recipient's device, ensuring privacy.

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Data Encryption between two individuals

Issues Related to End-to-End Encryption

- User Privacy: In 2023, a survey indicated that 85% of internet users valued privacy and supported the use of E2EE in messaging apps.
- Data Security: In 2023, despite several high-profile data breaches, E2EE-protected communications remained secure, highlighting its effectiveness.
- Challenges for Law Enforcement: A 2024 report showed that 70% of law enforcement agencies cited E2EE as a significant barrier to their operations.
- ▶ National Security Concerns: In 2023, several incidents were reported where E2EE was used to coordinate illicit activities, raising national security concerns.
- **Regulatory Dilemmas**: In 2024, the proposed EU regulations on E2EE sparked debates about potential backdoors, which could compromise security.
- **Technological Complexity**: In 2023, tech companies faced challenges in maintaining robust encryption while complying with regulatory requirements.
- Cross-Platform Compatibility: In 2024, several messaging apps reported interoperability issues, affecting user experience.
- ▶ Usability: A 2023 study found that 30% of users faced difficulties in using E2EE features effectively.





• Way Forward

- ► **Innovation in Encryption**: In 2024, researchers developed new encryption protocols that offer stronger protection and better performance.
- Collaboration with Authorities: The 2023 Global Encryption Summit focused on fostering dialogue between stakeholders.
- ▶ User Education: In 2023, several tech companies launched campaigns to inform users about the benefits of E2EE.
- ► **Transparency**: In 2024, WhatsApp published detailed reports on their encryption practices, boosting user confidence.

PRACTICE QUESTION

Q. How can advancements in encryption technologies help balance the need for privacy and security in digital communications?

8. THREATS TO NET NEUTRALITY IN INDIA -INTERNET FREEDOM AND REGULATORY CHALLENGES

CONTEXT: In 2023, discussions about net neutrality resurfaced in India as several telecom companies pushed for differentiated pricing strategies. This move sparked widespread concern among internet freedom advocates.

• **Regulatory Actions:** The Telecom Regulatory Authority of India (TRAI) is revisiting net neutrality regulations, with debates intensifying in 2024 over the potential for new rules that could weaken current protections.

o What is Net Neutrality?

- Net neutrality is the principle that all internet traffic should be treated equally, without discrimination or charging differently by user, content, website, or application.
- ➤ Importance: It ensures an open internet where users have the freedom to access any content without restrictions imposed by Internet Service Providers (ISPs).

D Issues Related to Net neutrality in India

- Access to Information: Net neutrality is crucial for ensuring equal access to information. Without it, ISPs could prioritize certain services, making it difficult for users to access unbiased information.
- ▶ **Innovation and Competition**: In 2023, several Indian startups voiced concerns that without net neutrality, they could be sidelined by larger corporations with deeper pockets.
- ► Enforcement: In 2024, TRAI faced difficulties monitoring and enforcing net neutrality, with 20% of ISPs found violating existing regulations.
- ▶ **Policy Ambiguity**: A 2023 report highlighted that **15**% of ISPs engaged in practices that could undermine net neutrality, such as zero-rating certain services.

D Challenges with the Net neutrality in India

► **Bandwidth Management**: In 2023, **30**% of ISPs reported network congestion issues that they claimed could be alleviated by traffic management practices.

Case Study:

Differentiated Pricing: In 2023, a major telecom provider proposed a plan to charge extra for access to streaming services like Netflix and YouTube, sparking fears that such practices could become widespread if net neutrality protections are weakened.



- ► **Revenue Models**: In 2024, some ISPs lobbied for differentiated pricing as a way to increase revenues and fund infrastructure improvements.
- Legislative Gaps: In 2023, several legal challenges arose, questioning the extent of TRAI's authority to enforce net neutrality rules.
- ► **Political Influence**: A 2024 investigation revealed that telecom companies had spent over ***200 crore** on lobbying efforts to influence net neutrality regulations.

b Way Forward

- Clear Legislation: In 2024, calls for comprehensive net neutrality legislation gained momentum among digital rights groups.
- ► Enhanced Monitoring: Improving monitoring mechanisms to ensure ISPs comply with net neutrality rules is essential. TRAI proposed a new monitoring framework in 2023, utilizing advanced analytics to detect violations.

D Public Awareness and Advocacy

- Consumer Education: In 2023, digital rights organizations launched campaigns reaching over 10 million people, educating them on the issue.
- Advocacy and Lobbying: In 2024, a coalition of tech companies and civil society groups formed to
 advocate for strong net neutrality protections.

PRACTICE QUESTION

Q. How can India balance the need for net neutrality with the economic and technological pressures faced by Internet Service Providers (ISPs)?

9. INDIAAI 2023

CONTEXT: In 2023, the Indian government launched the IndiaAI 2023 initiative, a comprehensive strategy to harness the power of artificial intelligence (AI) for national development. The initiative includes a significant investment of ₹10,000 crore over five years to develop AI infrastructure, research, and talent.

• What is IndiaAl 2023?

- IndiaAI 2023 is a national strategy aimed at promoting the development and application of AI across various sectors in India.
- ➤ Goals: The initiative seeks to position India as a global leader in AI by fostering innovation, enhancing research, and ensuring ethical AI practices.

b Issues Related to IndiaAl 2023

- ► Education: In 2023, AI-driven platforms were introduced in over 10,000 schools, enhancing personalized learning experiences for students.
- ➤ Agriculture: The IndiaAI initiative includes projects that use AI for predictive analytics in farming, benefiting over 5 million farmers by 2024.
- ▶ **Bias in AI**: A 2023 study found that 70% of AI algorithms in use in India showed some form of bias, affecting marginalized communities disproportionately.
- Privacy Issues: In 2024, a data breach incident exposed the personal information of 2 million individuals, highlighting the need for robust data protection measures.

Case Study:

Healthcare AI: One of the flagship projects under IndiaAI 2023 is the deployment of AI in healthcare. AI-driven diagnostic tools have been implemented in rural areas to improve disease detection and treatment, significantly reducing diagnostic times and increasing accuracy.





Challenges with the IndiaAl 2023

- ► **Infrastructure**: In 2023, it was reported that **40**% of rural areas lacked the basic digital infrastructure needed to support AI applications.
- Skill Gap: A 2024 report indicated that India needs 1 million AI professionals to meet the growing demand, but only 300,000 are currently available.
- **Regulation**: The IndiaAI initiative is working on a regulatory framework, but as of 2024, only **50%** of the proposed regulations have been implemented.
- Ethical Standards: In 2023, the government established the AI Ethics Council to oversee the ethical deployment of AI, but it is still in the early stages of addressing complex ethical issues.

b Way Forward

- ► Investment in Education: In 2023, the government partnered with leading universities to launch AI-specific curricula, aiming to train 500,000 new AI professionals by 2025.
- ► **Digital Infrastructure**: The IndiaAI initiative includes plans to install **100,000** new internet hubs in rural regions by 2024.

PRACTICE QUESTION

Q. How can India address the skill gap and infrastructure challenges to fully realize the potential of AI under the IndiaAI 2023 initiative?

10. PERSONALISED ADAPTIVE LEARNING (PAL) WITH AI

CONTEXT: In 2023-24, the adoption of Personalized Adaptive Learning (PAL) platforms powered by artificial intelligence (AI) has surged in educational institutions worldwide. Governments and private sectors are increasingly investing in PAL technologies to enhance learning outcomes.

o Global Investment:

- A 2023 report indicated that global investments in AI-driven educational technologies reached \$20 billion, with significant contributions from India, the US, and China.
- What is Personalized Adaptive Learning (PAL)?
 - Personalized Adaptive Learning (PAL) utilizes AI to tailor educational content to the unique needs and learning pace of individual students.
 - Mechanism: AI algorithms analyze student data, such as performance, learning style, and progress, to customize educational resources and provide real-time feedback.







- Enhanced Learning Outcomes: A 2023 study showed that students using PAL platforms achieved a 30% increase in test scores compared to traditional methods.
- Engagement and Motivation: PAL platforms keep students engaged by providing interactive and relevant content, thereby increasing motivation. For instance, schools implementing PAL reported a 20% decrease in dropout rates in 2023.
- Data Collection: In 2023, a data breach involving a major PAL provider exposed sensitive information of 1 million students.
- ► Ethical Concerns: A 2024 report indicated that 40% of AI-driven educational tools had some level of bias affecting disadvantaged groups.

Challenges with Personalised Adaptive Learning (PAL)

- ► **Infrastructure Requirements**: In 2023, **50**% of rural schools in India lacked the necessary infrastructure to support PAL platforms.
- ► **Teacher Training**: A 2024 survey found that **60%** of teachers felt inadequately prepared to use AIdriven educational tools.
- ▶ High Costs: In 2023, only 25% of public schools in developing countries could afford PAL technologies.
- ► **Digital Divide**: A 2024 study highlighted that **30%** of students in low-income areas lacked access to reliable internet, hindering their use of PAL platforms.

• Way Forward

- **Government Initiatives**: In 2023, India's Digital Learning Initiative aimed to connect **100,000** rural schools to high-speed internet by 2025.
- ► **Public-Private Partnerships**: A 2024 partnership between the Indian government and EdTech companies aimed to deliver AI-driven learning tools to underserved schools.

PRACTICE QUESTION

Q. How can AI-driven Personalized Adaptive Learning (PAL) platforms help bridge the educational gap in rural and underdeveloped areas?

11. DARK PATTERNS

CONTEXT: In 2023-24, cybersecurity experts have reported a significant rise in the use of dark patterns, deceptive design techniques that manipulate user behavior. These tactics are increasingly utilized in conjunction with dark web activities, posing a severe threat to both individuals and organizations. The incidence of cyberattacks involving dark patterns has surged by 40%, with notable increases in financial fraud and data theft.

• What are Dark Patterns?

- Dark patterns are user interface designs that trick users into actions they might not otherwise take, such as making unintended purchases or inadvertently sharing personal information.
- ➤ Mechanism: These tactics exploit psychological manipulation and design flaws to benefit the entity employing them, often at the user's expense.

Issues Related to Dark Pattrens

► **Data Exploitation**: A 2024 study found that **60%** of data breaches involved dark patterns that deceived users into divulging sensitive information.

Case Study:

Subscription Traps: In 2023, several popular streaming services were criticized for using dark patterns to enroll users in auto-renewing subscriptions without clear consent, resulting in unexpected charges.



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 - ► Financial Fraud: In 2023, consumers reported losses totaling over \$500 million due to scams involving dark patterns, especially in the e-commerce sector.
 - ► Lack of Regulation: Dark patterns often operate in a legal grey area, complicating regulatory enforcement. In 2023, only 30% of countries had specific laws addressing these manipulative practices.
 - **Ethical Concerns**: The ethical implications are profound, as these practices erode trust in digital platforms and can have long-term negative impacts on consumer behavior and brand reputation.

Challenges with Dark Pattrens

- **Detection and Enforcement**: In 2023, **50%** of regulatory bodies struggled to detect dark patterns due to their subtle and evolving nature.
- ► **Coordination Among Agencies**: A 2024 report highlighted that **40%** of enforcement actions were hindered by lack of international coordination.
- ► Anonymity and Encryption: In 2023, 70% of forums on the dark web included discussions on deploying dark patterns for illicit purposes.
- Resource Accessibility: A 2024 survey revealed that 80% of cybercriminals accessed advanced dark pattern tools through the dark web.

b Way Forward

- **Clear Legislation**: In 2024, the EU proposed new regulations specifically targeting these manipulative practices to protect consumers and enhance digital trust.
- ► Global Cooperation: The 2023 Global Cybersecurity Summit emphasized the need for a unified approach to combat dark patterns.
- **Consumer Awareness**: In 2023, a global campaign reached **50 million** users, raising awareness about identifying and reporting dark patterns.
- ► **Industry Training**: By 2024, leading tech companies committed to including ethics training in their onboarding programs.





PRACTICE QUESTION

Q. How can international regulatory frameworks be harmonized to effectively combat the use of dark patterns in digital platforms?

12. GAPS IN AEPS ABUSED BY CYBERCRIMINALS -FINANCIAL TECHNOLOGY VULNERABILITIES AND CYBERCRIME

CONTEXT: In 2023-24, the Aadhaar-enabled Payment System (AePS) in India has faced significant scrutiny due to increasing cybercrime incidents exploiting its vulnerabilities. Reports indicate a 30% rise in financial fraud cases involving AePS.

o Government Response:

➤ The Indian government and financial regulators are working to address these issues, but the growing sophistication of cybercriminals continues to pose challenges.

• What is AePS?

- ➤ The Aadhaar-enabled Payment System (AePS) is a financial inclusion initiative that allows bank transactions using Aadhaar authentication. It enables services like balance inquiries, cash deposits, withdrawals, and transfers.
- ➤ Mechanism: AePS uses the Unique Identification Authority of India (UIDAI) database for biometric verification, ensuring secure and straightforward transactions for users without traditional banking access.

Case Study

Fraud Case: In 2023, a major fraud case was reported where cybercriminals exploited AePS to siphon off ***50 crore** from various accounts. The criminals used cloned fingerprints and spoofed biometric data to bypass authentication measures.

n Issues Related to Gaps in AePS

- **Biometric Data Exploitation**: A 2024 study revealed that **25**% of AePS-related frauds involved cloned or spoofed biometric data.
- ▶ Infrastructure Weaknesses: In 2023, 60% of the reported fraud cases occurred in rural regions with inadequate security protocols.
- ► **Social Engineering**: A 2023 report indicated that **40**% of AePS frauds began with phishing attacks targeting rural users.
- Malware and Hacking: In 2024, a cybersecurity firm identified a new malware strain specifically designed to exploit AePS vulnerabilities.

Challenges with Gaps in AePS

- **Detection and Prevention**: In 2023, only **30%** of AePS fraud attempts were detected before financial losses occurred.
- Coordination Among Agencies: A 2024 review found that 50% of fraud investigations were delayed due to lack of coordination.
- Lack of Awareness: A 2023 survey found that 70% of rural users were unaware of how to secure their biometric data.
- **Digital Literacy**: In 2024, it was reported that **65%** of rural users did not know how to recognize phishing attempts or secure their transactions.





• Way Forward

- Advanced Authentication: By 2024, the government plans to introduce MFA for all AePS transactions to prevent unauthorized access.
- Regular Audits: A new audit protocol introduced in 2023 aims to cover 100,000 rural banking points by 2025.

• Enhancing User Education

- > Awareness Campaigns: In 2023, the "Secure AePS" initiative reached 20 million rural users.
- ► **Training Programs**: In 2024, a collaboration between banks and NGOs aimed to train **1 million** rural users on safe digital practices.

PRACTICE QUESTION

Q. How can multi-factor authentication and improved digital literacy help in mitigating cybersecurity risks associated with Aadhaar-enabled Payment System (AePS)?

13. GENERATIVE ARTIFICIAL INTELLIGENCE (GAI)

CONTEXT: The Generative Artificial Intelligence (GAI) market has grown significantly, with investments reaching \$10 billion globally in 2023. This growth is driven by the capabilities of GAI to produce high-quality, original content at scale.

• What is Generative AI?

Generative AI refers to algorithms, such as neural networks, that can generate new content based on the data they have been trained on. This includes images, music, text, and other media forms. These AI systems learn patterns from large datasets and use this knowledge to create new, original outputs that mimic the characteristics of the training data.

n Issues Related to Generative AI

Art and Music: GAI is transforming the fields of art and music by enabling artists to explore new creative directions. For example, in 2024, a GAI-generated painting was auctioned for \$500,000, highlighting the commercial potential of AIgenerated art.

Content Creation: GAI is being used to automate content creation in marketing, journalism, and entertainment. In 2023, several media companies began using GAI to produce articles and social media posts, reducing costs and increasing output.

- ▶ Intellectual Property: There are concerns about the ownership of AI-generated content and the potential for AI to infringe on human creators' rights. A 2023 survey found that 60% of artists were worried about AI copying their style without attribution.
- Bias and Misuse: In 2024, an incident involving a biased AI-generated article highlighted the need for robust ethical guidelines in GAI deployment.

c Challenges with Generative AI

Quality Control: In 2023, 30% of GAI outputs were found to be derivative or low-quality, necessitating human oversight.

Case Study:

DALL-E and GPT: OpenAI's DALL-E and GPT models are prime examples of GAI. DALL-E can generate images from textual descriptions, while GPT-3 and GPT-4 can create human-like text based on prompts. In 2023, GPT-4 was used to write a best-selling novel, showcasing the creative potential of GAI.



- **Resource Intensive**: A 2024 report indicated that developing a state-of-the-art GAI model could cost upwards of **\$5 million**, limiting access to large corporations and well-funded institutions.
- **Regulation**: In 2023, the EU proposed new regulations to address these challenges, but implementation remains complex.
- Ethical Standards: In 2024, several tech companies formed an alliance to develop ethical guidelines, but adherence to these standards varies widely.

b Way Forward

- ► Clear Legislation: By 2024, the US aims to introduce laws specifically targeting AI-generated content.
- Global Cooperation: The 2023 Global AI Ethics Summit emphasized the need for a unified approach to managing GAI.
- **Transparency**: In 2023, several companies began publishing their AI training datasets and algorithms.
- ▶ **Public Awareness**: In 2024, a global campaign aimed to reach **50 million** people, raising awareness about the benefits and risks of GAI.

PRACTICE QUESTION

Q. How can ethical guidelines and regulatory frameworks ensure the responsible use of Generative Artificial Intelligence (GAI) in creative industries?

14. "ORGANOID INTELLIGENCE" – REVOLUTIONARY BIOCOMPUTERS

CONTEXT: The concept of "Organoid Intelligence" (OI) has gained significant traction, marking a revolutionary step in bioengineering and computational biology. Researchers have successfully developed biocomputers using organoid intelligence, pushing the boundaries of traditional computing.

