1. Basic Concepts

1.1. Nanotechnology

- Nanotechnology is the engineering of functional systems on an atomic or molecular scale.
- It refers to the technology of rearranging and processing of atoms and molecules to **fabricate materials at nanoscale.**
- Nanotechnology encompasses nanoscale science, engineering, and technology in fields such as chemistry, biology, physics, and materials science engineering.
- The technology enables manipulation of matter at the molecular level, creation of new structures with fundamentally new molecular organization and exploitation of the noble property at nanoscale.

1.2. Nanoscale

- Nanoscale deals with dimensions between approximately **1 and 100 nanometers.**
- Larger than that is the micro-scale, and smaller than that is the atomic scale.
- At the nanoscale, objects are so small that they cannot be seen even with a light microscope. Nano-scientists use tools like **scanning tunneling microscopes** or atomic force microscopes to observe anything at the nanoscale.

1.3. Nanomaterials

- Nanomaterials can be defined as materials possessing **at least one external dimension that measures 100 nanometres or less** or with internal structures measuring 100 nm or less.
- They may be in the form of particles, tubes, rods or fibres.
- Nanomaterials can occur naturally, be produced purposefully through engineering or be created as the by-products of combustion reactions to perform a specialized function.

1.4. Nanoscience

- Nanoscience is the **study of structures and molecules that range between 1 and 100 nm** on the scales of nanometers.
- The technology that utilizes nanoscience in practical applications is called nanotechnology.

1.5. Nanoengineering

- Nanoengineering is the field of engineering that focuses on the study, development and refinement of materials at a very small scale.
- In short, it is the practice of engineering on the nanoscale and can be thought of as the practical application of nanoscience.

History of Nanotechnology

- The American physicist and Nobel Prize laureate **Richard Feynman** introduced the concept of nanotechnology in 1959.
    - Feynman presented a lecture entitled **“There’s Plenty of Room at the Bottom”** at the annual meeting of the American Physical Society at the California Institute of Technology (Caltech).

- The term "nanotechnology" was defined by Tokyo Science University Professor Norio Taniguchi in 1974 as follows: "'Nano-technology' mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule."
- The technological significance of nano-scale was promoted by Dr. K. Erik Drexler in his book “Engines of Creation: The Coming Era of Nanotechnology” (1986).

2. Nanoscale

2.1. Factors that Govern the Behaviour of Nanoscale

Materials reduced to the nanoscale can show different properties compared to what they exhibit on a macro-scale, enabling unique applications of those materials in various unconventional ways. For instance:

- Opaque substances like copper become transparent.
- Inert materials like platinum and gold become catalysts.
- Stable materials like aluminum turn combustible.
- Solids like gold turn into liquids at room temperature.
- Insulators such as silicon become conductors.

The erratic behaviour of substances at the nanoscale is governed by two factors:

- **Quantum Mechanics:** When a substance is reduced to nanoscale it starts following the rules of quantum mechanics which are very different from classical physics, as a result the behaviour of substances at the nanoscale starts showing different and unique properties.
- **Surface to Volume Ratio:** At nanoscale the surface to volume ratio of a substance increases quite high resulting in different properties of the same material than usual. Melting points of materials can also change due to an increase in surface area at nanoscale.

2.2. Top-down and Bottom-up Approaches

Basically there are two ways of making nanoscale objects: top-down and bottom-up approaches.

Top-down Approach

- The top-down approach to nanotechnology involves the **creation of nano-objects from a parent entity** that is larger.
- This type of fabrication **uses lithographic patterning techniques** by which a bulk material is reduced in size to a nanoscale pattern.
- It is expensive and time-consuming for mass production but very suitable for laboratory experimentation.

Bottom-up Approach

- It is a comparatively newer approach where nanostructures can be constructed by **assembly of atoms and molecules.** These techniques include chemical synthesis, self-assembly and positional assembly.
- This approach will be able to produce devices in parallel and much cheaper than top-down methods, but could potentially be overwhelmed as the size and complexity of the desired assembly increases.

