

① "Nanomaterials."

* General introduction to nanoscience ⇒

Nanoscience is an emerging area of science which deals itself with the study of materials that have very small dimensions, in the range of nano scale.

In Greek "nanos" } meaning "Dwarf" &

In Latin "nanus" } "Science" meaning "Knowledge"

The rough definition of Nanoscience could be anything which has at least one dimension less than 100 nanometers.

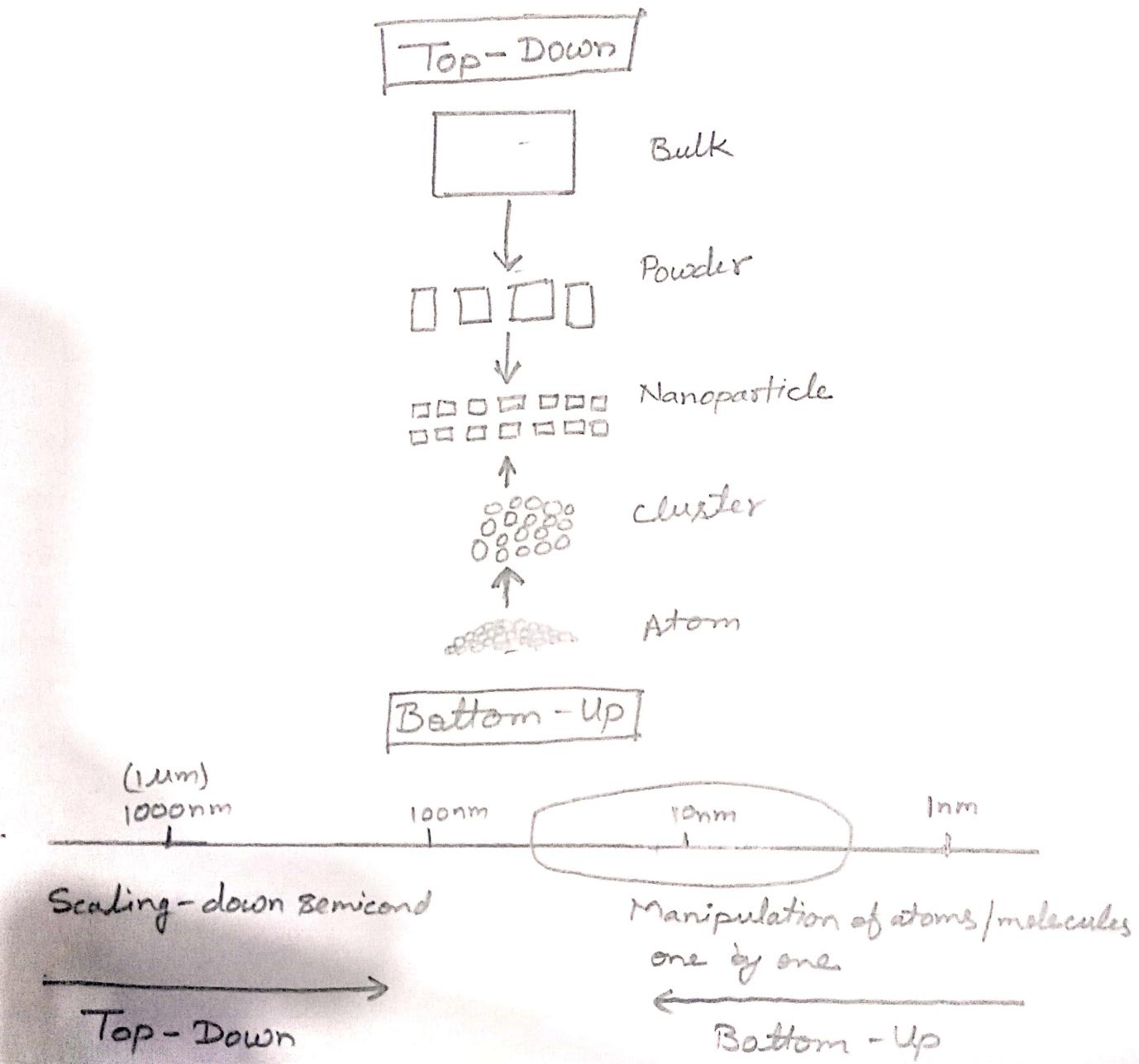
* Methods of Synthesis of Nanomaterials ⇒

Materials reduced to nano scale can suddenly show very different properties compared to what they exhibit on a macro scale, enabling unique applications.