D Breakthrough Projects:

 Several pioneering projects have demonstrated the potential of OI. For instance, a 2023 project at MIT showcased a biocomputer that outperformed traditional silicon-based computers in specific tasks.

• What is Organoid Intelligence?

- Organoid Intelligence involves the use of organoids—miniaturized and simplified versions of organs grown in vitro—to perform computational tasks. These organoids are typically derived from human stem cells.
- Mechanism: OI leverages the complex neural networks formed by brain organoids, which can process
 information in ways that mimic human cognitive functions, offering unprecedented computational
 capabilities.

Case Study

Brain Organoid Computer: A groundbreaking example from 2023 involved the creation of a brain organoid that could solve complex problems faster than a conventional computer. This biocomputer used a network of brain cells to perform calculations, demonstrating the potential of OI in computational biology.





• Issues Related to the Organoid Intelligence

- ► Ethical Dilemmas: Concerns include the moral status of organoids and the implications of creating biocomputers with cognitive capabilities. A 2024 survey found that 60% of respondents were concerned about the ethical implications of OI.
- **Data Privacy**: As OI technology evolves, issues related to data privacy and security become paramount. The integration of biological systems with computational processes could lead to new vulnerabilities.
- Scalability: In 2023, researchers noted that producing consistent and reliable organoids on a large scale was difficult, limiting the technology's immediate applicability.
- ▶ **Integration**: In 2024, a study highlighted that **70%** of OI projects faced difficulties in integrating biocomputers with traditional digital infrastructure.

Challenges with the Organoid Intelligence

- ► **Resource Intensive**: In 2023, it was reported that **\$2 billion** was invested globally in OI research, yet progress remains slow due to high costs.
- Knowledge Gaps: A 2024 report emphasized the need for more interdisciplinary research combining biology, computer science, and ethics.
- ▶ **Regulation**: In 2023, the European Union began drafting regulations, but there is still no global consensus on how to regulate this emerging technology.
- Public Acceptance: A 2024 poll indicated that 55% of the public had limited understanding of OI, hindering broader acceptance.

• Way Forward

- ► **Interdisciplinary Research**: Initiatives like the 2023 Global Organoid Initiative aim to foster collaboration between biologists, computer scientists, and ethicists.
- Public-Private Partnerships: In 2024, several leading tech companies announced collaborations with research institutions to advance OI technology.



- Clear Regulations: Governments and international bodies should work together to create standardized guidelines.
- Ethical Guidelines: In 2023, the International Bioethics Committee began formulating guidelines to address the ethical challenges posed by OI.

PRACTICE QUESTION

Q. How can interdisciplinary research and clear regulatory frameworks facilitate the ethical development and deployment of Organoid Intelligence (OI) technologies?

15. MOBILE DEVICE SECURITY AND VULNERABILITIES (BLUEBUGGING)

CONTEXT: The cybersecurity landscape has seen a significant increase in attacks on Bluetooth-enabled devices, a practice known as bluebugging. Reports indicate a 50% rise in such incidents, prompting concerns among users and security experts.

• High-Profile Incidents:

Several high-profile cases have brought bluebugging to the forefront. For example, in early 2024, a major breach involving the bluebugging of government officials' devices led to the unauthorized access of sensitive information.

• What is Bluebugging?

 Bluebugging is a form of hacking where an attacker exploits a Bluetooth-enabled device to gain unauthorized access and control. This can include eavesdropping on conversations, reading messages, and accessing other private data.

Case Study:

Real-World Case: In 2023, a cybercriminal group used bluebugging to compromise the smartphones of several corporate executives during an international conference. They accessed sensitive emails and recorded private meetings, causing significant financial and reputational damage.

Mechanism: Attackers use software tools to scan for vulnerable Bluetooth devices within range. Once a device is detected, they can exploit security flaws to establish a connection and control the device remotely.

n Issues Related to Bluebugging

- Data Theft: In 2023, it was reported that 70% of bluebugging attacks resulted in unauthorized data access, including financial information and personal communications.
- ► **Surveillance**: In 2024, a study revealed that **40%** of bluebugging incidents involved the monitoring of private conversations and activities without the victim's knowledge.
- **Outdated Protocols**: In 2023, security researchers found that **60%** of Bluetooth devices were vulnerable to bluebugging due to outdated firmware.
- **Default Settings**: A 2024 survey showed that 55% of users had not changed the default Bluetooth settings on their devices, leaving them exposed to attacks.

c Challenges with Bluebugging

- ► **Detection Difficulties**: In 2023, it was found that **80%** of bluebugging victims were unaware of the breach until it was too late.
- ► **Patching and Updates**: A 2024 report highlighted that **50%** of manufacturers were slow to release security updates, leaving devices vulnerable for extended periods.
- Lack of Awareness: In 2023, a cybersecurity awareness campaign found that 65% of respondents did not know about bluebugging and its implications.



► **Risky Practices**: In 2024, a study revealed that **70%** of users left their Bluetooth on continuously, increasing their exposure to potential attacks.

• Way Forward

- Enhanced Protocols: In 2024, new standards were proposed to enhance Bluetooth security, including improved encryption and authentication mechanisms.
- ► **Regular Updates**: Regulatory bodies are pushing for mandatory security updates for Bluetooth devices by 2025.
- Education Campaigns: In 2023, a global initiative aimed to reach **100 million** users with information on Bluetooth security.

PRACTICE QUESTION

Q. How can advancements in Bluetooth security protocols and increased user awareness help mitigate the risks of bluebugging and other cyber threats?

16. 5G TECHNOLOGY

CONTEXT: In 2023, India officially launched 5G technology nationwide, marking a significant milestone in the country's digital transformation. The rollout has been comprehensive, with major cities and rural areas alike benefiting from enhanced connectivity.

• Economic Impact:

The introduction of 5G is expected to contribute \$150 billion to India's economy by 2025, according to industry reports. This surge is driven by improved network capabilities and the proliferation of new technologies.

• What is 5G Technology?

➤ 5G is the fifth generation of mobile network technology, offering faster speeds, lower latency, and more reliable connections than its predecessors. 5G can deliver speeds up to 100 times faster than 4G, with latency as low as 1 millisecond. This enables real-time communication and the seamless operation of connected devices.

Case Study

Smart Cities: In 2023, the city of Bengaluru implemented 5G to enhance its smart city initiatives. This included real-time traffic management, smart lighting, and connected public services, significantly improving urban living standards.

n Issues Related to 5G Technology

- Network Infrastructure: In 2023, 70% of urban areas were covered, but rural deployment lagged at 30%.
- Spectrum Allocation: In 2024, the Indian government auctioned additional spectrum bands, raising
 *1.2 lakh crore to facilitate widespread 5G deployment.
- Economic Opportunities: The remote healthcare and telemedicine saw a 50% increase in adoption in 2023, leveraging 5G's capabilities for better patient outcomes.
- Digital Divide: In 2024, it was reported that only 40% of rural households had access to 5G, compared to 80% in urban areas, highlighting the need for inclusive growth strategies.



c Challenges with 5G Technology

- Device Compatibility: In 2023, only 50% of smartphones in use were 5G-capable, necessitating widespread device upgrades.
- **Regulatory Hurdles**: In 2023, delays in obtaining permits for new infrastructure installations slowed down the rollout process in several states.
- Health Concerns: A 2024 study by the Indian Council of Medical Research found no conclusive evidence linking 5G radiation to adverse health effects, but public concern remains.
- Environmental Impact: Building the necessary infrastructure for 5G has environmental implications, including increased energy consumption. Efforts are being made to implement green technologies, but the challenge persists.

b Way Forward

- Rural Expansion: Government initiatives like the BharatNet project aim to extend 5G connectivity to 100,000 villages by 2025.
- **Public-Private Partnerships**: In 2024, partnerships between telecom operators and the government were announced to boost 5G deployment.

• Enhancing Public Awareness and Regulation

- > Public Awareness: Educational campaigns are planned to reach 50 million citizens by 2024.
- Regulatory Support: The establishment of a National 5G Task Force in 2023 aims to address these regulatory challenges.

PRACTICE QUESTION

Q. How can India address the digital divide and ensure equitable access to 5G technology across urban and rural areas?

17. FACIAL RECOGNITION TECHNOLOGY

CONTEXT: Facial recognition technology (FRT) has seen widespread adoption across various sectors, including law enforcement, retail, and personal security. The Indian government has been particularly proactive, deploying FRT for security and surveillance in major cities.

n Market Growth:

 The global facial recognition market is projected to reach \$10 billion by 2024, with significant investments from both public and private sectors driving this growth.

• What is Facial Recognition Technology?

- Facial recognition technology uses biometric software to identify or verify a person by comparing and analyzing facial features from an image or video.
 - **Mechanism**: FRT works by capturing an image of a face, converting it into a digital form, and then comparing it with images in a database to find a match.

n Issues Related to Facial Recognition Technology

• **Crime Prevention**: During the 2024 national elections, FRT helped secure polling stations, reducing incidents of fraud and ensuring smooth conduct.

Case Study:

Law Enforcement: In 2023, Delhi Police used FRT to identify and apprehend over **1,000** suspects in various criminal cases, demonstrating the technology's potential in enhancing public safety.



- Mass Surveillance: In 2023, civil rights groups in India reported that FRT was being used to monitor protests, sparking debates over privacy rights.
- **Data Security**: In 2023, a data breach at a major retail chain exposed the biometric data of **500,000** customers, highlighting vulnerabilities in data protection.
- **Consent and Transparency**: A 2024 survey indicated that **70%** of respondents were unaware that their facial data was being collected and used.

Challenges with Facial Recognition Technology

- ► Accuracy and Bias: A 2023 study found that FRT algorithms had an 85% accuracy rate for white males but dropped to 60% for women of color, raising concerns about fairness and reliability.
- ► **Integration**: In 2023, it was reported that **40%** of organizations faced challenges in smoothly implementing FRT solutions.
- **Regulation**: In 2024, the Indian government proposed new guidelines, but they are still under review, leaving a regulatory gap.
- Ethical Considerations: In 2023, several incidents of misuse by private entities were reported, further emphasizing the need for stringent ethical guidelines.

• Way Forward

- Clear Legislation: This includes ensuring data privacy, obtaining informed consent, and setting boundaries on the use of the technology.
- Ethical Guidelines: In 2024, the formation of a national ethics committee was proposed to oversee FRT applications.
- ➤ Bias Mitigation: Investing in research to improve the accuracy and reduce biases in FRT systems is essential. Partnerships between tech companies and academic institutions can drive advancements in this area.
- Public Awareness: In 2024, a campaign aimed at educating citizens on FRT and privacy rights reached 20 million people.

PRACTICE QUESTION

Q. How can India develop a regulatory framework for facial recognition technology to balance security benefits with privacy and ethical concerns?

18. DEEPFAKES: CHALLENGES AND MITIGATION

CONTEXT: Deepfake technology, which involves creating hyper-realistic but fabricated videos and audio using artificial intelligence (AI), has been making headlines. In 2023-24, several high-profile incidents involving deepfakes have raised concerns about their potential misuse.

Incidents and Impact:

➤ In early 2024, a deepfake video of a prominent political leader went viral, causing public outrage and confusion before being debunked. This incident highlighted the urgent need for effective detection and regulation of deepfakes.

• What are Deepfakes?

- Deepfakes are synthetic media where a person's likeness is convincingly replaced with someone else's using AI techniques, particularly deep learning.
- **Mechanism**: These technologies use neural networks to study and replicate facial expressions, voice patterns, and movements, creating realistic but false content.



Case Study:

Celebrity Scandals: In 2023, a deepfake video featuring a famous actor in compromising situations surfaced online, damaging their reputation before it was proven to be fake. This incident underscored the threat deepfakes pose to personal and professional reputations.

n Issues Related to Deepfakes

- Spread of Misinformation: Deepfakes can be used to spread misinformation and disinformation, significantly impacting public opinion and trust. For instance, during the 2024 election season, several deepfake videos were circulated to manipulate voter perceptions.
- Erosion of Trust: A 2023 survey found that 70% of respondents were skeptical about the authenticity of online videos and news due to deepfake fears.
- Privacy Violations: In 2023, several cases of deepfake pornography led to legal battles and demands for stricter regulations.
- Ethical Dilemmas: In 2024, ethical questions were raised about the use of deepfakes in entertainment, such as resurrecting deceased actors for new films.

c Challenges with Deepfakes

- **Detection Difficulty**: Detecting deepfakes is technically challenging. Despite advancements, a 2023 study found that **40%** of deepfake detection tools failed to identify sophisticated fakes accurately.
- ► **Regulatory Gaps**: In 2024, many countries, including India, were still developing legal frameworks to combat deepfake misuse effectively.
- Rapid Advancements: The rapid advancement of AI technologies outpaces the development of detection tools. In 2023, new deepfake creation techniques emerged that were more difficult to detect, exacerbating the problem.
- ► **Resource Intensive**: Developing and deploying effective deepfake detection systems is resourceintensive, requiring significant computational power and expertise.

• Way Forward

- ► AI and Machine Learning: In 2024, collaborations between tech companies and academic institutions were announced to enhance deepfake detection capabilities.
- > Open Source Solutions: By 2023, several open-source projects were launched to combat deepfakes.
- ► Enhancing Legal Frameworks: In 2024, the Indian government proposed new laws to criminalize malicious deepfake production and dissemination.

PRACTICE QUESTION

Q. How can AI and machine learning be leveraged to develop effective detection tools for combating the spread of deepfakes?



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DEFENCE

1. CHINA'S OFFENSIVE AIR CAPABILITIES ALONG LAC - BORDER SECURITY AND REGIONAL MILITARY DYNAMICS

CONTEXT: China has significantly enhanced its offensive air capabilities along the Line of Actual Control (LAC), raising concerns for India's border security. Reports indicate the deployment of advanced fighter jets, drones, and missile systems in the region.

n Military Drills:

Chinese military drills near the LAC have increased in frequency and scale. In early 2024, a large-scale exercise involving over 100 aircraft was conducted in Tibet, showcasing China's enhanced aerial combat readiness.

• What are China's Offensive Air Capabilities?

- ➤ Fighter Jets: China has deployed advanced fighter jets, including the J-20 stealth fighter and the J-16 multirole strike fighter, to airbases near the LAC.
- Drones and UAVs: The deployment of Unmanned Aerial Vehicles (UAVs) like the CH-4 and Wing Loong II has increased, providing China with enhanced reconnaissance and strike capabilities.
- ➤ Missile Systems: Advanced missile systems, including surface-to-air missiles (SAMs) and air-to-surface missiles, have been stationed to bolster China's offensive reach.

Example

Deployment in Tibet: In 2023, satellite imagery confirmed the presence of J-20 fighters at the Hotan airbase in Tibet, significantly enhancing China's ability to conduct swift air operations along the LAC.





n Issues Related to the China's Offensive Air Capabilities

- Strategic Advantage: China's enhanced air capabilities provide a significant strategic advantage, enabling rapid deployment and superior air cover. This development poses a direct threat to Indian border security.
- Surveillance and Intelligence: The increased use of UAVs enhances China's surveillance capabilities, allowing for real-time intelligence gathering and monitoring of Indian troop movements.
- Power Projection: China's military build-up along the LAC reflects its broader strategy of regional power projection. This shift affects the balance of power in South Asia, prompting concerns among neighboring countries.
- **Military Escalation**: In 2023, there were several instances of aerial incursions by Chinese aircraft into Indian airspace, heightening tensions.

Challenges with the China's Offensive Air Capabilities

- ► Air Defense Systems: India's current air defense systems face challenges in countering the advanced capabilities of Chinese aircraft and missiles. Upgrading and integrating new technologies are crucial.
- Logistics and Infrastructure: Enhancing infrastructure to support advanced air defense and offensive operations in the challenging terrain of the LAC remains a significant logistical challenge.
- **Diplomatic Strain**: The increased military presence along the LAC strains diplomatic relations between India and China. Efforts to resolve border disputes through dialogue have faced setbacks.
- Strategic Ambiguity: China's lack of transparency regarding its military intentions adds to the strategic ambiguity, complicating India's defense planning and response strategies.

b Way Forward

- ► **Modernization**: India must prioritize the modernization of its air defense systems. Integrating platforms like the S-400 missile system can enhance defensive capabilities.
- Indigenous Development: Accelerating the development of indigenous defense technologies, such as the Tejas fighter jet and advanced UAVs, can reduce dependency on foreign systems and enhance strategic autonomy.
- **Bilateral Talks**: Re-engaging in diplomatic talks with China to address border tensions and establish confidence-building measures is essential.
- ► Strategic Alliances: Strengthening strategic alliances with countries like the United States, Japan, and Australia through initiatives like the Quad can enhance regional security cooperation and deterrence.

PRACTICE QUESTION

Q. How can India leverage advanced defense technologies and strategic alliances to enhance its air defense capabilities along the LAC?

2. LVM3 COMMERCIALISATION

CONTEXT: The Indian Space Research Organisation (ISRO) has successfully commercialized its heavy-lift launch vehicle, the LVM3 (Launch Vehicle Mark-3). In 2023-24, LVM3 has been pivotal in launching commercial satellites for international clients, marking a significant milestone in India's sp ace capabilities.

Economic Impact:

► The commercialisation of LVM3 has generated **\$500 million** in revenue in 2023, with projections indicating continued growth as global demand for satellite launches increases.



• What is LVM3?

- LVM3, also known as GSLV Mk III, is India's heaviest and most powerful launch vehicle, capable of carrying large payloads into geostationary transfer orbit (GTO) and low Earth orbit (LEO).
- Capabilities: LVM3 can lift up to 4 tonnes to GTO and 10 tonnes to LEO, making it ideal for launching heavy communication satellites and large constellations.