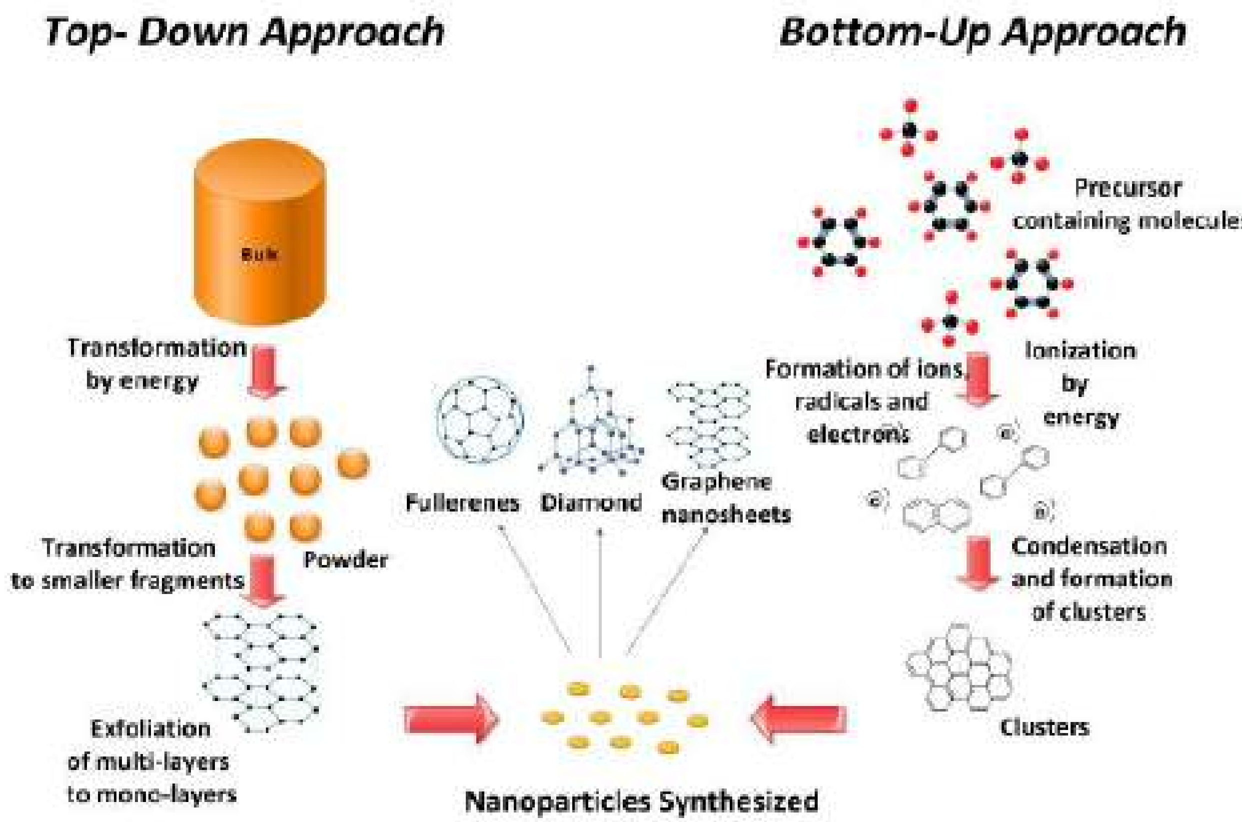

Figure.1. Top-down and bottom-up approaches in synthesis of carbon-based nanomaterials

3. Nanomaterials

3.1. Characterization of Nanomaterials

Physical Characterization Includes

- Shape, size, specific surface area, and ratio of width and height.
- Whether they stick together.
- Number size distribution and structure, including crystal structure and any crystal defects.
- How smooth or bumpy their surface is and how well they dissolve.

Chemical Characterization Includes

- Molecular structure, composition (purity, and impurity or additive) and surface chemistry.
- Whether it is held in a solid, liquid or gas, and attraction to water molecules or oils and fats.