For ex.

1. Copper which is an opaque substance become transparent.
2. Platinum which is an inert material turns become catalyst.
3. Aluminum which is a stable material turns combustible.
4. Silicon insulators become conductors.
5. Gold which is solid, inert and yellow on room temperature, at micro scale becomes liquid and red in color at nano scale on room temperature & also it gets unusual catalytic properties.

Methods of Synthesis of Nanomaterials 2 \Rightarrow



These are two general approaches for the synthesis of nanomaterials as shown in fig.

- Top-down approach
- Bottom-up approach

A] Top-down approach → ③

The Top-down approach to nanomaterial synthesis involves breaking down bulk materials into nano-sized structures or particles. This method is essentially an extension of traditional techniques used for producing larger micron-sized particles. It is characterized by its simplicity & dependence on either removing or dividing bulk material, or scaling down bulk fabrication processes to achieve the desired nanostucture with specific properties.

However, various techniques fall under the umbrella of top-down synthesis, including high-energy wet ball milling, electron beam lithography, atomic force manipulation, gas-phase condensation, and aerosol spray, among other.

B] Bottom-up approach →

The 'Bottom-up' approach involves building materials atom by atom or molecule by molecule, promising less waste and greater cost-effectiveness. Techniques like organometallic chemical routes and sol-gel synthesis are emerging for commercial nanopowder production, offering precise control over composition and structure, especially in preparing luminescent nanoparticles.

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Carbon Nanotubes (CNTs) →

Carbon nanotubes (CNTs) are nano-scale, hollow tubes composed of carbon atoms arranged in a hexagonal lattice, resembling rolled or folded graphene sheets.

Typically measuring 1-3 nanometers in diameter, CNTs exhibit remarkable mechanical strength. Their length surpasses their diameter, measured in micrometers.

Properties of Carbon Nanotubes →

- 1) Carbon nanotubes are exceptionally strong, boasting a hardness comparable to diamonds and a strength ten times that of steel.
- 2) They possess a low gravitational weight, being one-fourth as dense as steel.
- 3) Carbon nanotubes exhibit high heat capacity, approximately twenty times stronger than steel, making them resistant to expansion when heated.
- 4) Each carbon atom in a nanotube forms covalent bonds with three others, creating a hexagonal lattice structure.
- 5) Despite their strength, carbon nanotubes remain ductile, excellent heat and electrical conductors, and chemically inert, resisting corrosion.

Types of Carbon Nanotubes →

There are two types of carbon nanotubes.

- 1) Single-walled Carbon Nanotubes.
- 2) Multi-walled Carbon Nanotubes

⑤ Single-walled Carbon Nanotubes →

- ▷ Single-walled CNTs are cylindrical structures formed from rolled graphene sheets, with a one-dimensional shape.
- ▷ Different types of SWCNTs, such as armchair and zig-zag, are determined by how the graphene sheets are rolled.
- ▷ Armchair SWCNTs are always conductive, while other configurations can be semiconducting.
- ▷ The unique electronic properties of SWCNTs are determined by their specific atomic arrangement.
- ▷ SWCNTs offer exceptional strength, flexibility and electrical conductivity, making them valuable in various technological applications.