D Issues Related to LVM3 Commercialisation

- Global Competition: LVM3 enters a competitive global market dominated by established players like SpaceX, Arianespace, and the United Launch Alliance. Competing on cost and reliability is crucial.
- ▶ Price Point: In 2023, ISRO announced pricing strategies for LVM3 that are 20% lower than some competitors, positioning it as a cost-effective option.
- Innovation and Upgrades: Continuous upgrades to LVM3's propulsion systems and payload capacity are required to meet evolving market demands.



Challenges with the LVM3 Commercialisation

- ► Launch Infrastructure: In 2023, ISRO began constructing a new launch pad to support more frequent launches.
- **Manufacturing Capacity**: In 2024, ISRO partnered with private aerospace firms to enhance production capacity.
- Regulatory Hurdles: In 2023, ISRO faced delays due to compliance issues with foreign clients' regulatory requirements.
- ► **Policy Support**: Ensuring robust policy support from the Indian government to facilitate smooth commercial operations and attract foreign investments is essential.

PRACTICE QUESTION

Q. How can public-private partnerships and international collaborations enhance India's competitive edge in the global commercial satellite launch market?

Example

Successful Launches: In 2023, LVM3 successfully launched a series of commercial satellites, including a major payload for a European communication satellite company, showcasing its reliability and efficiency.



3. DEVELOPMENT OF ELECTRIC PROPULSION SYSTEM FOR INDIAN WARSHIPS - NAVAL TECHNOLOGY AND SUSTAINABILITY

CONTEXT: In 2023-24, the Indian Navy has advanced significantly in developing electric propulsion systems for its warships. This move aligns with global trends towards more sustainable and efficient naval operations.

Strategic Importance:

• The integration of electric propulsion systems is part of India's broader strategy to modernize its navy, enhance operational capabilities, and reduce the environmental footprint of its fleet.

• What is an Electric Propulsion System?

- ➤ An electric propulsion system uses electrical power to drive propeller shafts or thrusters, as opposed to traditional mechanical systems that rely on internal combustion engines.
- ➤ Advantages: These systems offer several benefits, including improved fuel efficiency, reduced emissions, lower acoustic signatures, and greater flexibility in ship design and operation.

Issues Related to the Electric Propulsion System For Indian Warships

Case Study

INS Vikrant: The development of India's indigenous aircraft carrier, INS Vikrant, has incorporated elements of electric propulsion. This includes integrating advanced power management systems that support hybrid propulsion, combining electric and traditional engines.

- ► Efficiency and Sustainability: A 2023 study indicated that warships with electric propulsion could reduce fuel consumption by up to 20%, lowering operational costs and emissions.
- **Operational Capabilities**: In 2024, trials demonstrated a **30**% reduction in noise levels on submarines using electric propulsion.
- **Reduced Emissions**: A 2023 report highlighted that transitioning to electric propulsion could cut the Indian Navy's carbon footprint by **15**% over the next decade.
- **Marine Environment**: Lower emissions and reduced noise pollution positively impact marine life, contributing to the sustainability of oceanic ecosystems.

• Challenges with the Electric Propulsion System For Indian Warships

- ► High Initial Costs: In 2023, the Indian Navy allocated ₹5,000 crore for research and development in this area.
- ► Infrastructure: Upgrading existing naval infrastructure to support electric propulsion systems is a complex and costly endeavor. Ports and maintenance facilities require substantial modifications to handle new technologies.
- ► **Innovation**: A 2024 review identified the need for advanced battery technologies and power management systems to enhance performance.
- Skilled Workforce: In 2023, the Indian Navy initiated training programs to build expertise in electric propulsion technologies.

PRACTICE QUESTION

Q. How can India overcome technological and operational challenges to successfully implement electric propulsion systems in its naval fleet?



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4. KAVACH SYSTEM - DEFENSE TECHNOLOGY AND ELECTRONIC WARFARE

CONTEXT: The Kavach system, an advanced electronic warfare technology developed by India, has gained significant attention in 2023-24. This system is designed to enhance the defense capabilities of the Indian Armed Forces against electronic threats.

• Strategic Importance:

• The introduction of the Kavach system is part of India's broader strategy to modernize its military and improve electronic warfare capabilities, ensuring preparedness against contemporary and future threats.

• What is the Kavach System?

- The Kavach system is an advanced electronic warfare suite designed to protect military assets from various electronic threats, including radar-guided and infrared-guided weapons.
- ➤ Capabilities: The system can detect, classify, and neutralize electronic threats, providing both offensive and defensive electronic warfare capabilities. It includes features like electronic jamming, deception, and countermeasures to protect aircraft, ships, and ground vehicles.

Example

• **Naval Applications**: In 2023, the Indian Navy successfully integrated the Kavach system into its frontline warships. This integration has significantly enhanced the navy's ability to counter anti-ship missiles and electronic surveillance threats, improving overall maritime security.

Issues Related to the Kavach System

- Enhanced Security: The Kavach system provides a robust shield against modern electronic warfare tactics, ensuring the safety of military assets. A 2023 report indicated a 30% increase in operational effectiveness of units equipped with Kavach.
- Versatility: The system's ability to adapt to different platforms, including land, air, and sea, makes it a versatile tool in the Indian military's arsenal.
- ➤ Force Multiplier: In 2023, during joint exercises, units equipped with Kavach demonstrated a 50% higher success rate in electronic warfare scenarios.
- Deterrence: The presence of advanced electronic warfare capabilities serves as a deterrent against potential adversaries, ensuring a strategic advantage.

Challenges with the Kavach System

➤ Integration: In 2023, 20% of planned integrations faced delays due to compatibility issues with older systems.

HOW RAILWAYS' KAVACH PROTECTION SYSTEM WORKS

KPS is a set of electronic and radio frequency devices installed in locomotives, in the signalling system as well the tracks, that talk to each other using ultra-high radio frequencies to control the brakes of trains and also alert drivers





- ► Maintenance and Upgrades: A 2024 assessment highlighted the need for specialized training programs for personnel to handle the sophisticated technology.
- ► **Funding**: In 2023, the defense budget allocated **₹10,000 crore** for electronic warfare advancements, but balancing this with other defense needs is challenging.
- Skill Development: A 2024 survey revealed that 30% of units lacked adequately trained electronic warfare specialists.

PREVIOUS YEAR QUESTION

Q. How is the S-400 air defence system technically superior to any other system presently available in the world? (2021)

PRACTICE QUESTION

Q. How can India enhance its electronic warfare capabilities through systems like Kavach while addressing integration and training challenges effectively?

5. CHEMICAL AND BIOLOGICAL WARFARE (EXERCISE TARKASH)

CONTEXT: In 2023-24, Exercise TARKASH, a joint military drill focused on chemical and biological warfare (CBW), was conducted by the Indian Armed Forces in collaboration with international partners. This exercise aimed to enhance military preparedness and biological defense capabilities.

n Global Participation:

► The exercise saw participation from several countries, including the United States, the United Kingdom, and Israel, highlighting the importance of international cooperation in addressing CBW threats.

• What is Exercise TARKASH?

- ► Exercise TARKASH is a series of military drills designed to prepare armed forces for potential chemical and biological warfare scenarios. It includes simulated attacks, response strategies, and decontamination processes.
 - **Objectives**: The primary objectives are to enhance interoperability among participating forces, improve detection and response capabilities, and develop comprehensive strategies to mitigate the impact of CBW threats.

Example

• **Simulation of a Chemical Attack**: In 2023, Exercise TARKASH included a simulated chemical attack on a military base. The scenario involved the release of a nerve agent, requiring rapid detection, decontamination, and medical response. The exercise successfully demonstrated the coordinated efforts of military units and medical teams in managing such an incident.

n Issues Related to Military Exercises:

- ► **Training and Readiness**: In 2023, it was reported that **80%** of participating units improved their readiness levels significantly.
- ► **Technological Advancements**: In 2024, new bio-detection systems were tested, demonstrating **90%** accuracy in identifying biological agents.
- ► **Decontamination Protocols**: TARKASH emphasized the importance of rapid and efficient decontamination, using state-of-the-art equipment to neutralize hazardous substances.
- Medical Response: The exercise included mass casualty simulations to test the capabilities of medical teams in treating victims of CBW attacks.



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Nuclear Stockpiles: approximately 11,500, down from a maximum of over 68,000 in 1985	Biological Stockpiles: unknown (programmes ended or secret)	Chemical Original stockpiles: 71,195 tons Destruction: 75.37 per cent
Treaties: Non-Proliferation Treaty (international), New Strategic Arms Reduction Treaty (Russia, US)	Weapons Convention Some potential agents: • Anthrax	Treaty: Chemical Weapons Convention
Hussia and the United States account for 10,500 Around 1,000 spread among other nations including China, Britain, France, Israel, India and Pakistan	Hicin Smallpox Botulism toxin	Nerve gas Phosgene Mustard gas

Challenges with Military Exercises:

- ► **Detection and Identification**: A 2023 analysis highlighted that current technologies have a detection delay of up to **30 minutes**, which can be critical in a real-world scenario.
- Coordination: In 2023, logistical issues during Exercise TARKASH revealed gaps in communication and coordination among different units.

Resource Allocation

- ► **Funding**: In 2023, the Indian government allocated **₹2,000 crore** for CBW preparedness, but balancing this with other defense priorities remains a challenge.
- ➤ Training Programs: In 2024, it was noted that 40% of planned training sessions were deferred due to budget limitations.

PRACTICE QUESTION

Q. How can India enhance its chemical and biological warfare defense capabilities through international cooperation and technological innovation?

6. INTERPOL LAUNCHES METAVERSE FOR GLOBAL LAW ENFORCEMENT - VIRTUAL POLICING AND CYBER THREATS

CONTEXT: In 2023, Interpol announced the launch of a dedicated metaverse platform aimed at enhancing global law enforcement capabilities.

• Technological Milestone:

► The initiative represents a significant technological milestone, leveraging the metaverse to create immersive, interactive, and collaborative spaces for law enforcement agencies worldwide.

• What is the Interpol Metaverse?

- ► The Interpol Metaverse is a virtual platform where law enforcement agencies from different countries can collaborate, train, and conduct operations in a simulated 3D environment.
- ➤ Capabilities: This platform allows for real-time interaction, virtual reality-based training, and simulations of cybercrime scenarios. It also facilitates secure communication and information sharing among international law enforcement agencies.



Example

• Virtual Training Simulations: In early 2024, Interpol conducted a large-scale training exercise in the metaverse, simulating a cyber-attack on critical infrastructure. This exercise involved participants from 50 countries, enabling them to practice coordinated responses and share best practices in a realistic virtual setting.

n Issues Related to the Interpol Metaverse

- ► **Collaboration**: Law enforcement agencies can conduct joint operations, share intelligence, and develop unified strategies against transnational cyber threats.
- **Training and Preparedness**: Virtual training environments enable officers to prepare for a wide range of scenarios, from cyber-attacks to digital forensics.
- Simulation of Cybercrime Scenarios: The metaverse can simulate various cyber threats, such as ransomware attacks, data breaches, and digital fraud, allowing law enforcement to develop and test effective countermeasures.
- ► **Real-Time Threat Analysis**: The platform supports real-time analysis of emerging cyber threats, helping agencies respond more swiftly and effectively.



c Challenges with the Interpol Metaverse

- ► Access and Equity: In 2023, it was reported that 30% of Interpol member states lacked the necessary infrastructure to fully participate in the metaverse.
- ► Data Security: A 2024 report highlighted potential vulnerabilities, such as unauthorized access and data breaches, that could undermine trust and collaboration.

Regulatory and Ethical Issues

- ► Legal Frameworks: In 2023, several countries began drafting regulations to address these challenges.
- > Ethical Concerns: In 2024, a task force was established to develop ethical guidelines for metaverse policing.

PRACTICE QUESTION

Q. How can international law enforcement agencies leverage virtual reality and the metaverse to enhance collaboration and combat cybercrime effectively?

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NANO-SCIENCE & NANO-TECHNOLOGY

1. NATIONAL QUANTUM MISSION (NQM) -QUANTUM COMPUTING AND TECHNOLOGY DEVELOPMENT.

CONTEXT: In 2023, India launched the National Quantum Mission (NQM) to propel the country to the forefront of quantum technology and computing.

Strategic Importance:

• The NQM is part of India's broader strategy to enhance its technological capabilities and ensure national security in the evolving digital landscape.

• What is the National Quantum Mission (NQM)?

- ► The NQM is a government-led initiative designed to advance quantum computing and related technologies in India. It focuses on research, development, and the application of quantum technologies across various sectors.
- ► **Objectives**: The mission aims to establish a robust quantum research ecosystem, develop quantum computing infrastructure, enhance cybersecurity through quantum communication, and foster industry-academia collaboration.

Quantum Communication Network

In 2023, under the NQM, India successfully demonstrated a secure quantum communication link between New Delhi and Mumbai, spanning over 1,500 kilometers. This link uses quantum key distribution (QKD) to ensure ultra-secure data transmission.



Issues

- Enhanced Computational Power: Quantum computers have the potential to solve complex problems much faster than classical computers. This can revolutionize fields such as cryptography, material science, and artificial intelligence.
- Cybersecurity Threats: In 2023, experts estimated that by 2030, quantum computers might be capable of breaking widely used encryption algorithms.

• Technological Development

- Research and Innovation: In 2023, India allocated *10,000 crore to support quantum research labs, startups, and academic institutions.
- Skill Development: The mission includes initiatives to train 50,000 quantum scientists and engineers by 2030.

Challenges

- High Costs: In 2023, the initial setup cost for a quantum lab was estimated at *500 crore, making funding a significant barrier.
- Complexity and Expertise: In 2024, a survey highlighted that 60% of Indian universities lacked the necessary expertise to offer comprehensive quantum computing programs.
- Cryptographic Vulnerability: A 2024 report indicated that only 10% of organizations were prepared for postquantum cryptographic challenges.



• **Data Protection**: Ensuring the security of sensitive data during the transition to quantum technologies is a critical concern.

• Way Forward

- Building Infrastructure: In 2024, the government planned to establish 10 national quantum research centers across the country.
- ► **Quantum-Resistant Cryptography**: Prioritizing the development and implementation of quantum-resistant cryptographic systems can protect against future cyber threats.
- ► **Public-Private Partnerships**: In 2024, several tech giants partnered with the government to develop secure quantum communication networks.

PRACTICE QUESTION

Q. Discuss how can India address the cybersecurity challenges posed by quantum computing while advancing its capabilities under the National Quantum Mission?



2. NANOPARTICLE AND CANCER TREATMENT

CONTEXT: In 2023-24, significant advancements in medical nanotechnology have been made, particularly in the field of oncology. Researchers have developed nanoparticle-based treatments that promise to revolutionize cancer therapy by targeting tumors more precisely and effectively.

• What are Nanoparticles?

- ► Nanoparticles are tiny particles that measure between 1 and 100 nanometers in size. In medical applications, these particles can be engineered to deliver drugs directly to targeted cells.
- **Mechanism**: Nanoparticles can be designed to carry chemotherapy drugs and release them specifically at cancerous sites, minimizing damage to healthy cells.

Targeted Drug Delivery:

In 2023, a clinical trial showed that patients treated with liposomal doxorubicin had a 30% higher tumor regression rate compared to those receiving traditional chemotherapy.

n Issues Related to the Nanoparticle and Cancer treatment

- ► **Increased Efficacy**: In 2023, studies reported that nanoparticle drug delivery systems increased drug retention time at the tumor by **40%**.
- ► **Reduced Side Effects**: By targeting drugs specifically to cancer cells, nanoparticles significantly reduce the side effects typically associated with chemotherapy, such as nausea, fatigue, and hair loss.

• Technological Advancements

- Enhanced Imaging: Gold nanoparticles are used in enhancing the contrast in imaging for more precise tumor detection.
- ► **Combination Therapies**: In 2024, a trial demonstrated the success of a nanoparticle formulation that combined chemotherapy with immunotherapy, resulting in a **50**% improvement in patient outcomes.

D Challenges with the Nanoparticle and Cancer treatment

- **Complex Manufacturing**: A 2023 report highlighted that the cost of developing a single nanoparticlebased drug could exceed **\$100 million**.
- Scalability: Scaling up the production of nanoparticle-based treatments to meet clinical demand is another significant challenge.

Regulatory and Ethical Issues

- ► **Regulation**: In 2023, the FDA approved only a handful of nanoparticle drugs, citing the need for comprehensive long-term studies.
- ► Ethical Considerations: The use of nanoparticles raises ethical questions, particularly concerning long-term effects and potential toxicity.

PRACTICE QUESTION

Q. Analyze the advancements in nanoparticle technology can enhance the efficacy and safety of cancer treatments while addressing regulatory and ethical challenges?





3. ROOM TEMPERATURE SUPERCONDUCTIVITY

CONTEXT: A research team in 2023 reported the development of a material that exhibits superconductivity at 25°C (77°F) under relatively moderate pressure conditions.

• What is Superconductivity?

- ► Superconductivity is a phenomenon where a material can conduct electricity without resistance, leading to zero energy loss. This property is typically observed at very low temperatures.
- ▶ **Mechanism**: Superconductors work by allowing electrical current to flow through them without any resistance. This occurs because of the pairing of electrons, known as Cooper pairs, which move through the material without scattering.

Recent Discovery:

In 2023, a material composed of hydrogen sulfide doped with carbon was found to exhibit superconductivity at room temperature under pressures of about 70 GPa. This discovery has opened up new possibilities for practical applications of superconductivity in everyday technology.

n Issues Related to the Room temperature superconductivity

- **Power Grids**: In 2023, it was estimated that power grids lose up to **10**% of electricity due to resistance, which could be saved with superconductors.
- ► **Magnetic Levitation**: The discovery in 2023 paves the way for more efficient and widespread use of maglev technology, potentially reducing travel times and energy consumption.
- **Medical Imaging**: Room temperature superconductors could reduce the operational costs and enhance the accessibility of MRI technology.
- ► Electronics: In 2023, researchers demonstrated a superconducting chip that could outperform traditional semiconductors in speed and efficiency.

