TARGET PRELIMS 2024
BOOKLET-39; S&T-13
NANO-TECHNOLOGY, ROBOTICS

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1. NANOTECHNOLOGY

- **N**anotechnology is science, engineering, technology, conducted at the nanoscale which is 1 to 100 nanometers. Nanotechnology and Nanoscience involve the ability to see and to control individual atoms and molecules. In other words, nanotechnology is the engineering of the functional system at molecular scale.
- Richard Feynman, the father of nanotechnology, in his 1959 talk described nanotechnology as a field which can manipulate and control things on the scale of a nanometer. He expected that matter will have surprising properties at Nano level and thus provide for enormous number of applications.

1) APPLICATIONS OF NANOTECHNOLOGY

- **Carbon Nanotubes** are used in various products ranging from paints and textiles to medical diagnostics tools and components of future quantum computers because of remarkable properties such as very high elastic strength alongside low mass density or very high current densities with no heat loss.

- **Electronics**
  - **Graphene** is used in transparent electrodes for solar cells, LCD, robust non-volatile atomic switches, chemical and biological sensors and in spintronic devices.
  - **Semiconducting nanowires** are highly versatile optoelectronic components, for a wide variety of applications such as nano-LEDs and nano-Lasers, solar cells, and biomedical sensors.

- **Health**
  - **Nanoparticles of silver** embedded into fibers have anti-microbial action. It is used in food packaging, clothing, disinfectants and household appliances. Bandages are being infused with silver nanoparticles to heal cuts faster.
  - **Gold Nanoparticles** have anti-bacterial properties
  - **Nano**medicines **–** Diagnosis and Treatment (see details separately)
  - **Water Purification: Special Filters using nanomaterials** can remove objects as tiny as viruses from water.

- **Nanotechnology in Agriculture –** Better fertilizers, pesticides, insecticides, feeds, better treatment for domesticated animals.
  - **Nano-Fibre based Agriculture Inputs**: For e.g., **FIB-SOL provides** a five-gram fiber that is soluble in water and can be applied on field using conventional or modern irrigation practices. The product addresses the demand for live bacteria that could rejuvenate the soil. It could also increase the nutrient utilization efficiency, allowing plants to assimilate nutrients in a better way.

- **Environmental Applications:**
  - **Iron nanoparticles** can be used to effectively clean-up organic solvents that are polluting the ground water. The nanoparticles disperse throughout the water and decompose the organic solvents in place.
  - Adding a **little boron to Carbon** while creating nanotubes produce solid, spongy, reusable blocks that can absorb large quantities of oil spilled in water.

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- **Nanotechnology based smart windows** have energy saving, easy cleaning, UV controlling and photovoltaic properties.
- **Renewable Energy Generation**
  - New and Cheap Solar Cells use nanoparticles of **Titanium oxide** coated with dye molecules to capture the energy of visible light and convert it into electricity.
  - A **novel catalytic nanosheet** from of a nickel molybdenum-nitride, a thousand time cheaper than traditional platinum, is the new model for harvesting hydrogen from water for use as fuel.

- **Structural Engineering Applications**
  - **Nano-enhanced Cement** contained by addition of nanoparticles like nano silica (silica fume), nanostructured metals, CNTs and carbon nanofibers give stronger, more durable, self-healing, air purifying, fire resistant, easy to clean quick compacting structure.
  - **Nano-enhanced Construction Ceramics** such as floor and wall tiles and sanitary ware have self-cleaning, anti-bacterial, hygienic and scratch resistant features.
  - **Nano-enhanced paints** can reduce emission of Nitrogen-di-oxide, hydrocarbons, and carbon monoxide in the atmosphere. It can also make paint scratch proof, easy cleaning, air purifying, UV resistant, water repellant, flame resistant, and anti-bacterial.
  - **Nanotechnology based smart windows** have energy-saving, easy cleaning, UN controlling and photovoltaic properties.
  - **Fire resistant glasses** are produced by addition of fumed silica nanoparticles in glasses.
- Nanotechnology can promote **different forms of insulation solutions** like coatings, vacuum insulations glazing and nanofoams.
- **Nano whiskers** on clothes create a cushion of air around the fabric so that liquids can't stain them.
- **Cosmetics:** Nanoparticles like Zinc oxides and titanium oxides are used in sunscreen and related products. They provide protection from UVA rays.