3.2. Properties of Nanomaterials

Properties	Details
Mechanical	Nanomaterials show different mechanical properties due to the

	increased number of surface atoms and interfaces. This includes increased strength, toughness, hardness, ductility and decreased elasticity.
Thermal	Increasing the number of grain boundaries enhances phonon scattering at the disordered boundaries and results in lower thermal conductivity. Thus, nanomaterials have lower thermal conductivity compared to conventional materials.
Electrical	Nanomaterials have lower electrical conductivities than bulk materials. They have a high density of grain boundaries, which makes electric-phonon and phonon-phonon scattering effective and reduces conductivity.
Magnetic	Materials with nanostructures have higher saturation magnetization and magnetic coercivity values. Nanoparticles become magnetic in the presence of an external magnet, but revert to a nonmagnetic state when the external magnet is removed.
Melting Point	Melting-point depression phenomenon is very prominent in nanomaterials. They melt at temperatures lower than bulk materials.
Optical	Nanomaterials exhibit distinctive optical characteristics such as absorption, transmission, reflection, greater scattering, and light emission. The shape and size of nanoparticles can be altered to change their optical properties.

3.3. Types of Nanomaterials

- **Inorganic-based nanomaterials:** Include different metal and metal oxide nanomaterials.
  - **Examples of metal-based inorganic nanomaterials:** Silver, gold, cadmium, copper, iron, zinc etc.
  - **Examples of metal oxide-based inorganic nanomaterials:** Zinc oxide, copper oxide, magnesium aluminum oxide, titanium dioxide, iron oxide, etc.
- **Carbon-based nanomaterials:** It includes nanomaterials made up of non-metals and thus include graphene, fullerene, single-walled carbon nanotube, multiwalled carbon nanotube, carbon fibre, an activated carbon, and carbon black.
- **Organic-based nanomaterials:** Formed from organic materials excluding carbon materials, for instance, dendrimers, liposomes, etc.
- **Composite nanomaterials:** They are any combination of metal-based, metal oxide-based, carbon-based, and/or organic-based nanomaterials. These nanomaterials have complicated structures like a metal-organic framework.

3.3.1. Carbon Nanotube (CNT)

- Carbon nano-tubes (also known as Bucky-tube) are an **allotrope of carbon.** These are hollow, tubular and caged molecules, having a diameter measuring on the nanoscale.
- They are made up of **continuous unbroken hexagonal mesh** with carbon molecules at the apexes of the hexagons.
- The bonding in carbon nanotubes is **sp^2, with each carbon atom joined to three neighbours**, as in graphite. The tubes can therefore be considered as **rolled-up graphene sheets** (graphene is an individual graphite layer).
- CNTs are of **two types: single-wall carbon nano-tubes** (SWCN) and **multiple-wall carbon nano-tubes** (MWCN).
- These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and materials science and technology.