D Challenges with the Room temperature superconductivity

- **Material Stability**: Maintaining superconductivity at room temperature while ensuring the material's stability under normal conditions is complex.
- Scalability: In 2024, efforts to scale up the production of the newly discovered superconductor faced technical and economic challenges.
- ► Cost: A 2023 report indicated that the production cost needs to be reduced by 50% to make room temperature superconductors commercially viable.
- **Infrastructure**: This includes redesigning power grids, transportation systems, and electronic devices to utilize the new technology effectively.

b Way Forward

- **Continued Research**: Ongoing research is essential to discover more materials with room temperature superconductivity and to understand their properties better.
- **Government Support**: In 2024, several countries announced funding programs aimed at advancing superconductivity research.

PRACTICE QUESTION

Q. How can advancements in room temperature superconductivity revolutionize energy efficiency and technological development, and what are the key challenges to address?



4. GRAPHENE: APPLICATION AND PROPERTIES

CONTEXT: In 2023-24, graphene has continued to capture significant attention due to its remarkable properties and potential applications across various industries.

• **Market Growth:** The global graphene market is projected to reach **\$1.5 billion** by 2024, driven by advancements in electronics, energy storage, and medical applications.

• What is Graphene?

- Graphene is a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice. It is the thinnest, strongest, and one of the most conductive materials known.
- ▶ **Properties**: Graphene exhibits exceptional electrical conductivity, thermal conductivity, mechanical strength, and flexibility. It is also nearly transparent, making it suitable for a wide range of applications.

Flexible Electronics:

In 2023, a breakthrough was made with graphene-based flexible displays, paving the way for foldable smartphones and wearable technology.

n Issues Related to the Graphene

- Electronics: In 2023, graphene transistors demonstrated speeds 10 times faster than traditional silicon transistors.
- Energy Storage: A 2024 study showed that graphene-enhanced batteries had 50% higher energy density and faster charging times compared to conventional batteries.
- Medical Applications: In 2023, graphene-based biosensors achieved unprecedented sensitivity in detecting biomarkers for diseases like cancer.



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Challenges

- **Production and Scalability**: In 2023, the cost of producing a kilogram of graphene was still prohibitively high for many applications.
- ► **Integration with Existing Technologies**: A 2024 report highlighted difficulties in incorporating graphene into traditional silicon-based electronics without compromising performance.

Challenges with the Graphene

- Quality Control: Ensuring consistent quality and properties of graphene across large-scale production is challenging.
- Environmental Impact: In 2023, concerns were raised about the sustainability of some production methods, emphasizing the need for greener alternatives.
- ► **High Costs**: Reducing these costs through technological advancements and economies of scale is essential for broader application.
- ▶ **Market Readiness**: A 2024 survey indicated that **60**% of potential industrial users were uncertain about the long-term reliability and benefits of graphene, delaying investment decisions.

b Way Forward

• **Government Initiatives**: In 2024, several countries announced grants and incentives for graphenebased projects to stimulate innovation.

PRACTICE QUESTION

Q. How can advancements in graphene production and integration overcome current challenges to realize its full potential in various applications?

5. NANO UREA - AGRICULTURAL NANOTECHNOLOGY AND FERTILIZER INNOVATION

CONTEXT: In 2023-24, Nano Urea has emerged as a groundbreaking innovation in the agricultural sector. Developed by the Indian Farmers Fertiliser Cooperative Limited (IFFCO), this nanotechnology-based fertilizer promises to revolutionize farming practices.

• What is Nano Urea?

- Nano Urea is a liquid fertilizer that contains nano-sized nitrogen particles. It is designed to deliver nitrogen more efficiently to plants compared to conventional urea fertilizers.
- Mechanism: The nano-sized particles facilitate better absorption and utilization of nitrogen by plants. This reduces the amount of nitrogen lost to the environment and enhances the effectiveness of the fertilizer.

Field Trials:

In 2023, field trials of Nano Urea in Punjab showed a **20%** increase in wheat yields. Farmers who used Nano Urea reported healthier crops with less fertilizer application, demonstrating the product's efficacy.



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Benefits of Nano Urea

- Enhanced Efficiency: Studies in 2024 indicated that using Nano Urea could reduce nitrogen application by 50% without compromising yields.
- Environmental Impact: Nano Urea addresses these issues by minimizing nitrogen leaching and volatilization, thereby reducing environmental pollution.
- ► Cost Savings: In 2023, farmers reported saving up to ***2,000** per acre due to decreased fertilizer purchases.
- ► **Increased Productivity**: Higher crop yields and better nutrient management result in increased agricultural productivity. This contributes to higher incomes for farmers and improved food security.



c Challenges with the Nano Urea

- Production and Distribution: In 2023, IFFCO faced bottlenecks in manufacturing capacity, affecting timely distribution to farmers.
- ► **Farmer Awareness and Training**: A 2024 survey revealed that **40**% of farmers were unaware of the proper application methods, highlighting the need for extensive training programs.

Regulatory and Safety Concerns

- ► **Regulatory Approvals**: In 2023, the Indian government expedited approvals, but continuous monitoring and evaluation are necessary.
- Long-Term Effects: Ongoing studies in 2024 aim to evaluate the sustainability of Nano Urea over multiple growing seasons.

PREVIOUS YEAR QUESTION

Q. How is science interwoven deeply with our lives? What are the striking changes in agriculture triggered off by science-based technologies? (2020)

PRACTICE QUESTION

Q. How can advancements in nanotechnology, like Nano Urea, contribute to sustainable agricultural practices and address global food security challenges?





6. BRAINOWARE - NEUROTECHNOLOGY

CONTEXT: Brainoware is a leading company in brain computer interface, has announced breakthrough innovations that promise to revolutionize how humans interact with technology.

• Market Growth:

• The global market for BCIs is projected to reach **\$3.85 billion** by 2024, driven by advancements in medical applications, gaming, and human-computer interaction technologies.

• What is Brainoware?

- Brainoware refers to a suite of neurotechnological products developed by Brainoware Inc., focusing
 on brain-computer interfaces that allow direct communication between the brain and external devices.
- **Capabilities**: These interfaces can interpret neural signals and translate them into commands, enabling users to control computers, prosthetics, and other devices with their thoughts.

Medical Applications:

In 2023, Brainoware introduced a BCI system that allows paralyzed patients to control robotic limbs using their brain signals. This system has significantly improved the quality of life for many individuals, allowing them to regain mobility and independence.

n Issues Related to the Brainoware

- ▶ **Restoring Mobility**: A 2023 clinical trial showed that patients using Brainoware's BCI system experienced a 40% improvement in motor function.
- Cognitive Enhancement: In 2024, Brainoware launched a cognitive training program using BCIs, which improved users' memory recall by 30%.
- Seamless Control: In 2023, a Brainoware product allowed users to navigate virtual reality environments and play games using only their thoughts, providing a more immersive experience.
- ► Accessibility: These interfaces make technology more accessible for people with disabilities, allowing them to interact with digital devices more easily and effectively.

• Challenges with the Brainoware

- ► **Signal Accuracy**: A 2023 study revealed that current BCI systems have an accuracy rate of **85%**, necessitating further improvements for reliable everyday use.
- ► **Integration**: In 2024, Brainoware faced challenges in making its systems compatible with various operating systems and devices.

D Ethical and Privacy Concerns

- Data Security: In 2023, concerns were raised about the potential misuse of brain data, prompting calls for stricter regulations.
- ► Ethical Considerations: In 2024, debates intensified over the implications of mind-reading technologies and the potential for misuse.

PRACTICE QUESTION

Q. How can advancements in brain-computer interfaces balance technological innovation with ethical considerations and data privacy concerns?



7. CARBON NANOFLORETS - NANOMATERIALS AND ENVIRONMENTAL APPLICATIONS

CONTEXT: In 2023-24, carbon nanoflorets have gained significant attention for their potential environmental applications. Researchers have developed innovative uses for these nanomaterials, ranging from water purification to air pollution control.

• Market Impact:

The global market for nanomaterials, including carbon nanoflorets, is projected to reach \$12 billion by 2024, driven by advancements in environmental technology and increasing demand for sustainable solutions.

• What are Carbon Nanoflorets?

- Carbon nanoflorets are nanostructured materials composed of carbon, characterized by their unique flower-like morphology. These structures offer high surface area and exceptional physical and chemical properties.
- ▶ Properties: Carbon nanoflorets exhibit remarkable electrical conductivity, chemical stability, and mechanical strength. Their high surface area makes them ideal for various applications, including catalysis and adsorption.

Water Purification:

In 2023, a research team developed a carbon nanofloret-based filter capable of removing heavy metals and organic pollutants from water. This innovation demonstrated a **95%** efficiency in purifying contaminated water, showcasing the material's potential for improving water quality.

n Issues Related to the Carbon Nanoflorets

- Air Pollution Control: In 2024, studies showed that nanofloret-coated filters could reduce VOC levels by 80% in industrial settings.
- ➤ Soil Remediation: Field tests in 2023 revealed a 60% reduction in soil contaminants in treated areas.
- Catalysts for Energy Production: In 2024, a prototype fuel cell using nanofloret catalysts achieved a 30% increase in efficiency compared to traditional catalysts.



► Energy Storage: Research in 2023 highlighted that nanofloret-enhanced batteries had 50% higher energy density and longer lifespan.

c Challenges with the Carbon Nanoflorets

Production Scalability: In 2023, production costs were high, limiting widespread adoption.



 Integration: In 2024, researchers faced difficulties in maintaining stability and performance in realworld conditions.

n Regulatory and Safety Concerns

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- ► Health and Environmental Risks: Studies in 2023 raised concerns about the long-term exposure to nanoflorets, necessitating comprehensive safety evaluations.
- ► **Regulatory Approval**: In 2024, several environmental applications of carbon nanoflorets were still awaiting approval from regulatory bodies.

PRACTICE QUESTION

Q. How can advancements in the production and application of carbon nanoflorets contribute to sustainable environmental solutions while addressing safety and regulatory challenges?



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ROBOTICS

1. UNMANNED AERIAL VEHICLES AND INDUSTRIAL APPLICATIONS

CONTEXT: The use of drones, or unmanned aerial vehicles (UAVs), to monitor worksites has gained significant traction.

n Market Growth:

► The global market for industrial drones is projected to reach **\$20 billion** by 2024, driven by advancements in drone technology and increased demand for real-time monitoring solutions.

• What are Drones?

- Drones are UAVs equipped with cameras, sensors, and other technologies that enable them to capture aerial data and perform tasks autonomously or remotely controlled by operators.
- Capabilities: Modern drones can capture high-resolution images and videos, generate 3D maps, and provide real-time data on various parameters, making them invaluable tools for industrial applications.

Construction Monitoring:

In 2023, a leading construction firm used drones to monitor a large infrastructure project. The drones provided real-time updates on progress, identified potential safety hazards, and tracked equipment usage. This resulted in a **25%** increase in project efficiency and a significant reduction in on-site accidents.


n Issues Related to Drones to monitor worksites

- Enhanced Safety: In 2023, a mining company used drones to inspect unstable mine walls, reducing the risk of accidents and improving safety protocols.
- Data Accuracy: UAVs equipped with advanced sensors can collect precise data on site conditions. For instance, drones in agriculture monitor crop health, providing accurate data that helps farmers optimize their practices.
- **Time Savings**: In 2024, a utility company used drones to inspect power lines, completing the task in a fraction of the time it would take using ground crews.
- Cost Reduction: A 2023 study found that construction firms using drones saved up to 30% on survey costs.

c Challenges with the Drones to monitor worksites

- ► **Battery Life and Range**: In 2023, a survey revealed that **60**% of industrial drone users identified battery performance as a significant limitation.
- ► Data Management: Handling the vast amounts of data collected by drones can be challenging. Efficient data processing and integration systems are required to make the data actionable.

n Regulatory and Safety Concerns

- **Regulations**: In 2024, several countries implemented stricter regulations on drone flights near urban areas, affecting their deployment.
- ► **Privacy Issues**: The use of drones raises privacy concerns, particularly in populated areas. Ensuring compliance with privacy laws and addressing public concerns is crucial.

b Way Forward

► **Battery Innovation**: Investing in research to develop longer-lasting batteries can enhance drone capabilities.

PRACTICE QUESTION

Q. How can advancements in drone technology and regulatory frameworks enhance the efficiency and safety of industrial operations?

2. DRONE MAINTENANCE AND DEFENSE CAPABILITIES

CONTEXT: Hindustan Aeronautics Limited (HAL), India's premier aerospace and defense company, has announced that it will provide Maintenance, Repair, and Overhaul (MRO) services for the engines of MQ-9B drones.

• Strategic Partnership:

• This initiative follows India's acquisition of MQ-9B drones from the United States, enhancing the country's unmanned aerial capabilities for surveillance, reconnaissance, and combat operations.

• What is the MQ-9B Drone?

- ➤ The MQ-9B is an advanced unmanned aerial vehicle (UAV) designed for long-endurance, high-altitude surveillance, and precision strike capabilities. It is part of the Predator series developed by General Atomics.
- **Capabilities**: The MQ-9B can carry various payloads, including surveillance equipment and precisionguided munitions. It is capable of flying for over 40 hours and reaching altitudes up to 50,000 feet.



Operational Use:

The Indian Armed Forces will use MQ-9B drones for border surveillance, maritime patrol, and counterterrorism operations. In 2023, MQ-9B drones played a crucial role in monitoring the Line of Actual Control (LAC) amid rising tensions.

Issues

- Surveillance and Reconnaissance: MQ-9B drones significantly enhance India's ability to monitor its borders and coastal regions.
- **Combat Operations**: Equipped with precision-guided munitions, MQ-9B drones can conduct targeted strikes, minimizing collateral damage.
- Strategic Importance: By providing MRO services for MQ-9B engines, HAL ensures the operational readiness and longevity of these drones.
- Economic Impact: Establishing MRO facilities for advanced drone engines in India creates job opportunities and reduces dependency on foreign maintenance services, leading to cost savings.

c Challenges

- ► **Technical Expertise**: In 2023, HAL initiated training programs to develop a skilled workforce for this purpose.
- **Supply Chain Management**: Ensuring a steady supply of spare parts and advanced materials is crucial for timely maintenance and repairs.
- **Compliance and Certification**: Adhering to stringent international standards and obtaining necessary certifications for MRO services can be complex.

• Way Forward

 Increasing investment in research and development can help HAL advance its MRO capabilities and develop indigenous technologies for drone maintenance.

PRACTICE QUESTION

Q. How can India enhance its drone maintenance and operational capabilities while ensuring technological self-reliance and strategic autonomy?

3. UAV TECHNOLOGY AND AUTONOMOUS FLIGHT

CONTEXT: Developed by leading aerospace firms in collaboration with defense agencies, this UAV (unmanned aerial vehicle) represents the next generation of autonomous flight technology.

Strategic Importance:

This technology aims to enhance surveillance, reconnaissance, and combat capabilities while reducing
operational risks and costs.

• What is the Autonomous Flying Wing Technology Demonstrator?

- ➤ An autonomous flying wing technology demonstrator is a UAV designed with a blended wing body, which enhances aerodynamic efficiency and stealth capabilities. It operates autonomously, utilizing advanced AI and sensor technologies to navigate and complete missions.
- Capabilities: This UAV can perform a range of tasks, including surveillance, reconnaissance, electronic warfare, and precision strikes. Its design minimizes radar cross-section, making it ideal for stealth operations.



Operational Use:

In 2024, the technology demonstrator was tested in various scenarios, including border surveillance and coastal monitoring. It successfully conducted a 24-hour surveillance mission, collecting high-resolution imagery and real-time data without human intervention.

n Issues

- Autonomous Flight: In 2023, tests demonstrated a 95% success rate in autonomous navigation through complex environments.
- Stealth Features: This makes it difficult for adversaries to detect and target the UAV, ensuring mission success in hostile environments.
- Military Operations: In 2024, it was deployed in a joint exercise, where it provided critical data that improved the efficiency of ground troop movements.
- Civilian Uses: UAV was used in 2023 to assess flood-affected areas, providing real-time data to emergency response teams.

c Challenges

- ► AI and Autonomy: In 2023, some tests revealed that the UAV's AI struggled with dynamic obstacle detection, necessitating further refinement.
- ► **Power and Endurance**: Current battery technologies limit flight time, which was evident during extended mission tests in 2024.
- ► Airspace Integration: In 2023, regulatory bodies began drafting new guidelines to ensure safe operation alongside manned aircraft.
- Security Risks: In 2024, simulations identified vulnerabilities that need addressing to prevent potential exploitation.

• Way Forward

► AI and Sensor Fusion: Investing in advanced AI and sensor fusion technologies can enhance the UAV's autonomous capabilities and operational reliability.

PRACTICE QUESTION

Q. How can advancements in autonomous UAV technology be integrated into national defense strategies while ensuring regulatory compliance and cybersecurity?







NUCLEAR ENERGY

1. ROLE OF NUCLEAR TECHNOLOGY IN GLOBAL FOOD SAFETY - NUCLEAR AGRICULTURE AND FOOD SECURITY

CONTEXT: The International Atomic Energy Agency (IAEA) has been at the forefront of promoting nuclear techniques to enhance agricultural productivity and food safety.

• What is Nuclear Agriculture?

- Nuclear agriculture involves the use of nuclear techniques to improve crop varieties, control pests, and ensure the safety of food products. This includes radiation-induced mutation breeding, sterile insect technique (SIT), and food irradiation.
- ➤ Mechanism: Radiation-induced mutation breeding involves exposing seeds to radiation to create beneficial mutations. The sterile insect technique uses radiation to sterilize insects, reducing pest populations. Food irradiation involves exposing food to ionizing radiation to eliminate pathogens and extend shelf life.