2) FUTURE POTENTIAL APPLICATIONS

- Advancements like **nano-machines** will lead to development in the field of nano-medicines, more advanced electronics circuitry, quantum computing etc.

3) CONCERNS AND LIMITATIONS

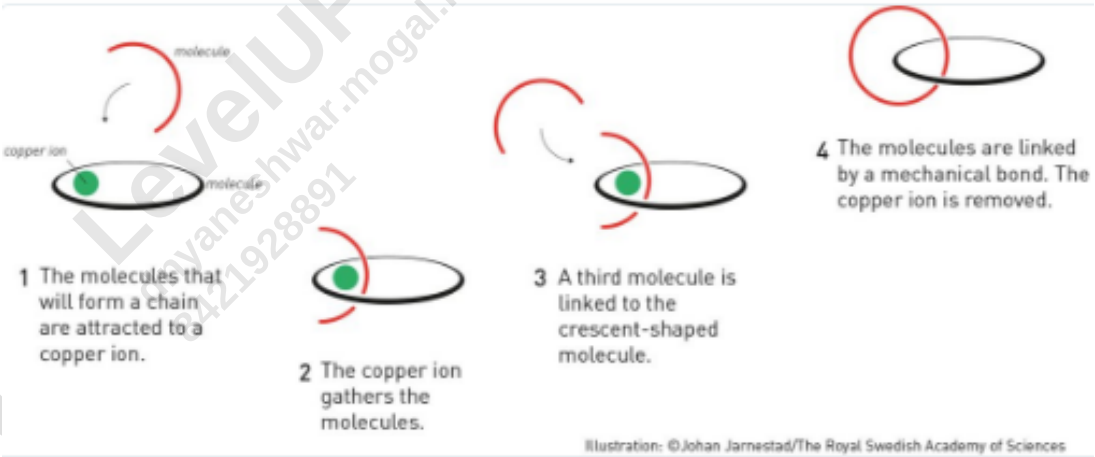
- Due to their extremely small dimensions, large surface area and high reactivity, they have the **potential ability to penetrate living cells** quite readily. As a result, their unique nano-features may also make them potentially hazardous for human health and environmental safety.
- **Health**
  - Inhaling airborne nanoparticles and nanofibers may lead to a number of **pulmonary diseases,** e.g. fibrosis. Some form of carbon nanotubes could be as harmful as asbestos if inhaled in sufficient quantities.
  - Experiments with rats have also shown impact on **skin (ageing) and brain**.
- **Toxicity**
  - Lack of investment on nanotoxicology research

- **Environmental impact**
  - **Lack of research on potential harmful impact:** Lack of study on Impact of nanomaterial on non-human species, on ecosystem or the global environment.
  - e.g. bacteriostatic **silver nanoparticles** used in socks to reduce foot odor are being released in the wash. These particles are then flushed into the wastewater stream and may **destroy bacteria which are critical component of natural ecosystem**, farms and wastewater treatment processes.
- **More dangerous Weapons**
  - As a general-purpose technology, it will be **dual use**, meaning it will have many commercial uses and it also will have military uses - making for **more powerful weapons and tools** of surveillance.
  - A technology this powerful could easily be misused. The rapid development cycle and massive manufacturing capability may lead to an **unstable arms race** between competing powers.
- **Other Concerns**
  - May lead to **loss of jobs** in traditional farming and manufacturing sector
  - May bring about **crash in certain markets** due to lowering of oil and diamonds due to possibility of developing alternative source of energy that are more efficient and won't require use of fossil fuels. Also, because people would be able to develop products at molecular level, diamond will lose its significance.
  - Atomic weapons may become more accessible and more powerful and more destructive.

4) MOLECULAR MACHINES OR NANO MACHINES

- Molecular Machine, or nano-machine, is any discrete number of molecular components that produce quasi-mechanical movements (output) in response to specific stimuli.

