Nano Materials

Nanoscale materials are defined as a set of substances where at least one dimension is less than about 100nm. A nanometer is one millionth of a millimeter.
Properties of Nanomaterials-

- large fraction of surface atoms
- high surface energy
- spatial confinement
- reduced imperfections

Can be classified by dimensions.

Surface effect

$$\boxed{\text{Size} \quad \alpha \quad \frac{1}{surface\ area}}$$

As the size of particle decreases, greater proportion of atom are found at the surface.
for e.g. Size 30 nm- 5% of atom on its surface. Size 10 nm- 20% of atom on its surface. Size 3 nm- 50% of atom on its surface.

To understand the effect of particle size on surface area, consider an American Silver Eagle coin. This silver dollar contains 31 grams of coin silver and has a total surface area of approximately 3000 square millimeters. If the same amount of coin silver were divided into nanoparticles– say 10 nanometer in diameter– the total surface area of those particles would be 7000 square meters (which is equal to the size of a soccer field)

Quantum Effect

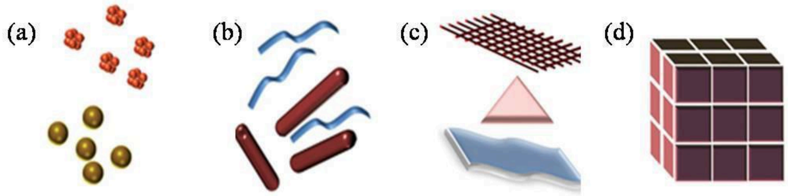
The quantum confinement effect can be **observed once the diameter of a particle is of the same magnitude as the wavelength of electrons** (very very small). This means that **quantum mechanical properties dominate.** This leads to changes in electronic, optical, and magnetic behaviors, such as discrete energy levels, quantum confinement, and enhanced reactivity.

- The quantum confinement effect is responsible for an increase of energy gap between the valence band and the conduction band.
- When particles are small, their electric, optical and magnetic properties differ significantly from bulk materials.

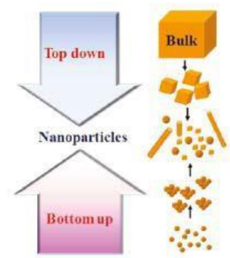
Classification of Nanomaterials:

- Zero dimension (quantum dots)
- One dimension (quantum wires, rods)

- Two dimension (plates, network, quantum wells)
- Three dimension (fullerenes- C60, hackelites)



Nanomaterial - synthesis and processing

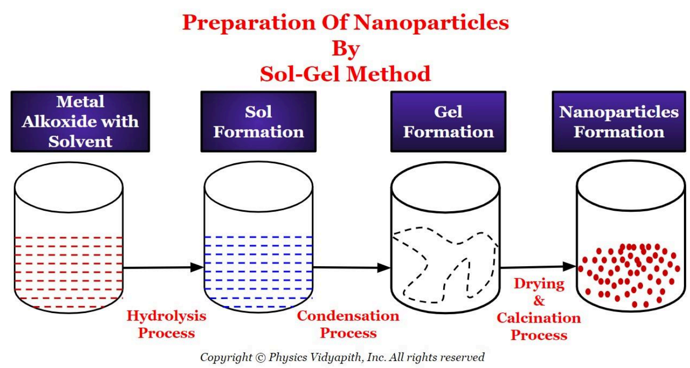


Nanomaterials deal with very fine structures: a nanometer is a billionth of a meter. This indeed allows us to think in both the 'bottom up' or the 'top down' approaches to synthesize nanomaterials.

Bottom up

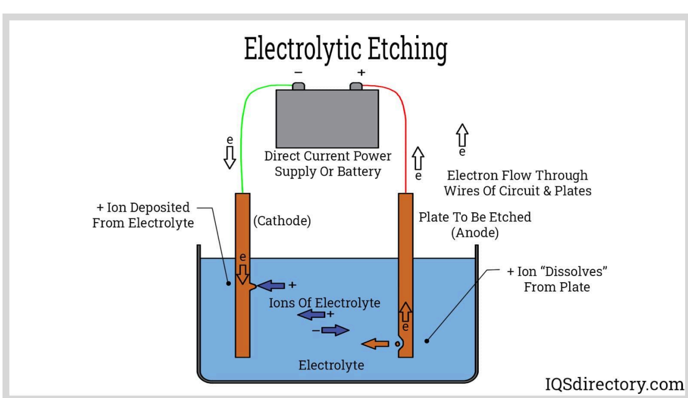
The bottom-up method of preparing nanomaterials involves building structures atom by atom or molecule by molecule. Techniques include chemical vapor deposition, sol-gel processes, and self-assembly.

Assemble atoms (sol-gel method, precipitation etc.) Example, synthesizing non metallic inorganic materials like glasses, glass ceramics or ceramic materials at very low temperatures.