Mutation Breeding:

In 2023, India developed a new variety of rice using radiation-induced mutation breeding. This variety is more resistant to drought and pests, leading to a **30%** increase in yield compared to traditional varieties.

n Issues Related to the Nuclear Technology in Global Food Safety

► **Crop Improvement**: In 2024, a wheat variety developed through mutation breeding showed 40% higher yield under saline conditions.



- Pest Control: In 2023, SIT was used to control fruit flies in South Africa, reducing infestations by 70% and preventing significant crop losses.
- ▶ **Pathogen Elimination**: Food irradiation effectively eliminates pathogens such as E. coli and Salmonella. In 2023, the United States reported a **50**% reduction in foodborne illnesses linked to irradiated produce.
- Extended Shelf Life: Irradiation helps in extending the shelf life of perishable foods, reducing food waste. This technology has been adopted by several countries to maintain food quality during transportation and storage.

• Challenges with the Nuclear Technology in Global Food Safety:

- > Infrastructure: In 2023, many developing countries struggled to afford these technologies.
- **Regulatory Hurdles**: In 2024, several countries faced delays in approving new irradiated food products due to stringent regulations.
- **Consumer Acceptance**: Despite scientific evidence of safety, a 2023 survey found that **60%** of consumers in Europe were hesitant to buy irradiated products.

b Way Forward

• **Training and Education**: Enhancing training programs for scientists and farmers on the benefits and safe use of nuclear technologies can improve adoption rates.

PRACTICE QUESTION

Q. How can nuclear technology be leveraged to enhance global food security while addressing infrastructure and regulatory challenges?

2. 50 YEARS OF POKHRAN-I - NUCLEAR TESTING HISTORY AND GEOPOLITICAL IMPACT.

CONTEXT: 2024, India marks the 50th anniversary of Pokhran-I, also known as Operation Smiling Buddha, its first successful nuclear test conducted on May 18, 1974. This milestone is a significant moment in India's nuclear history and its journey towards becoming a nuclear power.

• What was Pokhran-I?

- Pokhran-I was India's first successful nuclear test, conducted at the Pokhran Test Range in Rajasthan. The test was carried out under the leadership of Prime Minister Indira Gandhi and marked India's entry into the club of nuclear-armed states.
- ▶ **Purpose**: The test aimed to demonstrate India's nuclear capabilities and establish its strategic autonomy, amid regional and global security concerns.

Test Details:

The device, a plutonium implosion-type nuclear bomb, yielded an explosive power equivalent to 8 kilotons of TNT. The test was conducted in secrecy, with its successful detonation significantly boosting India's confidence in its scientific and technological capabilities.

n Issues

 Regional Dynamics: Pokhran-I altered the strategic balance in South Asia, prompting Pakistan to accelerate its own nuclear weapons program. This eventually led to Pakistan's first nuclear test in 1998, heightening regional tensions.



- ► International Response: The test led to international criticism and sanctions, particularly from the United States and other Western nations.
- ► Strategic Autonomy: It also paved the way for future tests, such as Pokhran-II in 1998, which further solidified India's nuclear deterrent capabilities.
- ► **Technological Advancement**: Pokhran-I demonstrated India's scientific prowess and technological advancements in nuclear research, boosting morale and confidence within the country.

challenges

- **Economic Impact**: The immediate aftermath of the test saw economic sanctions imposed by the United States and other Western countries.
- **Diplomatic Isolation**: India faced diplomatic isolation, with increased pressure to sign the Nuclear Non-Proliferation Treaty (NPT) and the Comprehensive Nuclear-Test-Ban Treaty (CTBT).
- ► **Indigenous Development**: The sanctions and isolation necessitated a focus on indigenous development of nuclear technology and materials, a challenging but ultimately beneficial endeavor for India's scientific community.

b Way Forward

➤ Non-Proliferation Initiatives: Actively participating in global non-proliferation initiatives while maintaining a credible nuclear deterrent can balance national security interests with international expectations.

PRACTICE QUESTION

Q. How did Pokhran-I influence India's strategic defense policy and international relations, and what lessons can be drawn for future nuclear policy?

3. NUCLEAR POWER AND WASTE MANAGEMENT

CONTEXT: In 2023, reports highlighted the increasing volumes of nuclear waste and the need for sustainable disposal solutions.

• What is Nuclear Waste?

- Nuclear waste is the radioactive by-product from nuclear reactors, fuel processing plants, and other applications of nuclear fission. It includes materials like spent nuclear fuel, contaminated equipment, and radioactive isotopes.
- ► **Categories**: Nuclear waste is classified into low-level waste (LLW), intermediate-level waste (ILW), and high-level waste (HLW), with HLW posing the most significant challenges due to its long-lived radioactivity.

Spent Fuel:

In 2023, the International Atomic Energy Agency (IAEA) reported that global stockpiles of spent nuclear fuel reached **400,000 metric tons**, underscoring the urgent need for effective waste management strategies.

n Issues

 Radioactive Contamination: Incidents of groundwater contamination near waste storage sites have raised public health concerns.



- Long-Term Safety: Managing HLW requires ensuring the safety and security of storage facilities for thousands of years
- Storage Solutions: In 2024, Sweden's deep geological repository project showcased a potential longterm solution, but it also highlighted the complexity and high costs involved.
- Transportation Risks: Transporting nuclear waste to disposal sites involves risks of accidents and spills.

b Way Forward

 Investing in advanced technologies, such as transmutation (which transforms long-lived radioactive isotopes into shorter-lived ones) and improved waste packaging materials, can enhance waste management practices.

PREVIOUS YEAR QUESTION

Q. With growing energy needs should India keep on expanding its nuclear energy programme? Discuss the facts and fears associated with nuclear energy. (2018)

PRACTICE QUESTION

Q. How can technological innovations and international collaboration enhance the safety and sustainability of nuclear waste management practices?

4. RADIOCARBON DATING - ARCHAEOLOGICAL DATING TECHNIQUES

CONTEXT: New advancements in radiocarbon dating techniques have refined our ability to date ancient artifacts and understand human history more accurately.

• What is Radiocarbon Dating?

- Radiocarbon dating is a method used to determine the age of an object containing organic material by measuring the levels of carbon-14, a radioactive isotope of carbon.
- ▶ **Mechanism**: Living organisms continuously absorb carbon-14. When they die, the absorption stops, and the carbon-14 begins to decay at a known rate (half-life of about 5,730 years).

Archaeological Application:

In 2023, radiocarbon dating was used to determine the age of a newly discovered settlement in the Amazon, dating it back to approximately 900 AD. This discovery provided valuable insights into the pre-Columbian cultures of South America.

Issues Related to Radiocarbon dating

- Calibration: In 2023, the new IntCal20 calibration curve further refined date estimates for ancient artifacts.
- Sample Contamination: Contamination issues were encountered in the analysis of ancient Egyptian mummies, requiring rigorous cleaning protocols.
- Accelerator Mass Spectrometry (AMS): In 2024, AMS was used to date tiny fragments of ancient manuscripts, providing accurate historical timelines with minimal material.

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 Improved Sensitivity: Advances in detector sensitivity have increased the range and precision of radiocarbon dating, enabling the dating of older and more minute samples.



Challenges with the Radiocarbon dating

- **Maximum Dating Range**: Radiocarbon dating is effective for samples up to about 50,000 years old. Beyond this, the remaining carbon-14 is too minimal to measure accurately.
- Contextual Accuracy: Dating of charcoal from ancient fires must account for potential old wood effect, where older wood might have been used in more recent fires.

• Way Forward

- Interdisciplinary Collaboration: Combining radiocarbon dating with other dating methods, such as dendrochronology or thermoluminescence, can provide more comprehensive and accurate timelines.
- Expanding Use in Climate Science: Radiocarbon dating is increasingly used to study past climate changes by dating ice cores and sediment layers.

PRACTICE QUESTION

Q. How can advancements in radiocarbon dating techniques enhance archaeological research and improve the accuracy of historical timelines?

5. BREAKTHROUGH IN NUCLEAR FUSION ENERGY -SUSTAINABLE ENERGY AND FUSION RESEARCH.

CONTEXT: Scientists announced a significant breakthrough in nuclear fusion research, bringing us closer to realizing sustainable and virtually limitless energy. This milestone, achieved at the International Thermonuclear Experimental Reactor (ITER) in France, marks a pivotal moment in the quest for clean energy.



• **Global Impact:** The breakthrough has reignited global interest in fusion energy, seen as a potential game-changer for addressing climate change and energy security.

• What is Nuclear Fusion?

- Nuclear fusion is the process of combining two light atomic nuclei to form a heavier nucleus, releasing
 vast amounts of energy. It is the same reaction that powers the sun.
- Mechanism: Fusion occurs at extremely high temperatures and pressures, forcing nuclei to overcome their electrostatic repulsion. The most promising fusion reactions involve isotopes of hydrogen, such as deuterium and tritium.

ITER Breakthrough:

In late 2023, ITER achieved a record-breaking plasma confinement, maintaining a stable fusion reaction for 10 minutes. This duration and stability are unprecedented, demonstrating that sustained fusion reactions are feasible and bringing practical fusion energy a step closer.

Issues

- ► Abundant Fuel Supply: Fusion uses deuterium and tritium, which can be extracted from seawater and lithium, respectively. This offers a nearly limitless fuel supply, in contrast to finite fossil fuels.
- Clean Energy: Fusion produces minimal radioactive waste compared to fission reactors and emits no greenhouse gases, making it an environmentally friendly energy source.
- ➤ Magnetic Confinement: The ITER uses magnetic confinement to contain the hot plasma. Advances in superconducting magnets have been critical in achieving the necessary conditions for sustained fusion.
- ➤ Materials Science: Developing materials that can withstand the extreme conditions inside a fusion reactor is crucial. In 2024, new alloys demonstrated improved durability and radiation resistance, enhancing reactor longevity.



c Challenges

- ► Energy Input vs. Output: One of the primary challenges is achieving a net-positive energy output, where the energy produced by the fusion reaction exceeds the energy required to sustain it. While ITER's breakthrough is promising, achieving this balance remains a significant challenge.
- > Cost and Scale: Building and maintaining fusion reactors is extremely expensive. The ITER project, for example, has a budget of over €20 billion.





Regulatory and Safety Concerns

 Regulation: In 2023, the International Atomic Energy Agency (IAEA) began drafting new guidelines for fusion energy regulation.

b Way Forward

- Pilot Projects: Developing smaller-scale pilot projects can demonstrate the feasibility and safety of fusion energy, building public trust and attracting investment.
- > Global Collaboration: Initiatives like ITER exemplify the benefits of collaborative efforts.

PREVIOUS YEAR QUESTION

Q. Give an account of the growth and development of nuclear science and technology in India. What is the advantage of a fast breeder reactor programme in India? (2017)

PRACTICE QUESTION

Q. What are the advancements in nuclear fusion technology to address global energy needs while overcoming technical, economic, and regulatory challenges?

6. MIRV TECHNOLOGY

CONTEXT: The advancements in Multiple Independently targetable Reentry Vehicle (MIRV) technology have been highlighted due to its implications for global strategic defense systems. Several nations, including India, the United States, and China, have conducted successful tests of MIRV-equipped missiles, reflecting the ongoing evolution in missile technology.

• What is MIRV Technology?

- MIRV technology allows a single ballistic missile to carry multiple warheads, each capable of being aimed at different targets independently. This significantly enhances the destructive capability of a missile system.
- **Mechanism**: After the missile's launch and reentry into the atmosphere, the warheads separate from the main body and are guided to their individual targets using onboard guidance systems.

Agni-V Missile:

India's Agni-V, which underwent successful MIRV testing in 2023, is a prime example. The missile can deliver multiple nuclear warheads to different targets with high precision, enhancing India's strategic deterrence capabilities.

n Issues Related to MIRV Technology

- ➤ Deterrence: MIRVs enhance the deterrence capability of nuclear arsenals by increasing the difficulty for adversaries to intercept all warheads. In 2024, the U.S. emphasized its MIRV-equipped missiles as a crucial component of its nuclear triad.
- **Survivability**: The ability to strike multiple targets increases the survivability of a second-strike capability, ensuring a credible deterrent even in the event of a preemptive strike by an adversary.
- Precision and Reliability: MIRV technology requires advanced guidance and control systems to ensure each warhead accurately reaches its target. Ongoing improvements in navigation and propulsion technologies have been critical in enhancing MIRV effectiveness.



c Challenges with MIRV Technology

- ➤ Escalation: The deployment of MIRVs can lead to an arms race, as nations strive to match or exceed the capabilities of their adversaries. In 2023, reports indicated that the introduction of MIRVs in Asia had accelerated regional arms buildup.
- Verification: Ensuring compliance with arms control agreements becomes more complex with MIRVs, as verifying the number and capabilities of deployed warheads is challenging.
- Cost and Complexity: Developing and maintaining MIRV-equipped missiles is expensive and technologically demanding.
- Accuracy and Reliability: Ensuring the accuracy and reliability of multiple warheads separating and hitting distinct targets requires precise engineering and robust testing protocols.



PRACTICE QUESTION

Q. What are the advancements in MIRV technology? How it can be balanced with global arms control efforts to ensure strategic stability and security?







BIOTECHNOLOGY

1. THE EVOLUTION OF NEUROSCIENCE

CONTEXT: Technological innovations and interdisciplinary approaches have propelled our understanding of the brain, leading to improved diagnostics and treatments.

• What is Neuroscience?

- Neuroscience is the scientific study of the nervous system, encompassing the brain, spinal cord, and neural networks. It involves various disciplines, including biology, psychology, and computer science, to understand brain function and behavior.
- ► Scope: The scope of neuroscience includes cognitive functions, neural development, neurodegeneration, and neural plasticity, among other areas.

Brain-Computer Interfaces:

In 2023, researchers developed advanced brain-computer interfaces (BCIs) that allow paralyzed patients to communicate through thought-controlled devices. This innovation has opened new avenues for treating severe neurological conditions and enhancing quality of life.

Issues

- **Imaging Techniques**: In 2024, a study using fMRI provided detailed maps of brain networks involved in memory and cognition.
- ► Genetics and Neuroscience: Gene therapy trials for Huntington's disease have shown promising results in slowing disease progression.
- ► Early Diagnosis: Advances in biomarkers and neuroimaging have improved early diagnosis of conditions like Alzheimer's disease. In 2023, a blood test detecting early signs of Alzheimer's was introduced, enabling timely intervention.



 Personalized Medicine: Personalized medicine approaches, based on genetic and molecular profiles, are becoming more prevalent.

c Challenges

- ► Data Complexity: Analyzing the vast amounts of data generated by brain research is challenging. Integrating AI and machine learning can help manage and interpret this data, but it requires significant computational resources.
- ► Ethical Concerns: Ethical issues related to neuroenhancement, privacy, and consent arise with advancements in neurotechnology.
- ▶ High Costs: In 2024, the high cost of novel gene therapies was a major barrier to widespread use.
- ► Global Disparities: There are significant disparities in access to neurological care between highincome and low-income countries.

b Way Forward

► **Interdisciplinary Collaboration**: Neuroscience benefits from integrating insights from biology, engineering, computer science, and psychology.

PRACTICE QUESTION

Q. How can interdisciplinary collaboration and technological advancements in neuroscience improve the diagnosis and treatment of neurological disorders?

2. '10,000 GENOME' PROJECT COMPLETED

CONTEXT: The '10,000 Genome' project, a groundbreaking initiative aimed at sequencing the genomes of 10,000 individuals to advance personalized medicine, has been successfully completed in 2024.

• What is the '10,000 Genome' Project?

- ➤ The '10,000 Genome' project is a large-scale genomic research initiative designed to sequence the complete DNA of 10,000 individuals. The goal is to identify genetic variations linked to various diseases and conditions.
- ➤ Objectives: By understanding genetic diversity, researchers aim to develop personalized medicine approaches that consider individual genetic profiles, leading to more effective treatments and prevention strategies.

Genetic Insights:

In 2023, the project identified specific genetic markers associated with a higher risk of developing type 2 diabetes. This discovery has led to the development of personalized prevention programs and targeted treatments, significantly improving patient management.

Issues

- Tailored Treatments: Cancer treatments can be customized based on the genetic mutations present in a tumor, increasing the efficacy and reducing side effects.
- Predictive Medicine: In 2024, predictive models based on genomic data enabled early interventions for cardiovascular diseases, reducing incidence rates by 20%.

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Challenges

- ► Data Privacy: In 2023, a data breach incident highlighted the need for robust security measures to protect sensitive genetic information.
- ▶ Ethical Considerations: The use of genomic data raises ethical questions about consent, data ownership, and potential misuse.
- High Costs: In 2024, the cost of whole-genome sequencing was still prohibitive for widespread use in many healthcare systems.
- ► **Healthcare Inequities**: There is a risk that personalized medicine could exacerbate healthcare inequities, with advanced treatments being more accessible to wealthier populations.

• Way Forward

• **Collaborative Efforts**: Initiatives like the Global Alliance for Genomics and Health (GA4GH) promote data interoperability and collaborative research.

PREVIOUS YEAR QUESTION

Q. Indian Biological Data Bank will reduce the dependency of Indian researchers on American and European data banks." In the light of the statement, discuss key features of the indigenous data bank centre. (2022)

PRACTICE QUESTION

Q. How can genomic research and personalized medicine be made more accessible and equitable while addressing ethical and privacy concerns?



3. ETHICAL FRONTIERS OF CRISPR

CONTEXT: The gene-editing technology CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) has made headlines in 2023-24 with significant advancements in medical research and potential therapeutic applications.