- **The 2016 Nobel Prize for Chemistry was awarded to 'Molecular Machine' trio:**
  - For the **design and synthesis of molecular machines**
  - **Details about their contributions**
    - » **Sauvage** in 1983 took the first step by linking two ring shaped molecule to form a chain



    - » **Stoddart** in 1991 developed a **rotaxane**, a dumbbell-shaped molecular structure that enabled him to **build molecular lift**, a molecular muscle and a molecule based computer chip

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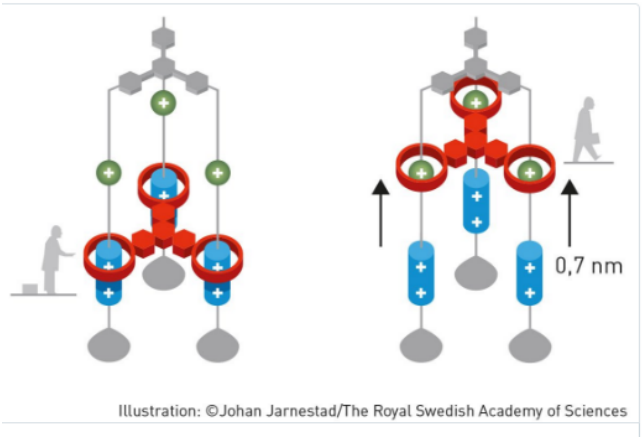
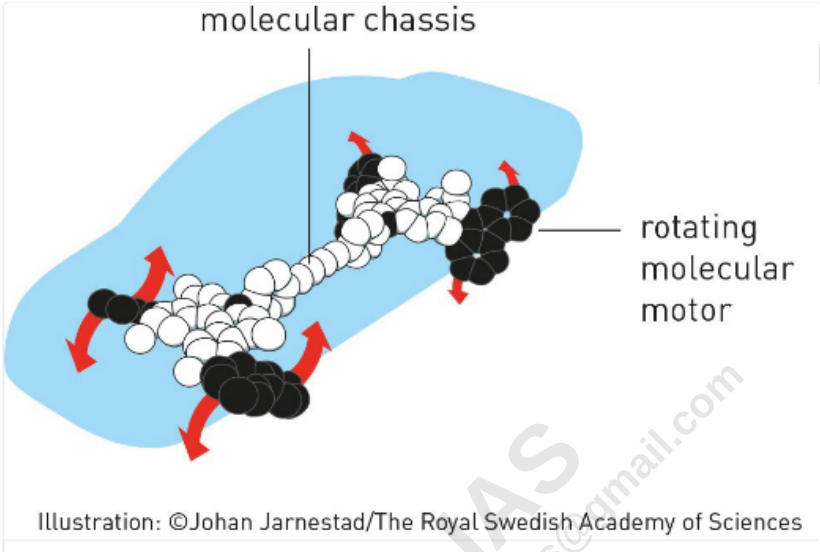


» Feringa in 1999 was the first person to develop a **molecular motor** and in 2011 designed a four-wheeled nano-car



- **Significance of those nano-machines**
  - These tiny machines that we can't even see have enormous potential.
  - » **Medicine and treatment**
    - Molecular technology could lead to development of machines that are so small they could be **swallowed or implanted into human bodies** with little negative effect.
    - They could be used to fight disease in the body, to repair damaged tissues, and even to probe DNA structure.
    - Such precise drug deliver will **minimize adverse side-effects**.
  - » **Smart materials** able to adapt to their environment, small sensors that can be controlled remotely, and drugs that are activated on command
  - » **Efficient energy storage devices**

5) EXAMPLES OF SOME MATERIAL

A) SCHWARZITE – NEW FORM OF CARBON CREATED – CLASS DISCUSSION

B) GRAPHENE

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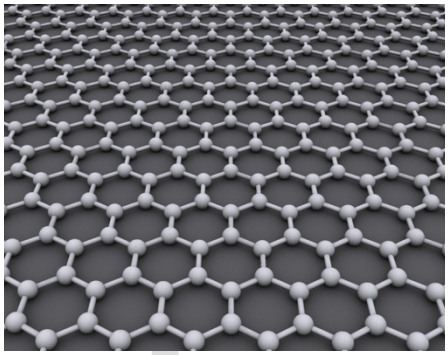
- It is an **allotrope of carbon** which is a one-atom thick layer of pure carbon. Carbon atoms are bounded together in a hexagonal honeycomb lattice.