Properties of SWCNTs →

- ▷ SWCNTs act like semiconductors, showing properties of both metals & semiconductor diodes.
- ▷ Their band gap, which determines their electrical behaviour, ranges from 0 to 2 electron volts (eV).
- ▷ They are used in circuit disassembly due to their special electrical properties.
- ▷ Shaped like tiny wires, SWCNTs are one-dimensional structures with a length of about 2 micrometers and a diameter of 2 nanometers.

* Single-walled Carbon Nanotube Applications →

SWCNTs serve as multifunctional additives, enhancing diverse material properties at minimal concentrations.

Industries utilize them in composites, coating, tires, structural components, and electrochemical device.

Secondary applications include adhesive, lubricants, anti-static products, conductive films, and cables, etc.

1) In Composite Materials →

SWCNTs are finding their way into industries like alternative energy, construction, automotive, and aerospace. They are used to strengthen composite materials in wind turbine blades, boat hulls, and aircraft parts, making them lighter and stronger.

2) In Reinforced Plastics →

SWCNTs are becoming increasingly important in reinforced plastics, especially in industries like automotive and aerospace. In automotive, they help reduce the weight of car components, which is crucial for improving fuel efficiency or reducing the load on batteries in electric vehicles. In aerospace, where materials need to withstand extreme conditions and loads, SWCNTs offer solutions for making materials stronger and more durable.

3) In Industrial Coatings →

SWCNTs are added to primers and paints for vehicle coatings, equipment, and storage containers, offering improved durability and anti-static properties, making them ideal for over half of industrial coating products.

4) In Car Tires →

SWCNTs boost tire quality by strengthening stiffness, tear resistance, fuel efficiency, and grip, requiring only small amounts and no changes to production methods. They provide electrical conductivity without extra fillers like carbon black. SWCNTs are expected to be used in 30% of premium tires and 10% of standard tires.

5) In Electrochemical Power Sources →

SWCNTs improve virtually all electrochemical power sources, like rechargeable batteries for electric vehicles, laptops, and mobile phones. They boost storage capacity and lifespan, enhancing performance in segments such as lithium-ion batteries and alkaline cells.

6) Enhancing Rubber Goods →

SWCNTs offer technological benefits in rubber-based products, including enhanced strength, elasticity, cohesion, abrasion resistance, and colour retention. They have potential applications in about one-third of rubber technical goods.

⇒ Multi-Walled Carbon Nanotubes →

MWCNTs are like rolled-up scrolls made of several layers of carbon nanotubes. They have both outer and inner diameters, as if a single graphene sheet is rolled around itself multiple times. MWCNTs are stronger and more resistant to chemical reactions than SWCNTs. Chiral MWCNTs are one example of this type.

Properties of MWCNTs →

- 1) They have an outside diameter of 2-20 nm.
- 2) They have an inner diameter of 1-3 nm.
- 3) They have a length of around 5-6 micrometers.
- 4) MWCNTs exhibit remarkable tensile strength, even more than steel, due to strong sp bonds between carbon atoms.
- 5) When added to materials like thermosets or thermoplastic, MWCNTs greatly increase the strength of the composite.
- 6) MWCNTs are excellent conductors of electricity when integrated into composites, mainly through their outer walls. They also exhibit outstanding chemical and thermal stability, enduring temperatures exceeding 600°C.

* Multi-Walled Carbon nanotubes Applications →

MWCNTs are utilized for electron field emitters and RFI shielding in electronics, while enhancing strength in composites for aerospace. They are also play a vital role in electrically conductive polymers, improving battery cathodes, and creating efficient water filtration membranes.

1) In Batteries →

Replacing graphite with MWCNTs doubles the storage capacity of lithium-ion batteries, essential for portable electronics. MWCNTs-based electrodes are lighter, thinner, and ten times more conductive than amorphous carbon, reducing battery weight and power needs, especially in electric vehicles.

In supercapacitors, MWCNTs increases power density, enabling faster charging times for devices like cell phones and laptops.