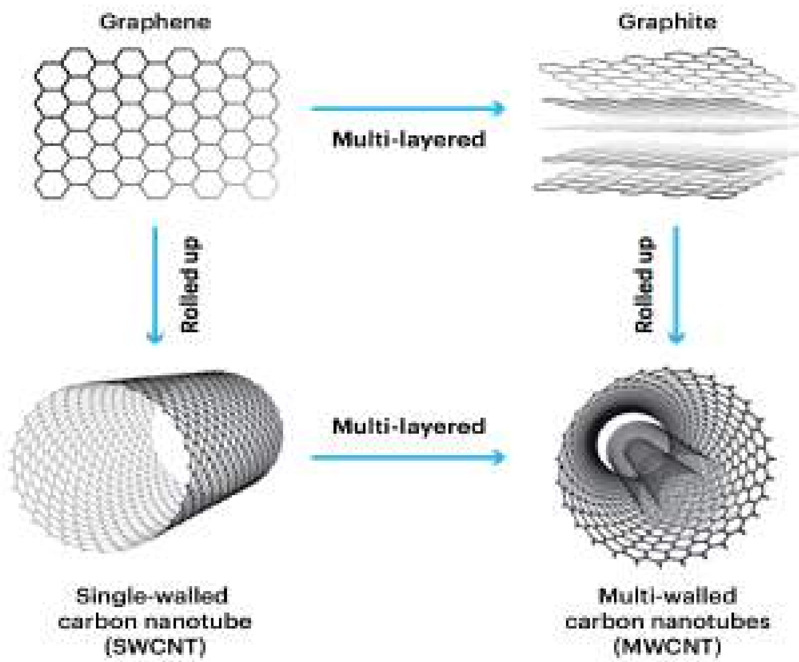

Figure.2. Carbon Nanotubes

Properties of CNT

- **Mechanical Properties:** CNT are the **strongest and stiffest** materials on earth in terms of tensile strength (ability to withstand a stretching force without breaking). They are hundred times stronger, yet six times lighter than steel. They are **one of the hardest substances known**; a standard single-walled carbon nanotube can withstand a pressure up to 24GPa without deformation.
- **Electrical Conductivity:** CNT can carry 1000 times more electric current than equivalent copper & silver wire, so is regarded as an ideal component for electric circuits.
- **Thermal Conductivity:** CNT are very good thermal conductors and the temperature stability of CNT is up to 2800℃ in vacuum & 780℃ in air.

Application of CNT

- Because of their extraordinary thermal and electrical conductivity and mechanical properties, carbon nano-tubes find applications in a wide range of materials.

- For instance, computer's processor and memory, electronic equipment, transistors, ultra-capacitors, solar cells, baseball bats, golf clubs, or car parts, combat jackets, cancer treatment and detection, etc.

3.3.2. Graphene

- Graphene is a **two dimensional allotrope** of carbon. It is one atom thick, planar and hexagonal arrangements of carbon atoms.
- The bonding of graphene is sp^2, with each carbon atom joined to three neighbours, as in graphite.
- It can be **wrapped up into 'zero-dimensional' fullerenes,** rolled into 'one-dimensional' nanotubes or stacked into 'three-dimensional' graphite. The word 'Graphene' came from graphite.
- In 2004, teams including Andre Geim and Konstantin Novoselov separated graphene from graphite and demonstrated that single layers of graphite could be isolated, resulting in the award of the Nobel Prize for Physics in 2010.

Properties of Graphene

- It is a good thermal and electric conductor and can be used to develop semiconductor circuits and computer parts. Experiments have shown it to be incredibly strong and hard.

Applications of Graphene

- Its unusual properties make it ideal for applications in various fields from composite materials to electronics.
- Graphene is a transparent conductor which can be used in touch-screen & light panel displays in smart phones & tablets. It can also be used in the making of solar cells.
- Graphene transistors are faster than those made out of silicon.
- Graphene components could pack a chip more tightly and can help make efficient and fast computers.
- Plastics could be made into electronic conductors, if only 1% of graphene were mixed into them, which will also increase the heat resistance and will make it mechanically robust.
- Graphene also helps in making new super strong materials which are thin, elastic & light weight; which can be used to make components of airplanes, cars and satellites.
- It can also be used in making many chemical and biological sensors to be used in healthcare, environmental and industrial processes.

3.3.3. Fullerenes

- Fullerenes are a carbon allotrope. They are **molecules composed entirely of carbon,** in the form of a hollow sphere, ellipsoid, or tube.
- Spherical fullerenes are called **buckyballs** whereas cylindrical fullerenes are called **buckytubes or nanotubes.**
- Fullerenes are similar in structure to graphite, which is composed of a sheet of linked hexagonal rings, but they also contain pentagonal (or sometimes heptagonal) rings that prevent the sheet from being planar.

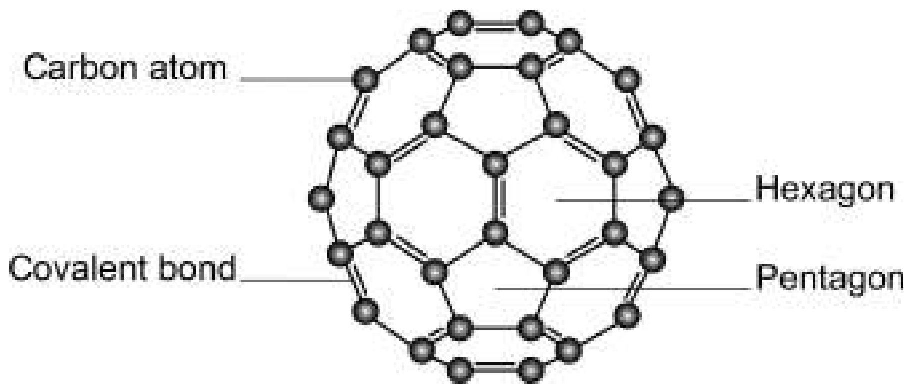

Figure.3. Fullerene C-60

Buckminster Fullerenes

- The C-60 fullerene is the most stable and was the first to be identified. It **contains 60 carbon atoms** which are arranged in the shape of a football.
- It contains 20 six-member hexagonal rings and 12 five-member pentagonal rings.
- C-60 fullerene look like **geodesic domes** designed by the United States architect Buckminster Fuller, therefore, they are called Buckminster Fullerenes.