- **How is it produced?**
  - By separating a single atom layer film from graphite.

- **Properties: Physical**
  - **2D** – world's first 2D material
  - Graphene is **harder** than diamond, **more elastic** than rubber, **tougher** than steel and yet **lighter than aluminum**.
    - In fact, it is 200 times stronger than steel (100 times stronger than the strongest steel).
  - **Thickness**: 1 million times thinner than a human hair
  - Stretchable as well as transparent, flexible and impermeable.
  - It can also act as **perfect barrier** – not even helium can pass through it.

- **Properties: Thermal, Electrical and Magnetic Properties**
  - **Highest electronic conductivity** of any material in the world.
  - **Best Heat conductivity** of any material in the world
  - Shows a **large and nonlinear diamagnetism.**

- **Applications:** Graphene's unique combination of extraordinary properties offer a fascinating material platform for the development of next-generation technologies in many areas.
  - **Energy Harvesting and Storage:** It can be used for better rechargeable batteries; superior capacitors; newer methods of making solar cells etc. Further, proton transfer in graphene shows promise for artificially mimicking photosynthesis.

  - **Electronics:** Very high electron conductivity allows graphene to be used for low-cost printable electronics, high performance transistors; thermal management and heat dissipation in nano-electronic devices.
    - **The optical properties** of graphene can also be controlled by doping and make it well suited for optoelectronic devices.

  - **Composites and Coatings:** Its low mass and low loading requirements make graphene standout as a reinforcing agent in composites. It can be used for making lubricants with enhanced anti-wearing capabilities; radiation shielding and lighting strike protection; superhydrophobic coating; transparent, flexible and conductive thin films etc.

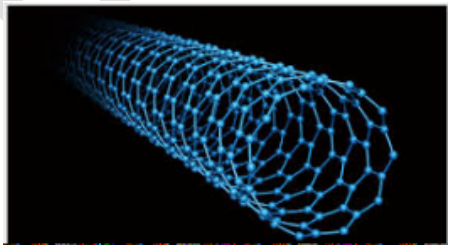
  - **Membranes** – It can improve the quality of filters used in desalination or other water purifying instruments. Graphene oxide is used for the purpose.
    - It can also act as gas barrier for e.g., in food packaging.
    - It can be used for separation of organic solvent with water.

  - **Biomedical Technologies:** Very high surface area, electron mobility etc. is paving the way for novel biomedical technologies. Graphene bioelectronics (transistors and electrode arrays) has become a ground-breaking field that offers existing opportunities for developing new

kinds of biosensors. Key **applications include** Thermal ablation of highly resistant cancer cells; Bioelectronics (bionics); Electronic interface to living cells and nerve tissues; etc.
    - **Sensors**: Since every atom of graphene is exposed, it is an ideal material for biological, gas and chemical sensors. It can be used for explosive detection; detecting biomarkers for Parkinson's disease; selective gas sensing; self-healable, multifunctional electronic sensor tattoos; environment monitoring etc.
    - Wearable technologies
    - Light weight cars, planes etc.

- **Health Risks:** Extensively debated.
    - Toxicity depends on several factors such as shape, size, purity, post-production processing steps, oxidative state etc.

C) CARBON NANOTUBES (CNT)



- **Intro**
    - » Carbon nanotubes are allotropes of carbon with a cylindrical nanostructure. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of material science and technology.

- **Properties**
    - » Strength: One of the most tensile and elastic material discovered yet.

- **Wettability**
    - » Exhibits a super hydrophobic property.
    - » By applying a low voltage as low as 1.3 V, the extreme water repellants surface can be switched into super hydrophilic.

- **Electrical Properties**
    - » CNT are either metallic or semiconducting along the tubular axis.

- **Thermal Properties**
    - » All nanotubes are expected to be very good thermal conductors along the tube, exhibiting a property known as "ballistic conduction", but good insulators lateral to the tube axis.

- **Application**
    - » **Current uses and application** of nanotubes has mostly been limited to the use of bulk nanotubes, which is a mass of rather unorganized fragments of nanotubes.
    - » Used as composite fibers in polymers to improve the mechanical, thermal and electrical properties of the bulk product.
    - » Tips for atomic force microscope probes
    - » In tissue engineering, carbon nanotubes can act as scaffolding for bone growth.