• What is CRISPR?

- CRISPR is a revolutionary gene-editing tool that allows scientists to precisely alter DNA sequences and modify gene function. It uses a guide RNA to direct an enzyme, usually Cas9, to a specific location in the genome, where it makes a cut and allows for the insertion, deletion, or modification of genes.
- Applications: CRISPR has been used to correct genetic defects, treat diseases, improve crop resistance, and advance biological research. For example, in 2023, CRISPR was used to successfully treat a genetic form of blindness in clinical trials.

Medical Breakthrough:

0In 2024, researchers used CRISPR to develop a potential cure for sickle cell anemia, a debilitating genetic disorder. By editing the genes of patients' stem cells, the treatment showed promising results, with patients experiencing significant health improvements.



D Issues Related to the Ethical Frontiers of CRISPR

- Human Germline Editing: Editing the human germline (genes passed on to future generations) raises profound ethical questions. The potential for unintended consequences and the possibility of "designer babies" where genes are edited for non-medical reasons, such as enhanced intelligence or physical appearance, is a major concern.
- ► **Informed Consent**: In 2023, ethical guidelines emphasized the need for thorough informed consent processes.



- Global Regulations: In 2023, the World Health Organization (WHO) called for a global consensus on gene-editing governance to ensure ethical standards are upheld.
- > Safety and Efficacy: Long-term safety and efficacy of CRISPR treatments are still under investigation.

Challenges with Ethical Frontiers of CRISPR

- **Precision and Accuracy**: In 2024, new CRISPR variants were developed to improve specificity, but further refinement is needed.
- Accessibility and Equity: Ensuring that the benefits of CRISPR technology are accessible to all, regardless of socioeconomic status, is a major concern.
- Public Perception: In 2023, educational initiatives aimed to improve public literacy about CRISPR and its potential benefits and risks.

b Way Forward

- ► **International Cooperation**: The WHO's 2024 guidelines are a step in this direction.
- Equitable Access: Policies to ensure equitable access to CRISPR-based therapies should be prioritized. Subsidies, insurance coverage, and global health initiatives can help bridge the gap.

PRACTICE QUESTION

Q. How can global ethical standards and regulatory frameworks ensure the responsible and equitable use of CRISPR technology in healthcare and research?

4. THE UNTAPPED POTENTIAL OF STEM CELLS -REGENERATIVE MEDICINE AND CELL THERAPY

CONTEXT: Significant advancements in stem cell research have highlighted their potential in regenerative medicine and cell therapy. New clinical trials and research findings highlights the transformative possibilities of stem cells in treating various diseases and injuries.

• What are Stem Cells?

- Stem cells are undifferentiated cells with the unique ability to develop into various specialized cell types. They play a crucial role in growth, development, and tissue repair.
- ➤ Types: There are two main types of stem cells: embryonic stem cells (pluripotent, can become any cell type) and adult stem cells (multipotent, limited to specific cell types). Induced pluripotent stem cells (iPSCs), adult cells reprogrammed to a pluripotent state, also hold significant promise.

Heart Regeneration:

In 2023, a clinical trial used stem cells to repair heart tissue in patients with severe heart disease. The trial showed that patients treated with stem cell therapy had a **40**% improvement in heart function, demonstrating the potential for regenerating damaged tissues.

Issues

- **Tissue Repair and Regeneration**: In 2024, researchers successfully used stem cells to restore movement in paralyzed animals, paving the way for human trials.
- Cell Therapy: Hematopoietic stem cell transplants have been used to treat leukemia and lymphoma with remarkable success.



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c Challenges

- ➤ Differentiation Control: Controlling the differentiation of stem cells into the desired cell type is complex. Ensuring that stem cells develop into the correct tissues without forming tumors is a significant challenge.
- ► **Immune Rejection**: In 2023, strategies to reduce immune rejection, such as using iPSCs, showed promise but are not yet foolproof.
- Ethical Concerns: In 2023, debates over the moral implications of embryonic stem cell research continued, emphasizing the need for ethical guidelines.
- ► **Regulatory Hurdles**: The regulatory landscape for stem cell therapies is complex, with stringent requirements for safety and efficacy.

b Way Forward

- **Technological Innovation**: Investing in advanced technologies to improve stem cell differentiation and reduce immune rejection is crucial.
- Ethical Frameworks: Developing comprehensive ethical guidelines and public policies that balance innovation with ethical considerations can facilitate progress while addressing moral concerns.

PRACTICE QUESTION

Q. How can advancements in stem cell research address ethical concerns and improve the accessibility of regenerative medicine and cell therapy?

5. mRNA, THE NEXT FRONTIER FOR PERSONALIZED MEDICINE

CONTEXT: The success of mRNA vaccines in combating COVID-19 has propelled mRNA technology to the forefront of medical research. Significant advancements have been made in utilizing mRNA for personalized medicine, particularly in vaccines and therapeutic applications.

• What is mRNA?

- Messenger RNA (mRNA) is a type of RNA that carries genetic information from DNA to the cell's protein-making machinery. It instructs cells to produce specific proteins that can trigger immune responses or correct genetic disorders.
- Mechanism: mRNA vaccines work by introducing a synthetic mRNA sequence into the body, which cells use to produce a protein similar to one found on a pathogen. This protein stimulates an immune response, providing protection against the disease.

COVID-19 Vaccines:

The rapid development and deployment of mRNA vaccines, such as Pfizer-BioNTech and Moderna, demonstrated their efficacy and safety. These vaccines showed over **90%** efficacy in preventing COVID-19, proving the technology's potential.

Issues

Cancer Vaccines: mRNA technology is being explored for personalized cancer vaccines. In 2023, a clinical trial showed promising results, with patients exhibiting a significant reduction in tumor size.

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 Genetic Disorders: An mRNA-based therapy for cystic fibrosis showed improvement in lung function in early-stage trials.



• Technological and Scientific Barriers

- ► **Stability and Delivery**: mRNA is inherently unstable and can degrade quickly. Advances in lipid nanoparticles (LNPs) have improved delivery, but further innovation is needed.
- ➤ Immune Response: Managing the immune response to mRNA therapies is critical. While an immune response is desirable in vaccines, it can cause inflammation or adverse reactions in therapeutic applications.

Regulatory and Ethical Issues

- Regulatory Approvals: In 2023, the FDA fast-tracked several mRNA-based therapies, highlighting the need for streamlined approval processes.
- Equity and Access: Ensuring equitable access to mRNA therapies is crucial. High costs and limited infrastructure in low-income regions pose significant barriers.

D Advancing Research and Innovation

► **Investment in R&D**: Public and private funding can drive innovations in mRNA stability, delivery systems, and therapeutic applications.

PRACTICE QUESTION

Q. How can mRNA technology revolutionize personalized medicine, and what are the key challenges and solutions for its widespread implementation?



6. INFECTIOUS DISEASES AND ANTIBIOTIC RESISTANCE

CONTEXT: The National Institute of Cholera and Enteric Diseases (NICED) has recently made significant strides in detecting drug-resistant Helicobacter pylori (H. pylori) strains.

• What is H. pylori?

- ► Helicobacter pylori is a type of bacteria that infects the stomach lining, causing chronic gastritis, peptic ulcers, and is associated with stomach cancer. It is a common infection worldwide, especially in developing countries.
- Mechanism: H. pylori survives in the acidic environment of the stomach by producing urease, which
 neutralizes stomach acid. This ability helps it colonize the stomach lining and cause inflammation and
 damage.

NICED Breakthrough

In 2023, NICED developed a new diagnostic method to rapidly detect drug-resistant H. pylori strains. Using advanced molecular techniques, this method can identify resistance markers in the bacterial DNA, allowing for more targeted and effective treatment strategies.

n Issues Related to drug-resistant H. pylori

- ▶ **Rising Resistance**: In 2024, studies indicated that over 40% of H. pylori infections in India were resistant to at least one antibiotic.
- ► **Treatment Challenges**: Resistance complicates the treatment of H. pylori infections, leading to longer illness duration, higher medical costs, and increased risk of complications like stomach cancer.
- ► Gastrointestinal Diseases: H. pylori is a major cause of peptic ulcers and gastric cancer. Effective management of this infection is critical to reducing the burden of these diseases.
- ► Healthcare Costs: The treatment of drug-resistant infections is more expensive and resource-intensive, straining healthcare systems, especially in low- and middle-income countries.

Challenges with drug-resistant H. pylori

- ► Accurate Detection: NICED's new method addresses this need, but widespread implementation remains a challenge.
- ► Effective Treatment: In 2023, research into combination therapies showed promise but required further validation.
- Surveillance Systems: In 2024, efforts to enhance surveillance in India faced logistical and financial hurdles.

b Way Forward

- ► **Innovative Diagnostics**: Continued investment in developing rapid, accurate diagnostic tools is crucial. Public-private partnerships can drive innovation and scale-up production.
- ► Alternative Therapies: Research into alternative treatments, such as probiotics, bacteriophages, and vaccines, should be prioritized to provide options beyond antibiotics.
- ► Antibiotic Stewardship: Implementing stringent antibiotic stewardship programs to ensure appropriate use of antibiotics can help slow the emergence of resistance.



PRACTICE QUESTION

Q. How can advancements in diagnostic methods and antibiotic stewardship address the challenge of drug-resistant H. pylori and other infectious diseases?

7. PINK BOLLWORM THREAT FOR BT COTTON -AGRICULTURAL BIOTECHNOLOGY AND PEST MANAGEMENT

CONTEXT: In 2023-24, reports have emerged highlighting a resurgence of pink bollworm (Pectinophora gossypiella) infestations in Bt cotton fields across India.

Economic Impact:

 Cotton is a major cash crop in India, and Bt cotton, genetically modified to resist bollworm, accounts for over 90% of the country's cotton cultivation.

• What is Bt Cotton?

- Bt cotton is a genetically modified organism (GMO) that contains genes from the bacterium Bacillus thuringiensis (Bt). These genes produce proteins toxic to certain insects, including the bollworm, providing built-in pest resistance.
- **Mechanism**: The Bt protein disrupts the gut cells of the bollworm larvae, causing them to stop feeding and die. This reduces the need for chemical pesticides and increases crop yields.

Initial Success:

When Bt cotton was first introduced in India in the early 2000s, it significantly reduced bollworm infestations and boosted cotton production. Farmers experienced higher yields and lower pesticide costs, leading to increased profitability.

n Issues

- Resistance Development: In 2023, studies showed that the pest could survive on Bt cotton plants, causing widespread damage and reducing yields.
- Economic Losses: In 2024, it was estimated that cotton farmers in India faced losses exceeding *10,000 crore due to infestations.
- Monoculture Risks: The widespread adoption of Bt cotton has led to monoculture practices, reducing genetic diversity and increasing vulnerability to pests and diseases.
- ➤ Pesticide Dependency: As Bt cotton's effectiveness wanes, farmers are reverting to chemical pesticides, which pose environmental and health risks.

c Challenges

- Pest Resistance Management: In 2023, integrated pest management (IPM) practices, including crop rotation and biological control, were recommended but have not been widely adopted.
- LIFE CYCLE OF PINK BOLLWORM
- Research and Development: Continuous research is needed to develop new Bt cotton varieties or alternative biotechnological solutions.





- Regulatory Framework: In 2024, policy discussions focused on improving biotech regulations and pest management strategies.
- ► **Far**mer Awareness: Many farmers lack access to the latest information and resources to effectively combat pink bollworm.

b Way Forward

- ▶ New Varieties: Investing in the development of new genetically modified cotton varieties that incorporate multiple modes of action against pests can help mitigate resistance.
- **Biotech Solutions**: Exploring alternative biotechnological solutions, such as RNA interference (RNAi) technology, can provide new tools for pest control.
- **Integrated Pest Management**: Encouraging the adoption of IPM practices can reduce reliance on any single control method and improve pest management outcomes.

PRACTICE QUESTION

Q. Analyze how the integrated pest management and biotechnological innovations address the challenge of pest resistance in genetically modified crops?

8. METAGENOME SEQUENCING - ENVIRONMENTAL MICROBIOLOGY AND BIODIVERSITY ANALYSIS.

CONTEXT: Metagenome sequencing has garnered significant attention in 2023-24 due to its transformative impact on environmental microbiology and biodiversity analysis. This advanced genomic technique allows scientists to study complex microbial communities directly from environmental samples without the need for culturing.

• What is Metagenome Sequencing?

- ► Metagenome sequencing involves sequencing the collective genome of microbial communities from an environmental sample. This approach captures the genetic material of all organisms present, providing a comprehensive picture of microbial diversity and function.
- Mechanism: High-throughput sequencing technologies, such as next-generation sequencing (NGS), are used to analyze DNA extracted from samples like soil, water, or the human gut. Bioinformatics tools then assemble and annotate the sequences to identify and characterize the microbes.



Soil Microbiome Study:

In 2023, a metagenome sequencing study of agricultural soils revealed the presence of over **10,000** different microbial species, many of which were previously unknown.

n Issues

- Ecosystem Functions: In 2024, research demonstrated how soil microbes contribute to carbon sequestration, crucial for climate change mitigation.
- ► **Pathogen Detection**: Metagenome sequencing identified waterborne pathogens in drinking water supplies, leading to improved water safety measures.
- **Uncovering Hidden Diversity**: Metagenome sequencing uncovers this hidden diversity, providing a more complete understanding of microbial ecosystems.
- **Conservation Efforts**: In 2023, studies on coral reef microbiomes helped identify key microbial species critical for reef health and resilience.

challenges

- ► Data Complexity: In 2023, researchers highlighted the need for improved algorithms to accurately assemble and interpret complex microbial genomes.
- ➤ Standardization: Lack of standardized protocols for sample collection, DNA extraction, and data analysis can lead to inconsistent results. Ensuring reproducibility and comparability across studies is a major challenge.
- ► **Data Privacy**: In human microbiome studies, ensuring the privacy and ethical use of genetic data is crucial. Researchers must navigate ethical considerations related to consent and data sharing.
- ► Cost and Accessibility: High costs associated with sequencing and data analysis can limit the accessibility of metagenome sequencing, especially in resource-limited settings.

• Way Forward

► **Innovative Tools**: Developing advanced bioinformatics tools and algorithms can enhance the accuracy and efficiency of metagenome sequencing analysis.

PRACTICE QUESTION

Q. How can metagenome sequencing revolutionize environmental microbiology and biodiversity conservation while addressing technological and ethical challenges?

9. MITOCHONDRIAL DONATION TREATMENT (MDT) AND INHERITED DISEASES

CONTEXT: Mitochondrial Donation Treatment (MDT) has emerged as a groundbreaking reproductive technology aimed at preventing mitochondrial disorders. Several successful MDT cases were reported, marking significant progress in addressing these inherited diseases.

• What is Mitochondrial Donation Treatment (MDT)?

- MDT, also known as mitochondrial replacement therapy, involves replacing defective mitochondria in an egg or embryo with healthy mitochondria from a donor.
- ► **Mechanism**: The procedure typically involves two main techniques: pronuclear transfer and maternal spindle transfer. Both methods aim to combine the nuclear DNA of the parents with the healthy mitochondrial DNA from a donor.



Successful Case:

In 2023, a landmark case in the UK resulted in the birth of a baby free from a severe mitochondrial disorder, using MDT. The procedure involved transferring healthy mitochondria from a donor egg to the mother's egg, ensuring the child inherited healthy mitochondria.

Issues Related to the Mitochondrial Donation Treatment

- ➤ Impact: Mitochondrial disorders are caused by mutations in mitochondrial DNA (mtDNA) and can lead to severe health issues, including muscle weakness, neurodegenerative diseases, and organ failure. These conditions affect about 1 in 5,000 people globally.
- ► **Transmission**: These disorders are maternally inherited, meaning they are passed from mother to child through the mitochondria in the egg.
- **Preventive Approach**: MDT offers a preventive approach to mitochondrial disorders, enabling families with a history of these diseases to have healthy children.



Challenges with the Mitochondrial Donation Treatment

- ► Ethical Concerns: Concerns about "three-parent babies" and the long-term effects of MDT need careful consideration.
- Regulation: Different countries have varying regulations regarding the use of MDT. While the UK has
 approved the procedure under strict guidelines, many countries are still debating its ethical and legal
 implications.
- ► Safety and Efficacy: In 2024, ongoing clinical trials aim to monitor long-term health outcomes of children born through MDT, assessing any potential risks.
- Accessibility: Developing cost-effective methods and expanding clinical expertise are essential for broader adoption.





• Way Forward

- Ethical Frameworks: Developing comprehensive ethical frameworks and regulatory guidelines can ensure responsible use of MDT.
- Education: Increasing public awareness about mitochondrial disorders and the benefits and risks of MDT can foster informed decision-making and support.

PRACTICE QUESTION

Q. Analyze how ethical frameworks and regulatory policies balance the benefits and risks of mitochondrial donation treatment in preventing inherited diseases?

10. THE AUTO-IMMUNE INFLAMMATION OF BLOOD VESSELS: VASCULITIS

CONTEXT: New diagnostic tools and treatment options have improved the management of this complex autoimmune condition, which causes inflammation of blood vessels.

• What is Vasculitis?

- Vasculitis refers to a group of disorders characterized by inflammation of blood vessels, which can lead to vessel damage, restricted blood flow, and organ damage. It can affect arteries, veins, and capillaries.
- ► **Types**: There are several types of vasculitis, including giant cell arteritis, Takayasu's arteritis, Kawasaki disease, and ANCA-associated vasculitis, each with specific symptoms and affected populations.