Properties of C-60

- Buckminster Fullerenes (C-60) is a dark solid at room temperature and its hardness lies between diamond and graphite. It is neither very hard nor very soft.

Application of C-60

- It is a strong antioxidant; enough to kill resistant bacteria and cancer cells in the human body.
- C-60 molecules can engage and transport atoms and molecules (e.g. drugs, radioactive labels) through the human body.
- C-60 could also inhibit the HIV virus. The C60 molecule could block the active site in a key enzyme in the human immunodeficiency virus known as HIV-1 protease; this could inhibit reproduction of the HIV virus in immune cells.
- The C-60 molecule can also bind large numbers of hydrogen atoms without disrupting the structure. This property suggests that C60 may be a better storage medium for hydrogen than metal hydrides and hence a key factor in the development of a new class battery or even non-polluting automobiles.
- It shows the properties of superconductivity and thermal resistance which makes it perfect to be used in electronic engineering.

3.3.4. Carbon Fibres

- Carbon fibres can be defined as **fibers with a carbon content of 90% or above.**
- They are produced **by thermal conversion of organic fibers** with a lower carbon content such as polyacrylonitrile (PAN) containing several thousand filaments with diameter between 5 and 10 μm.
- Carbon fibers have high tensile strength, high stiffness, low density, and a high chemical resistance.
- The main application areas of carbon fiber-reinforced polymers are aerospace, defense, automotive, wind turbines, sport and leisure, and civil engineering.

4. Applications of Nanomaterials

4.1. Medical and Health Applications

- **Absorb and move quickly:** Nanoparticles have a significant surface-area-to-volume ratio due to their nanoscale size, which allows them to absorb vast amounts of medications and move quickly throughout the bloodstream. Their increased surface area gives them distinct capabilities, allowing them to be used in more pharmaceutical applications.
- **Quantum dots to enhance biological imaging:** Quantum dots are semiconducting nanocrystals that can enhance biological imaging for medical diagnostics. When illuminated with ultraviolet light, they emit a wide spectrum of bright colors that can be used to locate and identify specific kinds of cells and biological activities. These crystals offer optical detection up to 1,000 times better than conventional dyes used in many biological tests, such as MRIs (Magnetic Resonance Imaging), and render significantly more information.
- **Drug delivery and nanobots:** Nanobots for targeted drug delivery are meant to reach hard-to-access parts of the body. Traditional drug treatments, for example cancer chemotherapy, can come with toxic compounds that indiscriminately damage healthy tissues. Nanobots could circumvent this issue by protecting the drug until it’s delivered to the intended target. Nanobots can also be used to clear the blockage in arteries.
- **Early diagnosis of plaque in arteries:** Nanotechnology has been used in the early diagnosis of atherosclerosis, or the buildup of plaque in arteries. Researchers have developed an imaging technology to measure the amount of an antibody-nanoparticle complex that accumulates specifically in plaque. Clinical scientists are able to monitor the development of plaque as well as its disappearance following treatment.
- **Use of gold nanoparticles:** Gold nanoparticles can be used to detect early-stage Alzheimer’s disease. Gold nanoparticles can also be used for the detection of targeted sequences of nucleic acids, and can be clinically investigated as potential treatments for cancer and other diseases.
- **To detect molecular signals:** Molecular imaging for the early detection where sensitive biosensors constructed of nanoscale components (e.g. nanocantilevers, nanowires, and nanochannels) can recognize genetic and molecular events and have reporting capabilities, thereby offering the potential to detect rare molecular signals associated with malignancy.
- **Research enablers:** Such as microfluidic chip-based nanolabs capable of monitoring and manipulating individual cells and nanoscale probes to track the movements of cells and individual molecules as they move about in their environments.
- **Treating Glaucoma:** Blindness can be prevented by treating glaucoma using nanoparticle eye drops. Nanomaterials can incorporate the drugs in two ways: through encapsulation inside the nanomaterials or conjugation on the surface of nanomaterials. The encapsulated drug is released as the nanomaterial disassembles at the target site, while the nanomaterial-conjugated drug is released after the bond between the nanomaterial and drug is cleaved at the target site.
- **Bone Regeneration:** Nanoparticles can be used to facilitate bone regeneration in the treatment of osteoporosis.