2) In Solar Cells →

Solar cells with tall towers of MWCNTs grown on ~~iron~~-coated silicon ~~wafers~~ ^{sheet} absorb more light. Each tower contains millions of vertically aligned MWCNTs, leading to efficiency peaks at 45 and 90 degrees to the sun, making them ideal for space applications without requiring mechanical orientation.

3) In Transistors →

MWCNTs can be used as transistors in modern integrated circuits, offering a potential alternative to traditional silicon switches, although they may initially require very low temperatures and operate at the scale of individual electrons.

4) In Nano-Electronics →

MWCNTs play a vital role in nanoelectronics due to their high conductivity, offering potential as semiconductor alternatives to silicon, with conductivity influenced by their structure.

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5) In Enhancing Flat Panel Displays →

MWCNTs are used in flat panel displays, forming cathode stripes on glass plates and interacting with phosphor-coated Indium-Tin-Oxide (ITO) anode stripes to create pixels.

Samsung developed a Field Emission Display with MWCNTs stripes aligned with the anode, synthesized via arc-discharge, dispersed in isopropyl alcohol, and mixed with nitrocellulose.

6) In Energy Production and Storage Applications →

MWCNTs are essential for energy production and storage, offering superior properties for electrodes in batteries, fuel cells, and electrochemical applications compared to traditional carbonaceous materials like carbon fibers and graphite.

3) Uses of Nanomaterials in Catalysis →

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Nanomaterials are revolutionizing catalysis by enhancing how catalysts interact with substances they are designed to react with. Their tiny size and unique surface properties make them highly effective in various catalytic processes.

a) HYDROGEN STORAGE ⇒ CNTs are like tiny tubes made of carbon atoms. Scientists are interested in them because they can store hydrogen gas really well. Research has shown that CNTs can hold more hydrogen than other materials, even at room temperature. This makes them promising for storing hydrogen, which is a clean and efficient energy source.

b) WATER PURIFICATION ⇒ Nanoparticles made of titanium dioxide are used to clean water. Titanium dioxide is a special material that can absorb light and create a reaction that clean water. When light hits titanium dioxide nanoparticles in water, it makes electrons move around, which helps to break down harmful substance in water. Scientists are also looking into using silver nanoparticles to make water filters that can kill bacteria and keep water clean.

c) CO OXIDATION IN CATALYTIC CONVERTERS ⇒ Catalytic converters are devices in cars that clean up harmful gases from the exhaust. Nanomaterials, tiny particles measured in nanometers, are used in catalytic converters to clean up carbon monoxide (CO) emission. By using really small nanoparticles, scientist hope to make catalytic converter more efficient at reducing pollution from cars.

4) Uses of Nanomaterials in Environment

Nanomaterials play a vital role in addressing environmental challenges like pollution, climate change and resource depletion by providing innovative solutions and applications specifically designed for these issues.

⇒ CLEANING POLLUTION ⇒ Nanomaterials like graphene oxide can absorb oil spills in water, while titanium dioxide nanoparticles break down pollutants in soil.

⇒ PURIFYING WATER ⇒ Nanoparticles such as carbon nanotubes are used in water filters to remove contaminations and silver nanoparticles can kill bacteria in water purification system.

⇒ FILTERING AIR ⇒ Air purifiers with nanomaterial filters, like nanofibers made from polymers or metal oxides, trap harmful particles and gases, improving indoor air quality.

⇒ FIXING SOIL ⇒ Nanoparticles like iron oxide can bind to heavy metals in soil, making them easier to remove, while nanoscale zero-valent iron can degrade organic pollutants.

⇒ SENSORS FOR MONITORING ⇒ Nanoparticle based sensors, such as CNTs sensor for detecting volatile organic compounds, provide real-time data on environmental parameters.

⇒ GENERATING CLEAN ENERGY ⇒ Quantum dots enhance the efficiency of solar panels by converting more sunlight into electricity, and nanocatalysts improve the performance of fuel cells for cleaner energy production.