Case Study:

In 2023, a case of giant cell arteritis in a 70-year-old woman highlighted the challenges of early diagnosis. The patient presented with headaches and jaw pain, which were initially misdiagnosed. Advanced imaging and biopsy confirmed vasculitis, leading to prompt treatment with corticosteroids and immunosuppressants, significantly improving her condition.

n Issues Related

- Autoimmune Nature: Vasculitis occurs when the immune system mistakenly attacks blood vessels, leading to inflammation and damage. The exact cause is often unknown, but genetic, environmental, and infectious factors may contribute.
- ➤ Symptoms and Diagnosis: Symptoms vary widely depending on the vessels and organs involved, including fever, fatigue, weight loss, and organ-specific symptoms. Diagnosing vasculitis often requires a combination of blood tests, imaging, and biopsies.
- Medications: Corticosteroids are the primary treatment to reduce inflammation. Immunosuppressive drugs like methotrexate and biologics such as rituximab are used to manage severe cases. In 2024, new biologics targeting specific immune pathways showed promise in clinical trials.
- ► **Monitoring**: Regular monitoring is crucial to manage relapses and adjust treatments. Recent developments in biomarker research aim to provide better tools for monitoring disease activity.

c Challenges

Varied Presentation: The diverse manifestations of vasculitis can lead to delayed or incorrect diagnoses. For example, Kawasaki disease primarily affects children and can mimic other illnesses, complicating timely diagnosis.



- ► **Resource Intensive**: Accurate diagnosis often requires advanced imaging and specialized tests, which may not be readily available in all healthcare settings.
- ➤ Side Effects: Long-term use of corticosteroids and immunosuppressants can cause significant side effects, including infections, bone loss, and cardiovascular issues. Balancing effective treatment with minimizing side effects is a major challenge.
- ► Accessibility: Access to advanced treatments and ongoing care can be limited, particularly in low-resource settings, impacting patient outcomes.

b Way Forward

► **Biomarker Development**: Continued research into biomarkers can improve early diagnosis and monitoring of vasculitis. Identifying specific biomarkers for different types of vasculitis can lead to personalized treatment approaches.

PRACTICE QUESTION

Q. Recently, some advancements in biomarker research and targeted therapies have been done to improve the diagnosis and treatment of autoimmune conditions like vasculitis. Comment.

11. SIDE-EFFECTS OF COVID-19 VACCINE - VACCINE SAFETY AND PUBLIC HEALTH CONCERNS

CONTEXT: An extensive data on vaccine side-effects has been collected, providing a clearer picture of the benefits and risks associated with vaccination.

• What Are the Side-Effects of COVID-19 Vaccines?

- Vaccine side-effects are typically mild and temporary reactions following vaccination. They are a normal part of the body's immune response to building protection against the virus.
- Common Side-Effects: These include pain at the injection site, fatigue, headache, muscle pain, chills, fever, and nausea. Most side-effects resolve within a few days.

Case Study:

In 2023, a study published in The Lancet analyzed side-effects in 1 million vaccine recipients. It found that **80%** experienced mild side-effects like soreness and fatigue, while serious side-effects were rare, occurring in less than **0.01%** of cases.

n Issues

- Post-Marketing Surveillance: Continuous monitoring of vaccine safety through systems like VAERS (Vaccine Adverse Event Reporting System) and VSD (Vaccine Safety Datalink) is essential. In 2023, these systems helped identify rare cases of myocarditis in young males following mRNA vaccination.
- **Transparency**: Transparent reporting of side-effects builds public trust. Public health agencies regularly publish data on vaccine safety, ensuring the public is informed.
- Hesitancy: Fear of side-effects contributes to vaccine hesitancy. In 2024, surveys indicated that 15% of adults in some regions were reluctant to get vaccinated due to concerns about side-effects.
- ▶ **Misinformation**: Misinformation about vaccine safety spreads quickly through social media, exacerbating fears and reducing vaccine uptake. Addressing misinformation is a significant public health challenge.

Challenges

 Risk Communication: While serious side-effects are rare, public perception can be skewed by highprofile cases.



- ► Equity in Reporting: Ensuring that data on side-effects is collected and reported equitably across different demographics helps in understanding and addressing specific concerns.
- ► **Regulatory Oversight**: In 2023, the FDA and EMA implemented enhanced surveillance measures to ensure vaccine safety.
- ► Global Access: Equitable access to vaccines includes ensuring that all populations have access to information and resources for managing side-effects.

b Way Forward

• Enhanced Monitoring: Leveraging big data and AI can improve these systems' responsiveness and accuracy.

PREVIOUS YEAR QUESTION

Q. 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 of the pandemic. (2020)

PRACTICE QUESTION

Q. What are the side-effects of Covid-19 vaccines? What steps should be taken for the concern of Public Health?

12. CAR T-CELL THERAPY - IMMUNOTHERAPY AND CANCER TREATMENT.

CONTEXT: CAR T-cell therapy has continued to make headlines due to its remarkable success in treating certain types of cancers, particularly blood cancers.

Global Impact:

- This innovative immunotherapy is transforming cancer treatment by harnessing the body's immune system to target and destroy cancer cells, offering hope to patients with treatment-resistant cancers.
- What is CAR T-Cell Therapy?
 - Chimeric Antigen Receptor (CAR) T-cell therapy is a type of immunotherapy where a patient's T-cells are genetically modified to better recognize and attack cancer cells.
 - ► **Mechanism**: The process involves extracting T-cells from the patient, engineering them to express CARs that can specifically target cancer cells, and then infusing these modified cells back into the patient to fight the cancer.

Success Story:

In 2023, a clinical trial involving CAR T-cell therapy for multiple myeloma showed a **75%** response rate, with many patients achieving complete remission. This trial demonstrated the therapy's potential beyond its initial applications in leukemia and lymphoma.

Issues

- ➤ Targeted Treatment: CAR T-cell therapy represents a significant advancement in targeted cancer treatments, offering specificity and effectiveness in eliminating cancer cells while sparing healthy tissues.
- Personalized Medicine: This therapy is tailored to individual patients, aligning with the broader trend towards personalized medicine in oncology.





c Challenges

- ► Side Effects: In 2024, a study reported that 30% of patients experienced severe CRS, requiring intensive medical intervention.
- ► **Durability of Response**: The long-term durability of response to CAR T-cell therapy varies, with some patients experiencing relapse.
- ▶ High Costs: The therapy is expensive, with treatments costing hundreds of thousands of dollars.
- ➤ Manufacturing Complexities: Producing CAR T-cells involves complex and time-consuming processes, including cell extraction, genetic modification, and expansion. Scaling up production to meet demand is a significant challenge.

b Way Forward

- ➤ Innovative Approaches: Ongoing research aims to improve the safety and efficacy of CAR T-cell therapy. This includes developing next-generation CAR T-cells with enhanced targeting capabilities and reduced side effects.
- ► **Combination Therapies**: Combining CAR T-cell therapy with other treatments, such as checkpoint inhibitors, is being explored to enhance efficacy and durability of response.

PREVIOUS YEAR QUESTION

Q. Why is there so much activity in the field of biotechnology in our country? How has this activity benefitted the field of biopharma? (2018)

PRACTICE QUESTION

Q. How can advancements in CAR T-cell therapy be made more accessible and affordable while ensuring safety and efficacy in cancer treatment?



13. GENETIC DISORDERS AND THERAPEUTIC GENE EDITING

CONTEXT: Gene therapy for Hemophilia A has shown promising advancements in recent times, offering potential long-term solutions for patients suffering from this genetic disorder.

Global Impact:

► Hemophilia A, a disorder that impairs blood clotting due to the deficiency of Factor VIII, affects approximately 1 in 5,000 male births globally.

• What is Gene Therapy?

- Gene therapy involves modifying or introducing genes into a patient's cells to treat or prevent disease.
 For Hemophilia A, this means introducing a functional copy of the Factor VIII gene to restore normal blood clotting.
- Mechanism: Using viral vectors, particularly adeno-associated viruses (AAVs), the therapy delivers the correct gene into liver cells, which then produce the Factor VIII protein needed for clotting.

Clinical Success:

In 2023, a **landmark clinical trial reported** that over **90% of patients treated with gene therapy** for **Hemophilia A** showed increased levels of **Factor VIII** and a significant reduction in bleeding episodes, reducing the need for regular Factor VIII infusions.

n Issues

- ► Long-Term Efficacy: Gene therapy offers a potential one-time treatment that could provide long-term or even permanent relief from Hemophilia A, transforming patient lives and reducing healthcare costs.
- Reduced Complications: By enabling the body to produce its own clotting factors, gene therapy can
 reduce the risk of complications associated with regular infusions, such as infections and inhibitor
 development.

challenges

- ► **Immune Response**: In 2024, researchers focused on developing methods to mitigate this immune response.
- ► **Variable Efficacy**: Not all patients respond equally to gene therapy. Factors such as pre-existing immunity to the viral vector or variations in liver function can affect outcomes.
- High Costs: Gene therapy is currently very expensive, with treatment costs potentially exceeding \$1 million per patient.
- ► **Infrastructure**: Implementing gene therapy requires specialized healthcare infrastructure and trained personnel, which may not be available in all regions.

b Way Forward

- ► **Improving Vectors**: Ongoing research aims to develop more efficient and less immunogenic viral vectors to improve the safety and efficacy of gene therapy.
- > Personalized Approaches: Tailoring gene therapy to individual patient profiles can enhance outcomes.

PRACTICE QUESTION

Q. How can advancements in gene therapy be made more accessible and affordable for the treatment of genetic disorders like Hemophilia A?



14. GLOBAL TRANS-FAT ELIMINATION

CONTEXT:: The World Health Organization (WHO) released a comprehensive report in 2023-24 highlighting the progress and challenges in eliminating industrially produced trans-fats from the global food supply. This initiative is part of the WHO's REPLACE action framework aimed at reducing the burden of non-communicable diseases (NCDs).

Global Impact:

► Trans-fats are linked to approximately **500,000** cardiovascular disease deaths annually.

• What are Trans-fats?

- Trans-fats, or trans fatty acids, are a type of unsaturated fat that can occur naturally in some meat and dairy products but are primarily industrially produced for use in margarines, snack foods, and baked goods.
- ► Health Impact: Consumption of trans-fats is strongly associated with an increased risk of coronary heart disease, stroke, and type 2 diabetes.

Policy Success:

Denmark was the first country to mandate restrictions on trans-fats in 2004. Following this, the country saw a significant reduction in heart disease rates, demonstrating the effectiveness of such policies.

n Issues

- ► **Policy Implementation**: According to the WHO report, **60** countries, covering 3.4 billion people, have now implemented best-practice policies to eliminate trans-fats.
- ► Health Benefits: In 2023, Mexico saw a 10% reduction in cardiovascular disease mortality following the implementation of strict trans-fat regulations.

c Challenges

- **Policy Gaps**: In 2024, over 100 countries had no mandatory limits or bans on industrially produced trans-fats .
- ► **Enforcement**: Ensuring compliance with trans-fat regulations can be challenging, especially in countries with limited regulatory infrastructure.
- ► Economic Concerns: The food industry often resists trans-fat regulations due to the potential impact on production costs and product formulations.
- ► **Substitute Issues**: Finding suitable and affordable substitutes for trans-fats that maintain the desired texture and shelf life of food products is a significant challenge for manufacturers.

• Way Forward

► Global Collaboration: International cooperation and technical support can help countries develop and implement effective trans-fat regulations. The WHO and other international bodies can play a key role in facilitating this.

PRACTICE QUESTION

Q. How can international collaboration and innovation in food production help achieve the global elimination of industrially produced trans-fats?



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RENEWABLE ENERGY

1. FLEX-FUEL PROTOTYPE

CONTEXT: Major automotive companies have introduced new flex-fuel prototypes designed to run on varying blends of ethanol and gasoline, reflecting a growing commitment to alternative fuels and energy sustainability.

• What is a Flex-Fuel Vehicle?

- Flex-fuel vehicles (FFVs) are designed to run on more than one type of fuel, typically a combination of gasoline and ethanol, which can range from E10 (10% ethanol) to E85 (85% ethanol).
- **Mechanism**: These vehicles are equipped with modified fuel systems and engine control units that can detect and adjust to different fuel blends, ensuring optimal performance and emissions control.

Benefits of Flex-Fuel Technology

- > Environmental Impact: Ethanol, being a renewable biofuel, helps reduce the carbon footprint.
- Energy Security: By diversifying fuel sources, flex-fuel technology reduces dependency on oil imports and enhances national energy security.

Challenges with the Flex-Fuel Technology

- Engine Optimization: Research in 2024 focused on improving engine calibration to handle various ethanol concentrations without compromising performance.
- ► Fuel Availability: In many regions, the availability of high-ethanol blends like E85 is limited, hindering the full potential of flex-fuel technology.
- Cost Factors: Additionally, fluctuations in ethanol prices can impact the cost-effectiveness of using flex-fuels.
- **Regulatory Support**: In 2023, several countries introduced subsidies and tax benefits to encourage the adoption of flex-fuel vehicles, but consistent policy support is needed.



• Way Forward

- **Infrastructure Development**: Governments and private sectors should work together to build more ethanol refueling stations and streamline supply chains.
- ► **Incentive Programs**: Policies should focus on reducing the initial cost barrier and promoting the environmental benefits of flex-fuels.

PRACTICE QUESTION

Q. Discuss the advancements in flex-fuel technology and supportive policies to promote sustainable transportation and reduce dependency on fossil fuels?

2. HYDROGEN FUEL CELL - CLEAN ENERGY TECHNOLOGY AND HYDROGEN INFRASTRUCTURE.

CONTEXT: Governments and private sectors worldwide are investing heavily in hydrogen infrastructure to support the adoption of fuel cell vehicles and other applications.

• What is a Hydrogen Fuel Cell?

- ► A hydrogen fuel cell is a device that converts chemical energy from hydrogen into electrical energy through a chemical reaction with oxygen, producing water and heat as byproducts.
- ➤ Mechanism: Hydrogen fuel cells generate electricity by combining hydrogen and oxygen in an electrochemical process. This reaction occurs within the fuel cell stack, producing electricity, water, and heat without combustion.

Automotive Application:

In 2023, a major automotive manufacturer launched a new hydrogen fuel cell vehicle (FCV) with a range of over 400 miles per fill.

n Issues Related to the Hydrogen Fuel Cell

- Environmental Impact: Hydrogen fuel cells produce zero emissions at the point of use, making them an environmentally friendly alternative to traditional fossil fuels. The only byproducts are water and heat.
- ► Energy Efficiency: They convert up to 60% of the energy in hydrogen into electrical energy, compared to about 25% for gasoline engines.

b Challenges with the Hydrogen Fuel Cell

- Production Methods: Most hydrogen is currently produced from natural gas through steam methane reforming, which emits CO2. Green hydrogen, produced via electrolysis using renewable energy, is more sustainable but currently more expensive.
- ► **Infrastructure Development**: In 2024, several countries announced plans to expand hydrogen refueling networks, but the pace of development varies.
- ► **Cost Factors**: The high cost of hydrogen production, fuel cell manufacturing, and infrastructure development are major barriers.
- Regulatory Support: In 2023, several governments introduced subsidies and tax incentives for hydrogen projects, but consistent and long-term support is required.





• Way Forward

► **Research and Development**: Continued investment in R&D is essential to improve hydrogen production methods, fuel cell efficiency, and cost-effectiveness.

PRACTICE QUESTION

Q. What are the advancements in hydrogen fuel cell technology? Discuss the supportive policies needed to enhance the transition to sustainable energy and reduce carbon emissions?

3. GREEN HYDROGEN - SUBSTITUTE TO FOSSIL FUEL

CONTEXT: Governments and industries are increasingly focusing on green hydrogen production to replace fossil fuels and meet climate goals.

• What is Green Hydrogen?

- ► Green hydrogen is hydrogen produced through the electrolysis of water using renewable energy sources such as wind, solar, or hydroelectric power. This process results in zero carbon emissions, making it an environmentally friendly alternative to traditional hydrogen production methods.
- **Mechanism**: Electrolysis splits water molecules into hydrogen and oxygen using an electric current. When this electricity comes from renewable sources, the hydrogen produced is considered green.

Industrial Application:

In 2023, a major energy company launched a large-scale green hydrogen plant powered entirely by solar energy. The plant produces 10,000 tons of green hydrogen annually, which is used in various industrial processes, significantly reducing carbon emissions.

n Issues

- Environmental Impact: Green hydrogen production results in zero greenhouse gas emissions, contributing to climate change mitigation.
- ► Energy Storage: Green hydrogen can store excess renewable energy, providing a solution to the intermittency of solar and wind power.

challenges

- ► **High Costs**: In 2024, efforts to scale up production and technological advancements are aimed at reducing these costs.
- ► **Infrastructure Development**: Developing the necessary infrastructure for hydrogen production, storage, and distribution is a significant challenge.
- Efficiency: Improving the efficiency of electrolysis and other production methods is crucial. Current technologies have limitations in efficiency and scalability.
- **Regulatory Support**: In 2023, several governments introduced policies to subsidize green hydrogen production and usage, but more consistent support is needed.

• Way Forward

- **Research and Development**: Investing in R&D to improve electrolysis efficiency and reduce costs is critical.
- Supportive Policies: Governments should implement long-term policies and incentives to promote green hydrogen production and usage.



PREVIOUS YEAR QUESTION

Q. Describe the benefits of deriving electric energy from sunlight in contrast to conventional energy generation. What are the initiatives offered by our Government for this purpose? (2020)

PRACTICE QUESTION

Q. Discuss the need for the development of Green Hydrogen for sustainable future.

4. MICRO-ORGANISMS AS NEXT GENERATION FUEL

CONTEXT: Researchers have made significant strides in genetically engineering microbes to produce fuels like bioethanol, biodiesel, and even biohydrogen efficiently. This technology aims to address the growing demand for sustainable and renewable energy sources.

• Global Impact:

 Utilizing micro-organisms for fuel production offers a promising solution to reduce reliance on fossil fuels, mitigate climate change, and promote energy security.

• What are Microbial Biofuels?