- **Cancer nanomedicine:** Cobalt oxide nanoparticles have a lot of usage in cancer nanomedicine due to their wide variety of biological uses.
- **Repairment of spinal cord:** Researchers are studying ways to use graphene nanoribbons to help repair spinal cord injuries.
- **COVID-19:** Recently, researchers from the Pacific Northwest National Laboratory have demonstrated that they can identify SARS-CoV-2, the virus that causes COVID-19, in the air by employing a nanotechnology-packed bubble that ruptures when it comes into contact with the virus. Also, Pfizer-BioNTech and Moderna used lipid nanoparticles for the development of COVID-19 mRNA-based vaccines namely the BNT162b2 and mRNA-1273 respectively.

4.2. Everyday Materials and Processes

- **Polymer composite materials:** Nanoscale additives in polymer composite materials for baseball bats, tennis rackets, motorcycle helmets, automobile bumpers, luggage, and power tool housings can make them simultaneously lightweight, stiff, durable, and resilient.
- **Fabrics:** Nanoscale additives to or surface treatments of fabrics help them resist wrinkling, staining, and bacterial growth, and provide lightweight ballistic energy deflection in personal body armor.
- **Nanomaterial films:** Nanoscale thin films on eyeglasses, computer and camera displays, windows, and other surfaces can make them water-repellent, anti reflective, self-cleaning, resistant to ultraviolet or infrared light, anti fog, antimicrobial, scratch-resistant, or electrically conductive.
- **Cosmetic products:** Nanoscale materials in cosmetic products provide greater clarity or coverage; cleansing; absorption; personalization; and antioxidant, anti-microbial, and other health properties in cleansers, complexion treatments, creams and lotions, shampoos, and specialized makeup.
- **Food industry:** Nano-engineered materials in the food industry include nanocomposites in food containers to minimize carbon dioxide leakage out of carbonated beverages, or reduce oxygen inflow, moisture outflow, or the growth of bacteria in order to keep food fresher and safer, longer. Nanosensors built into plastic packaging can warn against spoiled food. Nanosensors are being developed to detect salmonella, pesticides, and other contaminants on food before packaging and distribution.
- **Automotive products:** Nano-engineered materials in automotive products include high-power rechargeable battery systems; thermoelectric materials for temperature control; lower-rolling-resistance tires; high-efficiency/low-cost sensors and electronics; thin-film smart solar panels; and fuel additives and improved catalytic converters for cleaner exhaust and extended range.
- **Household products:** Nano-engineered materials make superior household products such as degreasers and stain removers; environmental sensors, alert systems, air purifiers and filters; antibacterial cleansers; and specialized paints and sealing products.
- **Coating of machine parts:** Nanostructured ceramic coatings exhibit much greater toughness than conventional wear-resistant coatings for machine parts.
- **As Catalyst:** Nanoparticles are used increasingly in catalysis to boost chemical reactions. This reduces the quantity of catalytic materials necessary to produce desired

results, saving money and reducing pollutants. Two big applications are in petroleum refining and in automotive catalytic converters.