- **Concerns:** Toxicity, health risk not clear yet.

6) ELABORATING ON SOME NANOTECHNOLOGICAL APPLICATIONS

A) NANOTECHNOLOGY IN HEALTH:

- **Medical Applications**:
  - » **Prevention of disease**:
    - **Nanoparticles of silver** embedded into fibers have anti-microbial action. It is used in food packaging, clothing, disinfectants, and household appliances. Bandages are being infused with silver nanoparticles to heal cuts faster.
    - **Gold Nanoparticles** have anti-bacterial properties.
    - **Water Purification: Special Filters using nanomaterials** can remove objects as tiny as viruses from water.

  - » **Diagnostics**
    - **By** studying and identifying individual molecules, it is possible to diagnose disease in time to improve the prognosis for the patient.

  - » **Improved Treatment**
    - Indian Institute of Nano Science and Technology (INST) is developing **Magnetic Hyperthermia mediated cancer therapy** - delivery and localization of magnetic material within the targeted tumour site followed by subsequent application of an alternating Magnetic Field (AMF), thereby generating heat at the tumour site.
    - E.g: **Scientist** are using gold **nanoparticles to target prostate cancer**. Here the nanoparticles or nano shells are made of small payers of Silica glass formed into a sphere and wrapped in a thin layer of gold. This is made to reach the tumour site and then harnessed to cause the tumorous tissue to pulse with extreme temperature when light is applied through a laser specifically designed to excite the particles
    - A team of scientists from IISc Bengaluru have developed nano robots to be used in dental procedure (like root canal therapy).
    - With more advancement in **Nanomachines –** complex surgical procedures would become less intrusive and less complicated.

USING NANOROBOTS FOR DENTAL PROCEDURE

- **Background/Need**
  - A significant percentage of root canal treatments fail, because the procedure leaves out some bacteria that are located deep within the dentinal tubules.

- **The new method:**
  - Scientists have developed **Spiral Silica robots** measuring 300 nanometers to travel through dentinal tubules and target bacterias.

MAGNETIC HYPERTHERMIA-MEDIATED CANCER THERAPY (MHCT)

B) ENVIRONMENTAL NANOTECHNOLOGY

- **Key areas where nano-material researchers are working:**
  i. **Ensuring Potable Drinking Water** – Use of Graphene based water filters are expected to increase the accessibility of clean drinking water in coming future

  ii. **Removing pollutants from water**
    - **Cleaning up organic chemicals polluting ground water**
      - **Iron nanoparticles** can be used to effectively clean-up organic solvents that are polluting the ground water. The nanoparticles disperse throughout the water and decompose the organic solvents in place. This method is more effective and costs significantly less than treatment methods that require the water to be pumped out of ground.
    - **Cleaning up of oil spills**
      - Using photocatalytic cooper tungsten oxide nanoparticles to break down oil into bio-degradable compounds.

  iii. **Generating Less pollution during manufacturing of materials**
    - E.g. Use of silver nano particles as catalysts can significantly reduce the polluting by products in the process used to manufacture propylene oxide.
      - Propylene oxide is used to produce common materials such as plastics, paint, detergents and brake fluid.

  iv. **Producing solar cells that generate electricity at competitive cost**
    - E.g. Silicon nanowires embedded in a polymer result in low cost but high efficiency solar cells.

  v. **Increasing the electricity generated by windmills**
    - E.g. use of carbon nanotubes in windmill blades results in stronger and lower weight windmill blades. This helps in more amount of electricity generated by each windmill.

  vi. **Reducing cost of fuel cells**
    - Changing the spacing of platinum atom in fuel cells increases the catalytic ability of the platinum. This allows the fuel cells to function with 80% less platinum, significantly reducing the cost of the fuel cells.

C) NANOTECHNOLOGY IN AGRICULTURE

i. **Nano-Fertilizers**

- **Introduction**:
  - India has become the first country in the world to have developed and roll out **nano-fertilizers**.
    - » So far, it has launched nano-versions of two fertilizers – Urea and Diammonium Phosphate (DAMP).
    - » While nano-Urea has been made available to farmers since late 2021, nano-DAP was launched in April 2023.