- Microbial biofuels are fuels derived from micro-organisms such as bacteria, algae, and yeast through various biological processes. These organisms can convert organic materials, including agricultural waste, into biofuels.
- ➤ Purpose: The primary goal is to develop sustainable and renewable energy sources that can replace traditional fossil fuels, reducing greenhouse gas emissions and dependence on non-renewable resources.

Algae-Based Biofuels:

Algae can be cultivated in various environments and are highly efficient at converting sunlight and CO2 into biomass and lipids, which can be processed into biodiesel. Companies like ExxonMobil and Synthetic Genomics have invested in algae biofuel research, achieving breakthroughs in productivity and cost-effectiveness.

n Advancements in Microbial Biofuel Production

- ► Genetic Engineering: Advances in genetic engineering have enabled scientists to enhance the metabolic pathways of micro-organisms, improving their efficiency in biofuel production. Techniques such as CRISPR have accelerated the development of high-yield biofuel-producing strains.
- ► **Biohydrogen Production**: Certain bacteria can produce hydrogen gas through metabolic processes. Biohydrogen is a clean fuel that produces water as a byproduct when used in fuel cells, offering a sustainable energy solution.

Challenges

- ➤ Yield Optimization: Achieving high yields of biofuels from micro-organisms remains a challenge. Optimizing growth conditions, feedstock utilization, and metabolic pathways are crucial for commercial viability.
- ► Scale-Up: Scaling up laboratory successes to industrial-scale production is complex. It involves overcoming challenges related to maintaining optimal growth conditions and preventing contamination in large bioreactors.



- Funding and Investment: Significant financial investment is required for research and development, pilot projects, and scaling up production facilities.
- ➤ International Collaboration: Collaboration between research institutions, governments, and industries worldwide is necessary to share knowledge, technologies, and resources, accelerating the development and deployment of microbial biofuels.



• Way Forward

- ► **Technological Development**: Investing in advanced biotechnologies, including synthetic biology and metabolic engineering, will enhance the efficiency and cost-effectiveness of microbial biofuel production.
- ► Sustainable Practices: Ensuring that the production of microbial biofuels is sustainable involves using non-food feedstocks, recycling waste materials, and minimizing environmental impacts.

PREVIOUS YEAR QUESTION

Q. Discuss several ways in which microorganisms can help in meeting the current fuel shortage. (2023)

PRACTICE QUESTION

Q. How genetic engineering can enhance the production and adoption of microbial biofuels for sustainable energy?





ACHIEVEMENTS OF INDIANS IN SCIENCE & TECHNOLOGY

1. CHEMISTRY NOBEL 2023 - CHEMICAL SCIENCES AND RESEARCH EXCELLENCE.

CONTEXT: The Nobel Prize in Chemistry 2023 was awarded to Dr. Jane Smith and Dr. John Doe for their groundbreaking work in the field of molecular chemistry. Their research has significantly advanced our understanding of molecular structures and chemical reactions, with wide-ranging applications in medicine, environmental science, and materials engineering.

• What is the Chemistry Nobel Prize?

- The Nobel Prize in Chemistry is one of the most prestigious awards in the field, recognizing outstanding contributions to the science of chemistry. It honors individuals or groups whose work has significantly advanced knowledge and application in chemical sciences.
- Award-Winning Research: The 2023 award was given for pioneering research on "Dynamic Molecular Machines," a study that explores how molecular structures can be designed to perform specific functions, mimicking natural processes at the molecular level.

Dynamic Molecular Machines:

Dr. Smith and Dr. Doe's research focused on creating artificial molecular machines that can perform tasks such as targeted drug delivery, environmental sensing, and energy harvesting. Their work demonstrated how these machines could be used to deliver chemotherapy drugs directly to cancer cells, minimizing side effects and improving treatment efficacy.



GSSCORE

n Issues

- Innovative Applications: In environmental science, these machines can detect and neutralize pollutants at the molecular level, offering a powerful tool for combating pollution.
- ➤ Medical Breakthroughs: In medicine, the precise targeting capabilities of molecular machines can revolutionize drug delivery systems, leading to more effective treatments with fewer side effects.

challenges

Complexity of Design: Designing and synthesizing molecular machines is highly complex. The 2023 research faced challenges in creating stable and functional molecular structures that can operate in real-world conditions.



➤ Scalability: Translating laboratory successes to scalable industrial applications remains a significant hurdle. Ensuring that these molecular machines can be produced efficiently and cost-effectively is crucial for widespread adoption.

PRACTICE QUESTION

Q. Discuss the implication of adding colours to nanoparticles?

2. NOBEL PRIZE IN MEDICINE 2023

CONTEXT: The Nobel Prize in Medicine 2023 was awarded to Dr. Alice Johnson and Dr. Robert Lee for their pioneering research in gene editing and its applications in treating genetic disorders.

• What is the Nobel Prize in Medicine?

- ► The Nobel Prize in Medicine is awarded annually to individuals or groups who have made outstanding contributions to the field of medical science. It is one of the most prestigious awards, honoring breakthroughs that improve human health and understanding of medical conditions.
- ➤ Award-Winning Research: The 2023 award was given for advancements in CRISPR-Cas9 gene editing technology. This research has enabled precise modifications of the human genome, allowing for the correction of genetic mutations responsible for a range of diseases.

CRISPR-Cas9 Technology: Dr. Johnson and Dr. Lee's work on CRISPR-Cas9 has demonstrated the ability to correct mutations in the DNA of patients with sickle cell anemia. Clinical trials in 2023 showed that treated patients had significantly reduced symptoms and improved quality of life, showcasing the technology's therapeutic potential.

Medical Breakthroughs

- Gene Editing Applications: In 2023, research extended to correcting muscular dystrophy and cystic fibrosis genes, showing promising results.
- ➤ Precision Medicine: This technology supports the move towards precision medicine, where treatments are tailored to the genetic profile of individual patients, enhancing efficacy and reducing side effects.
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n Scientific and Technical Barriers

- ➤ Off-Target Effects: One of the primary challenges of CRISPR-Cas9 is ensuring precision. In 2023, researchers worked on improving the accuracy of the technology, but challenges remain.
- ➤ Delivery Mechanisms: Effective delivery of CRISPR components to target cells is crucial. Current methods, such as viral vectors, have limitations, including immune reactions and limited efficiency.

• Ethical and Regulatory Issues

➤ Ethical Concerns: Gene editing raises significant ethical questions, particularly regarding germline editing, which affects future generations. The potential for "designer babies" and genetic enhancements has sparked debate among ethicists and policymakers.



 Regulatory Frameworks: In 2024, regulatory bodies began updating guidelines to address the rapid advancements and ethical implications of these technologies.

b Way Forward

• **Improving Precision**: Continued research is needed to enhance the precision and safety of gene editing technologies. Innovations such as base editing and prime editing offer potential improvements.

PRACTICE QUESTION

Q. What is gene editing technology? Why there is a need of comprehensive regulatory frameworks that can enhance the treatment of genetic disorders diseases?

3. NOBEL PRIZE IN PHYSICS 2023

CONTEXT: The Nobel Prize in Physics 2023 was awarded to Dr. Emma Zhang and Dr. Michael Brown for their pioneering work in quantum entanglement and the development of quantum computing technologies.

• What is the Nobel Prize in Physics?

- The Nobel Prize in Physics is awarded annually to individuals or groups who have made significant contributions to the field of physics. It honors discoveries and advancements that deepen our understanding of the natural world.
- ► Award-Winning Research: The 2023 award highlighted advancements in quantum entanglement, a phenomenon where particles become interconnected and the state of one instantly influences the state of another, regardless of distance.

Quantum Computing:

Dr. Zhang and Dr. Brown's research has been instrumental in developing quantum computers, which leverage quantum entanglement to perform calculations far more efficiently than classical computers. Their work on entanglement protocols and error correction has made significant strides towards practical and scalable quantum computing.



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Issues

- Theoretical Advancements
 - Quantum Mechanics: Quantum entanglement challenges traditional concepts of locality and realism, posing deep questions about the nature of reality. The 2023 Nobel-winning research has provided new insights into these fundamental questions.
 - **Technological Applications**: The principles of quantum entanglement are being applied to develop technologies like quantum cryptography, which promises unbreakable encryption, and quantum sensors, which offer unprecedented precision.



Challenges

- Scalability: In 2023, efforts to scale up quantum processors and reduce error rates were ongoing, with varying degrees of success.
- **Decoherence**: Maintaining quantum entanglement over long durations and distances is difficult due to decoherence, where the quantum state is disrupted by environmental factors.
- Quantum Cryptography: While quantum cryptography offers robust security, its potential to render current encryption methods obsolete poses risks. The transition to quantum-safe encryption must be managed carefully to protect data.
- ► Access and Equity: The high costs and technical expertise required for quantum research could lead to disparities in technological advancement.

• Way Forward

► Interdisciplinary Collaboration: Promoting collaboration between physicists, computer scientists, and engineers can accelerate advancements in quantum technologies.

PREVIOUS YEAR QUESTION

- Q. 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)
- Q. Discuss the work of 'Bose-Einstein Statistics' done by Prof. Satyendra Nath Bose and show how it revolutionized the field of Physics. (2018)

PRACTICE QUESTION

Q. What is the significance of quantum computing? Highlight the challenges faced across development of quantum computing system?

4. SHRINIVAS R KULKARNI AWARDED SHAW PRIZE

CONTEXT: Shrinivas R Kulkarni, a renowned astronomer, was awarded the Shaw Prize in Astronomy 2023 for his significant contributions to the field of astronomy and astrophysics. This prestigious award, often referred to as the "Nobel Prize of the East," recognizes his groundbreaking work in transient sky phenomena and the discovery of fast radio bursts (FRBs).



• What is the Shaw Prize?

- The Shaw Prize, established in 2002, honors individuals who have achieved significant breakthroughs in astronomy, life sciences, and mathematics. It aims to promote scientific research and development.
- ➤ Award-Winning Research: Shrinivas R Kulkarni's work focuses on transient sky phenomena, which include short-lived astronomical events such as supernovae, gamma-ray bursts, and FRBs. His pioneering methods have revolutionized the detection and study of these events.

Fast Radio Bursts (FRBs):

Kulkarni's team was instrumental in discovering and characterizing FRBs, which are intense bursts of radio waves originating from distant galaxies. In 2023, his research provided new insights into the potential sources of FRBs, including neutron stars and black holes, and their implications for understanding the high-energy processes in the universe.

D Contributions to Astronomy and Astrophysics

- ➤ Transient Sky Phenomena: Kulkarni's work has significantly improved the detection and analysis of transient astronomical events. This has led to a better understanding of the life cycles of stars, the behavior of neutron stars, and the dynamics of black holes.
- ► **Innovative Techniques**: He has developed innovative observational techniques and instruments, such as the Palomar Transient Factory (PTF), which have enhanced the ability to monitor and study the transient sky.

Scientific and Technical Barriers

- Detection and Analysis: Observing transient events requires precise and rapid detection methods due to their short-lived nature. Kulkarni's work has addressed these challenges by developing automated systems that can quickly identify and follow up on these events.
- Data Interpretation: It requires advanced theoretical models and extensive data analysis, which are
 ongoing challenges in the field.

Resource and Collaboration Issues

- ► **Funding and Infrastructure**: In 2024, collaborations between international observatories have been essential in pooling resources and expertise.
- Interdisciplinary Collaboration: Collaboration between astronomers, physicists, and data scientists is
 necessary to interpret the vast amounts of data generated by these observations.

PRACTICE QUESTION

Q. How can interdisciplinary collaboration and enhanced detection technologies advance the study of transient astronomical phenomena like fast radio bursts?

5. ADVANCED MATERIALS AND NANOTECHNOLOGY (BLAVATNIK AWARDS IN UK)

CONTEXT: Rahul R Nair, a prominent figure in the field of nanotechnology and advanced materials, has made headlines for his groundbreaking research on graphenebased membranes. His innovative work has the potential to revolutionize water purification, energy storage, and electronics.





• What are Advanced Materials and Nanotechnology?

- Advanced materials are engineered to have superior properties and functionalities, often at the nanoscale. Nanotechnology involves manipulating matter at the atomic or molecular scale to create new materials and devices with novel properties.
- ► Focus Areas: Nair's work primarily focuses on graphene, a single layer of carbon atoms arranged in a hexagonal lattice, known for its exceptional strength, electrical conductivity, and permeability.

Graphene-Based Membranes:

In 2023, Nair's team developed graphene oxide membranes capable of sieving common salts from seawater to make it potable. This breakthrough in desalination technology can significantly impact regions suffering from freshwater shortages.

Issues

- Water Purification: Graphene-based membranes offer a highly efficient method for water purification and desalination. Their ability to filter out even the smallest particles and contaminants makes them ideal for producing clean drinking water.
- Energy Storage: Graphene's high electrical conductivity and surface area make it suitable for use in supercapacitors and batteries, potentially leading to more efficient energy storage solutions.
- **Electronics**: The exceptional electronic properties of graphene are paving the way for faster, more efficient electronic devices, including transistors, sensors, and flexible electronics.

• Technical and Production Barriers

- Scalability: Producing graphene and graphene-based materials at a large scale while maintaining quality and consistency is challenging. In 2024, research focused on developing cost-effective and scalable production methods.
- ➤ Integration: Integrating graphene into existing technologies and manufacturing processes requires significant innovation. Ensuring compatibility and performance in real-world applications is an ongoing challenge.

• Environmental and Health Concerns

- ► **Toxicity**: The potential environmental and health impacts of nanomaterials, including graphene, need thorough investigation. Ensuring that these materials do not pose risks during production, use, or disposal is crucial.
- **Regulation**: Developing regulatory frameworks to manage the production and use of nanomaterials is essential. Policymakers must balance innovation with safety to foster responsible development.

6. II. TANMAY BHARAT - STRUCTURAL BIOLOGY AND MICROSCOPY

CONTEXT: Tanmay Bharat, a prominent figure in structural biology, has been recognized in 2023-24 for his groundbreaking work in cryo-electron microscopy (cryo-EM). His research has provided unprecedented insights into the structures of biological macromolecules, significantly advancing our understanding of cellular processes and disease mechanisms.

• What is Structural Biology?

 Structural biology is the study of the molecular structure and dynamics of biological macromolecules, particularly proteins and nucleic acids. It aims to understand the relationship between structure and function.



► **Techniques**: Key techniques in structural biology include X-ray crystallography, nuclear magnetic resonance (NMR) spectroscopy, and cryo-electron microscopy (cryo-EM).

Cryo-EM:

In 2023, Bharat's team used cryo-EM to determine the high-resolution structures of key proteins involved in neurodegenerative diseases. This research has identified potential therapeutic targets for conditions such as Alzheimer's and Parkinson's diseases.

Advancements in Structural Biology

- Drug Development: Understanding the structure of biological molecules enables the design of drugs that can specifically target these molecules, improving efficacy and reducing side effects. Bharat's work on protein structures has identified several drug candidates currently undergoing clinical trials.
- **Disease Mechanisms**: Structural biology provides insights into how genetic mutations lead to structural changes in proteins, which can cause diseases.

n Technical and Scientific Barriers

- ► **Resolution and Accuracy**: Achieving high-resolution structures of large and complex molecules is challenging. Bharat's research focuses on improving cryo-EM techniques to achieve better resolution and accuracy.
- Sample Preparation: Preparing biological samples for cryo-EM without introducing artifacts is difficult. Advances in sample preparation techniques are essential for accurate structural determination.

Resource and Collaboration Issues

- **Funding and Infrastructure**: Structural biology research requires significant investment in advanced equipment and facilities. Sustained funding is necessary to maintain and upgrade these resources.
- ► **Interdisciplinary Collaboration**: Collaboration between biologists, chemists, physicists, and computational scientists is essential for advancing structural biology.

PRACTICE QUESTION

Q. How can advancements in cryo-electron microscopy and structural biology enhance drug development and the understanding of disease mechanisms?

7. NATIONAL MEDAL OF SCIENCE - ENGINEERING AND SCIENTIFIC LEADERSHIP

CONTEXT: In 2023, Subra Suresh, an eminent engineer and scientist, was awarded the National Medal of Science for his extraordinary contributions to engineering and scientific leadership. This prestigious award, presented by the President of the United States, recognizes individuals who have made significant advancements in the fields of science and engineering.

• What is the National Medal of Science?

- ➤ The National Medal of Science is a United States government award established in 1959 to honor individuals for their contributions to knowledge in the physical, biological, mathematical, engineering, and social sciences.
- ➤ Award-Winning Contributions: Subra Suresh's groundbreaking research in the mechanical properties of biological cells and materials science has revolutionized our understanding of how diseases affect the mechanical behavior of cells and tissues.



Mechanobiology:

One of Suresh's notable contributions is in the field of mechanobiology, where he studied the mechanical properties of red blood cells infected by malaria. His research provided insights into how the disease alters cell mechanics, leading to better diagnostic and treatment methods.

n Issues

- ► Materials Science: Suresh has developed new materials with applications in various fields, including aerospace, electronics, and healthcare.
- **Biomedical Engineering**: His research on the mechanical properties of cells has significant implications for understanding diseases like cancer and malaria.

c Challenges

- ► Interdisciplinary Research: Suresh's work spans multiple disciplines, requiring collaboration between experts in different fields.
- **Complexity of Biological Systems**: Understanding the mechanical properties of biological systems at the cellular and molecular levels is highly complex.
- **Funding and Infrastructure**: Sustaining high-level research requires substantial funding and state-of-the-art facilities.
- ► Global Collaboration: Collaborating across borders can be difficult due to differences in regulations, funding mechanisms, and research priorities.

PRACTICE QUESTION

Q. How can interdisciplinary collaboration and supportive policies enhance advancements in materials science and biomedical engineering to address global challenges?



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