4.3. Electronics and Information Technology Applications

- **Faster, smaller and portable system:** Nanotechnology is already in use in many computing, communications, and other electronics applications to provide faster, smaller, and more portable systems that can manage and store larger and larger amounts of information.
- **Saving data:** Magnetic random access memory (MRAM) enabled by nanometer-scale magnetic tunnel junctions can quickly and effectively save even encrypted data during a system shutdown or crash, enable resume-play features, and gather vehicle accident data.
- **OLEDs:** Displays for many new TVs, laptop computers, cell phones, digital cameras, and other devices incorporate nanostructured polymer films known as organic light-emitting diodes, or OLEDs. OLED screens offer brighter images in a flat format, as well as wider viewing angles, lighter weight, better picture density, lower power consumption, and longer lifetimes.
- **Other computing and electronic products:** Include Flash memory chips for iPod nanos; ultra responsive hearing aids; antimicrobial/antibacterial coatings on mouse/keyboard/cell phone casings; conductive inks for printed electronics for RFID/smart cards/smart packaging; more life-like video games; and flexible displays for e-book readers.
- **Carbon nanotube transistor:** Because of their excellent electrical conductivity, transistors based on carbon nanotubes have also long been seen as a potential replacement for silicon transistors in a computer. Carbon nanotube transistors would let developers sidestep the problem of heat generation and leakage, enabling chip makers to put more and more transistors on a chip.

4.4. Sustainable Energy Applications

- **Nanostructured solar cells and panels:** Prototype solar panels incorporating nanotechnology are more efficient than standard designs in converting sunlight to electricity, promising inexpensive solar power in the future. Nanostructured solar cells already are cheaper to manufacture and easier to install, since they can use print-like manufacturing processes and can be made in flexible rolls rather than discrete panels.
- **Fuel production and consumption efficiency:** Nanotechnology is improving the efficiency of fuel production from normal and low-grade raw petroleum materials through better catalysis, as well as fuel consumption efficiency in vehicles and power plants through higher-efficiency combustion and decreased friction.
- **Efficient batteries:** Nanotechnology is already being used in numerous new kinds of batteries that are less flammable, quicker-charging, more efficient, lighter weight, and that have a higher power density and hold electrical charge longer.
- **Alternate transport technology:** Nanostructured materials are being pursued to greatly improve hydrogen membrane and storage materials and the catalysts needed to realize fuel cells for alternative transportation technologies at reduced cost. Researchers are also working to develop a safe, lightweight hydrogen fuel tank.

- **Conversion of waste:** Various nanoscience-based options are being pursued to convert waste heat in computers, automobiles, homes, power plants, etc., to usable electrical power.
- **Carbon nanotubes for windmill:** An epoxy containing carbon nanotubes is being used to make windmill blades that are longer, stronger, and lighter-weight than other blades to increase the amount of electricity that windmills can generate.
- **Carbon nanotube wires:** Researchers are developing wires containing carbon nanotubes to have much lower resistance than the high-tension wires currently used in the electric grid and thus reduce transmission power loss.

4.5. Environmental Remediation Applications

- **Purification of drinking water:** Nanotechnology could help meet the need for affordable, clean drinking water through rapid, low-cost detection of impurities in and filtration and purification of water. For example, researchers have discovered unexpected magnetic interactions between ultrasmall specks of rust, which can help remove arsenic or carbon tetrachloride from water; they are developing nanostructured filters that can remove virus cells from water; and they are investigating a deionization method using nano-sized fiber electrodes to reduce the cost and energy requirements of removing salts from water.
- **Cleaning industrial water pollutants:** Nanoparticles will someday be used to clean industrial water pollutants in ground water through chemical reactions that render them harmless, at much lower cost than methods that require pumping the water out of the ground for treatment.
- **Oil cleanup:** Researchers have developed a nanofabric "paper towel," woven from tiny wires of potassium manganese oxide, that can absorb 20 times its weight in oil for cleanup applications.
- **Mechanical filtration:** Many airplane cabins and other types of air filters are nanotechnology-based filters that allow “mechanical filtration,” in which the fiber material creates nanoscale pores that trap particles larger than the size of the pores. They also may contain charcoal layers that remove odors.
- **Filter and neutralize harmful agents:** New nanotechnology-enabled sensors and solutions may one day be able to detect, identify, and filter out, and/or neutralize harmful chemical or biological agents in the air and soil with much higher sensitivity than is possible today. Researchers around the world are investigating carbon nanotube “scrubbers,” and membranes to separate carbon dioxide from power plant exhaust.