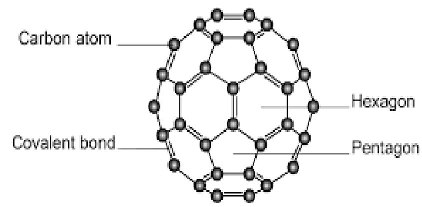
Top down

The top-down method involves breaking down bulk materials into nanoscale structures through processes like milling, lithography, or etching.
For example, the synthesis of porous silicon by electrochemical etching.



Fullerenes

Fullerenes are spherical carbon-cage molecules with sixty (C60) or more carbon atoms. A hollow pure carbon molecule in which atom lies at the vertices of polyhedron with 12 pentagonal faces and any number of hexagonal faces. Each carbon is bound to other three carbon in pseudo spherical arrangement of alternating pentagonal and hexagonal rings in the manner of a soccer ball. Hence the nickname Bucky ball. They measure about 0.7-1.5 nm in diameter.

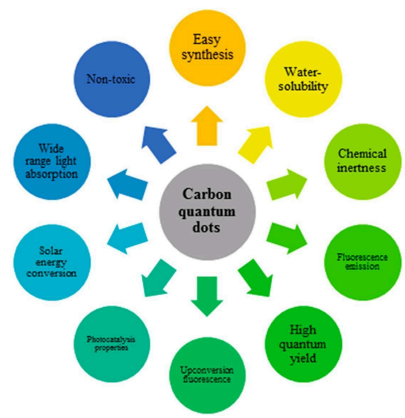


Structure of Fullerene(C60)

Properties:
They are fascinating for scientists because they show unusual properties for carbon materials.

- Fullerenes are studied for **potential medical** use: they are **strong antioxidants**; one could also bind specific antibiotics to the structure to target resistant bacteria and even target certain cancer cells such as melanoma.
- **Heat resistance and superconductivity** are some of the more heavily studied properties of fullerenes in mechanical engineering.

Quantum Dot



The average distance between an electron and a hole in an exciton is called the Excited Bohr Radius.

- When the **size of the semiconductor falls below the Bohr Radius, the semiconductor is called a quantum dot.**
- By changing size, shape, and composition, quantum dots can change their absorptive and emissive properties dramatically.

Advantages:

1. Medicine
    - Can be set to any arbitrary emission spectra to allow labeling and observation of detailed biological processes.
    - Quantum Dots can be a **useful tool for monitoring cancerous cells** and providing a means to better understand its evolution.
    - In the future, Q-dots could also be armed with **tumor-fighting toxic therapies to provide the diagnosis and treatment of cancer.**
    - Q-dots are much more resistant to degradation than other **optical imaging probes** such as organic dyes, allowing them to track cell processes for longer periods of time.
    - Quantum dots offer a **wide broadband absorption spectrum** while maintaining a distinct, static emission wavelength.
2. LED
    - Used to produce **inexpensive, industrial quality white light.**
    - Marked improvement over traditional LED–phosphor integration by dot's ability to absorb and emit at any desired wavelength.
    - **Produce white light by intermixing red, green, and blue emitting dots homogeneously** within the phosphor difficult to accomplish with the traditional LED-phosphor set up.

3. Solar Cells
    - Traditional solar cells are made of semi-conductors and expensive to produce.
    - Theoretical upper limit is 33% efficiency for conversion of sunlight to electricity for these cells.
    - **Utilizing quantum dots allows realization of third-generation solar cells at ~60% efficiency in electricity** production while being $100 or less per square meter of paneling necessary.
    - Effective due to quantum dots' ability to preferentially absorb and emit radiation that results in **optimal generation of electric current and voltage.**

CNTs

Carbon Nanotubes (CNTs) are cylindrical nanostructures made of carbon atoms arranged in a hexagonal lattice, exhibiting unique mechanical, electrical, and thermal properties. They are classified into single-walled (SWCNTs) and multi-walled carbon nanotubes (MWCNTs).

Properties:

1. Exceptional tensile strength (hundreds of times stronger than steel).
2. High electrical conductivity, similar to copper.
3. Superior thermal conductivity.
4. High aspect ratio and flexibility.

Applications:

1. Aerospace engineering
2. Used in electronics for better conductivity.
3. Energy storage in batteries and capacitors.
4. Medical uses, like administering medicine.

1. Arc Method

In the arc method, carbon nanotubes are synthesized by creating an electric arc between two carbon electrodes in an inert gas (like helium). The carbon vaporized from the electrodes condenses to form nanotubes. This method produces both single-walled and multi-walled CNTs but requires high temperatures and typically results in lower purity.

2. Laser Ablation Method

In the laser ablation method, a high-powered laser is used to vaporize a graphite target in an inert gas (like argon) at high temperatures. The vaporized carbon condenses onto a cooler surface, forming nanotubes. This method yields high-purity single-walled carbon nanotubes (SWCNTs) but is expensive and energy-intensive.

3. Chemical Vapor Deposition (CVD) Method

In CVD, a carbon-containing gas (e.g., methane) is heated in the presence of a metal catalyst (like iron or nickel) at high temperatures. The carbon decomposes and forms nanotubes on the catalyst particles. This method allows for large-scale production of CNTs and can be controlled to produce either single-walled or multi-walled CNTs with good purity.