- **The Indian Farmers Fertilizer Cooperative Limited (IFFCO),** which had developed the variants using propriety technology, claims that Nano-UREA and Nano-DAP have several advantages over their conventional granular counterparts.

- **More Details:**
  - Both Nano-Urea and Nano-DAP come in liquid form.
  - IFFCO claims that a 500 ml bottle of nano-urea an replace at least a 45 kg bag of granular urea and a bottle of 500 ml nano-DAP can replace a 50 kg bag of granular DAP.

- **Advantages:** The Parliamentary Standing Committee on Chemicals and Fertilizers (2022-23), headed by Shashi Tharoor have enumerated several advantages of nano-fertilizers in its March 2023 report:
  - **Soil Health:** Nano-UREA can address the imbalanced and excessive used of conventional urea in the country, which accounts for around 82% of nitrogenous fertilizers applied to majority of the crops.
  - It costs lesser than subsidized conventional fertilizer thus **reducing the cost for farmers**.
  - They also result in **better productivity** and **higher income** for farmers.
    - The PSC report notes that it has average 8% higher crop yield.
  - Experts also believe that these nano-fertilizers will lead to **reduced import dependency of fertilizers** and save **forex reserves**.
  - It will also **contribute to reduced fiscal burden** of government because of reduced fertilizer subsidy cost.

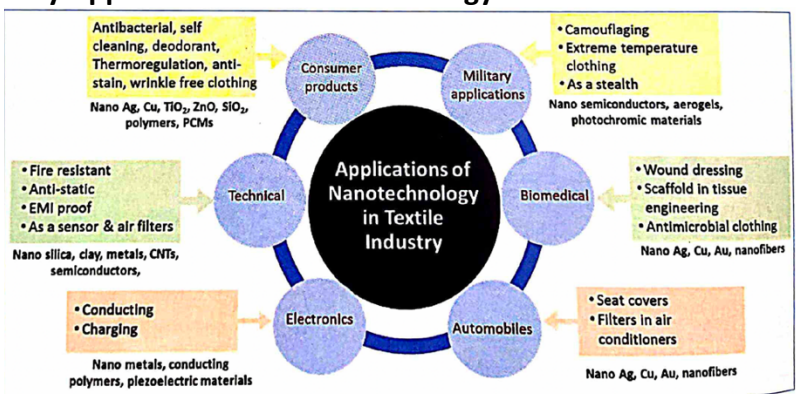
- **What is NANO UREA**
  - Fertilizer Minister, Mansukh Mandaviya has claimed that by 2025, India's domestic urea production as well as that of nano-Urea would together mean India would be "self-sufficient", in the manufacture of Urea and wouldn't require 90 lakh tonnes that it imported every year and would save the country close to Rs 40,000 crore.

- **When is Urea used in agriculture and when can it be replaced by Nano Urea?**
  - Urea is used on **two occasions** – at the time of sowing (or transplantation); and the second is done when the plant has sprouted a canopy of leaves and is approaching the reproductive phase of plant growth.
  - It is to be noted that **traditional Urea is still necessary during the initial stage**, as basal nitrogen, of crop development. The nano Urea could be useful once the plant grew after which the product could be sprayed on its leaves.

- **Limitations**:
  - **Doubts about Yield gain**: DTE has reported interviews of several farmers who had to resort back to traditional fertilizers after, nano-fertilizers didn't give good results.
  - **Labour cost for spraying fertilizer** is increasing the overall input cost for farmers.
  - **Complaints** about farmers being **forced** to buy Nano-Urea.
  - **Issue of Evaluation/Trial**: ICAR has given results of field trail based on a year (two seasons) of experiments in its affiliated labs. This was an exception as ICAR normally tests a new fertilizer for 2 years (or three seasons) before giving go ahead to a new fertilizer.

D) NANOTECHNOLOGY IN TEXTILES

Key Applications of Nanotechnology in textile sector



7) NANOTECHNOLOGY IN INDIA

- **Policies/Schemes/Programs**
  - **a. Mission on Nano Science and Technology (Nano Mission)**
    - **Introduction**
      - It is an umbrella program of GoI for overall development in the field of Nanotechnology.
      - It was launched in 2007 with an allocation of Rs 1,000 crore which was further extended during the 12th five-year plan.
      - It is structured in a fashion to **achieve synergy** between the national research efforts of various agencies in Nano Science and Technology and launch new programs in a concerted fashion.
      - Department of Science and Technology is the nodal agency for the mission.