4.6. National Security

- **Nano-bio-detection scheme:** They include new and powerful bio-detection schemes that can analyze a potential bioterrorism threat. It also includes nano-materials that can detoxify an area or humans exposed to a set of toxins.
- **Nano-tech for soldiers:** Another area of great importance to national security is that of protecting the country's troops. Nanomaterials can be used to produce nano-battlesuit, nano-sensors, drones, satellites, nano-weapons, etc.
- **Nano-sensors at public protection:** Nanosensors' ability to detect at the molecular or even atomic level is critical. They could be used to detect radioactive materials or toxins like anthrax. They could be embedded in clothing or painted on the side of a building.

The high sensitivity of nanosensors also means that large public works, like a water system, could be routinely tested and even extremely small amounts of contaminants would be detected.

- **Protecting information systems:** Computers and networks are the foundation of major sectors of an economy like financial institutions and electric power sectors. Researchers working in the areas of Nano-electronics and Nano-computing hope to integrate transistor-like nanoscale devices into system architecture, to provide substantial advantages over current technologies. They are also working on the creation of powerful “grid protocols” that could make the world wide web obsolete, and something called quantum cryptography that could provide the type of electronic security systems that are impossible to crack.

4.7. Transportation Applications

- Nano-engineering of steel, concrete, asphalt, and other cementitious materials, and their recycled forms, offers great promise in terms of improving the performance, resiliency, and longevity of highway and transportation infrastructure components while reducing their cost. New systems may incorporate innovative capabilities into traditional infrastructure materials, such as the ability to generate or transmit energy.
- Nanoscale sensors and devices may provide cost-effective continuous structural monitoring of the condition and performance of bridges, tunnels, rails, parking structures, and pavements over time. Nanoscale sensors and devices may also support an enhanced transportation infrastructure that can communicate with vehicle-based systems to help drivers maintain lane position, avoid collisions, adjust travel routes to circumnavigate congestion, and other such activities.

4.8. Other Applications

- **Sunscreen:** Many sunscreens contain nano-particles of zinc oxide or titanium oxide. Older sunscreen formulas use larger particles, which is what gives most sunscreens their whitish color. Smaller particles are less visible, meaning this sunscreen doesn't give a whitish tinge.
- **Self-cleaning glass:** A company called Pilkington offers a product they call Active Glass, which uses nano-particles to make the glass photo-catalytic and hydrophilic. The photo-catalytic effect means that when UV radiation from light hits the glass, nano-particles become energized and begin to break down and loosen organic molecules on the glass. Hydrophilic means that when water makes contact with the glass, it spreads across the glass evenly, which helps wash the glass clean.
- **Clothing:** Scientists are using nano-particles to enhance clothing. By coating fabrics with a thin layer of zinc oxide nano-particles, manufacturers can create clothes that give better protection from UV radiation. Some clothes have nano-particles in the form of little hairs or whiskers that help repel water and other materials, making the clothing stain-resistant.
- **Scratch-resistant coatings:** Engineers discovered that adding aluminum silicate nano-particles to scratch-resistant polymer coatings made the coatings more effective, increasing resistance to chipping and scratching. Scratch-resistant coatings are common on everything from cars to eyeglass lenses.

5. Nanotechnology in India

5.1. Developments of Nanotechnology in India

- The Department of Science and Technology (DST) under the Ministry of Science and Technology has been assigned the responsibility of development of nanotechnology in India.
- To create the background and infrastructure for research and development in the field of nano-technology, the National Nanoscience and Technology Initiative (NSTI) was rolled out in 2001.
- The motive of launching NSTI was to create research infrastructure and promote basic research in nanoscience and nanotechnology.
- DST under NSTI established the Centre of Excellence for Nano Science and Technology. 20 such centres have been established in various states of the country.

5.2. National Mission of Nano Science and Technology

- National Mission of Nano Science and Technology - an umbrella programme was launched in 2007 to promote Research & Development in this emerging area of research in a comprehensive fashion.
- Recognizing the success of Nano Mission, the Union Cabinet accorded approval for continuation of the Nano Mission in its Phase-II during the 12th Plan period.
- India has secured third position amongst nations of the world for Scientific Publications in Nanoscience & Technology due to the efforts led by the Nano Mission.

Main Objectives

- Basic research promotion
- Research infrastructure development
- Nano application and technology development
- Human Development in Nanotechnology
- International collaboration and orchestrating national dialogues
- Establishment of Development Centre for Nanosciences