⇒ MANAGING WASTE ⇒ Nanomaterials like nano-zero valent iron break down hazardous waste into harmless byproducts, while nanocomposites strengthen landfill liners to prevent leachate contamination.

⇒ MONITORING THE ENVIRONMENT ⇒ Smart nanosensor embedded in environmental monitoring devices, like wearable air quality monitors, track pollution levels and provide alerts to users.

⇒ RESTORING ECOSYSTEMS ⇒ Nanoparticles like biochar enhance soil fertility by improving water retention and nutrient availability, promoting plant growth and ecosystem restoration.

③ Uses of Nanomaterials in catalysis →

Nanomaterials are revolutionizing catalysis by enhancing how catalysts interact with substances they are designed to react with. Their tiny size and unique surface properties make them highly effective in various catalytic processes. For example: carbon nano-tube shows promise in efficiently storing hydrogen, while titanium dioxide nanoparticles are used to help purify water by harnessing sunlight to break down contamination. Similarly nanoparticles are exploited for preventing bacterial growth in water filters.

In automotive technology, nanoparticles are utilized in catalytic converters to reduce harmful emission from vehicle. However, challenges such as non-particle particulate clumping need to be addressed by scientist. Overall nanomaterials play a crucial role in developing clean energy sources and improving environmental protection measures. Their application in catalysis offers exciting possibility for creating more efficient and eco-friendly solutions to address issues like pollution and resources depletion.

Uses of Nanomaterials:

1) Use of Nanomaterials in electronics →

Electronics are crucial in our daily lives, powering devices like smartphones, computers, and TVs. Nanomaterials such as carbon nanotubes and graphene, are revolutionizing electronics by offering better creation of thinner, lighter, and more efficient electronic circuits and displays.

Nanoelectronics focuses on making electronic device smaller, lighter, and more powerful. By manipulating electronic ~~device~~ ~~size~~ materials at the nanoscale, scientist can unlock new capable for electronics. This field ~~has~~ holds promise for improving every efficiency, enhancing device performance of wearable technology,

One significant application of nano electronics is in energy storage capable of ~~lasting~~ and generations.

Nanomaterials ~~application~~ of enable of the development of display screens with lower power consumption and memory chip capable of storing vast amount of in compact space. Wearable electronics such as smart ~~watches~~ -watches and fitness tracker benefit from nanomaterials -lightweighted and energy - efficient properties.

Moreover, nanoelectronics contribute to advancement in green energy technologies like solar cell and supercapacitors, offering ~~more~~ sustainable and efficient power solution. Overall, nanomaterials play a pivotal role in shaping the future of electronics, paving the way for smaller, smarter, and more energy - efficient devices that enhance our daily lives.

2) Uses of Nanomaterials in Sensors →

Sensors, vital tools for detecting physical, chemical, or biological signals, can be greatly enhanced by incorporating nanomaterials. These tiny structures revolutionize sensors by boosting sensitivity, selectivity, and speed of response. For example, nanoscale particles and films empower sensors to detect even small quantities of gases, toxins, or biomolecules. These sensors can seamlessly integrate into wearable or implantable devices, simplifying health monitoring.

Moreover, nanomaterials unlock novel sensor types like nanophotonic sensors, which exploit light to detect changes in refractive index, or nanomechanical sensors which utilize vibrations to sense mass or force alterations. These advancements mark a significant step in sensor technology, offering heightened accuracy, efficient efficiency, and adaptability across numerous applications.

From monitoring air quality and detecting pollutants to tracking vital signs in healthcare, nanomaterial-based sensors promise transformative impacts. They enable us to better understand and interact with our environment, addressing pending challenges more effectively. As nanotechnology research progresses, the potential for further innovation in sensor design and functionality grows exponentially.

In essence, nano-material enhanced sensors represent a cornerstone of modern technology, poised to reshape industries and improve lives. With their unparalleled capabilities, these sensors herald a future where our ability to detect and respond to diverse stimuli is more precise, efficient, and accessible than ever before.