    - **Objectives of the Nano-Mission**
      - **Basic Research Promotion** – funding of basic research by individual scientists or groups of scientists and creation of centre of excellence for pursuing this research.
      - **Infrastructure Development** for Nano Science and Technology Research -> development of a chain of facilities across the country.
      - **Human Resource Development** – Providing effective education and training to researchers and professionals in diversified fields. Launching of M.Sc./M.Tech programmes, create national and overseas post-doctoral fellowships, chairs in universities etc.
      - **International Collaborations** – Exploratory visits of scientists, organization of joint workshops, conferences and joint research projects, facilitate access to sophisticated research facilities abroad, forge academia-industry partnership.
      - Development of **product and processes for national development**
        - Especially in areas of national relevance like
          - Safe Drinking Water
          - Materials Development
          - Sensors Development
          - Drug Delivery

- **Achievements of the Mission**
  - The mission has resulted into more than 5,000 research papers and **some useful products** like nano-hydrogel based eye drops, pesticide removal technology for drinking water, water filters for arsenic and fluride removal and nano-silver based on anti-microbial textile coating.
  - India has moved from the fourth to the third position in the world in terms of scientific publications in nano-science and technology.

- **Institute of Nanoscience and Technology (INST):** It is an autonomous institute of the Department of Science and technology, GoI.

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2. ROBOTICS

1) LAWS OF ROBOTICS:

- **Isaac Asimov** gave the three laws of robotics as:
  - A robot must not harm a human being, or, through inaction, allow a human being to come to harm
  - A robot must always obey the human beings unless it is in conflict with the first law.
  - A robot must protect itself from harm unless it is in conflict with the first and/or second law.

1) WHERE ARE ROBOTS BEING USED CURRENTLY AND AREAS WHERE THERE IS A POTENTIAL TO USE ROBOTS

- Robotics is being used across a range of sectors such as:
- **Warehouse Automation**
- **Automotive manufacturing**
  - » They add precession, tirelessness and continuity in the manufacturing process.
- **Search and Rescue** after Disaster
  - » From collapsing building (due to faulty construction) to earthquake to flooding.
  - » IIT Hyderabad is working on a search-and-rescue robot called **SARP (Snake like articulated platform).** The engineering institute is applying several technologies in building **SARP**: navigation, camera, infrared, haptic feedback (to identify survivors) and collaboration (multiple snake robots can communicate with one another)
- **Defence & National Security**
  - » Whether it is with Pakistan or China, our borders are unsafe for border forces and human lives are getting lost whenever there is firing or illegal movement of people at LoCs.
  - » Government is looking at DRDO to develop next generation of robotic soldiers.
  - » **Other dangerous security tasks** like **bomb disposal**, **reconnaissance** etc can be performed by Robots.
  - » For e.g. **Daksha** is one of India's current military robots. It is used to locate, handle, destroy, risky objects safely and even can climb stairs.
- **Hazardous Industries**
  - » BARC is using robots to clean radioactive water tanks.
- **Mining and Mineral Extraction**
- **Marine Engineering**
  - » **Amogh** is an autonomous underwater vehicle. It is designated to inspect and repair bridges, pipelines and hulls of ships at the depth of upto 15 meters. The robot has an endurance capacity of upto 3 hours.

- **Space**
  - » Robots are used for exploration when humans can't be used.
  - » E.g., Fedor of Russia, Vyomamitra of India etc.

- **Health Sector**
  - » Robots are being used in operation theatres and rehabilitation centres to augment the quality of life.

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» Robots can also **assist surgical procedures** like removing gallbladders, performing hysterectomies and repairing knee ligaments.

- **Agri-Robots**
  » Can replace costly human labor and add precision in agriculture.

- They can be used *anywhere to improve productivity*.

2) ADVANTAGES OF USING ROBOTS

Accuracy
Untiring nature of robots
Non-complaining
Safety in hostile environments
Reducing cost of production
Industries facing global competition can't survive without robots
For e.g. the automobile industry can't actually survive without use of robotics

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