

SEMICONDUCTORS

- Semiconductors are the materials which have a **conductivity between conductors** (generally metals) and non-conductors or **insulators** (such as ceramics).
- Semiconductors can be compounds such as gallium arsenide or pure elements, such as germanium or silicon.

Examples of Semiconductors:

- Gallium arsenide, germanium, and silicon are some of the most **commonly used semiconductors**. Silicon is used in electronic circuit fabrication and gallium arsenide is used in solar cells, laser diodes, etc.
- **Holes and electrons** are the types of charge carriers accountable for the flow of current in semiconductors.
- **Holes** (valence electrons) are the positively charged electric charge carrier whereas **electrons** are the negatively charged particles.
- Semiconductors can conduct electricity under preferable conditions or circumstances.
- This unique property makes it an excellent material to conduct electricity in a controlled manner as required.

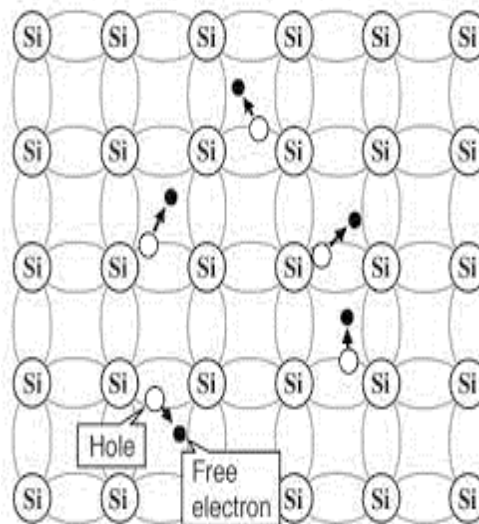
Properties of Semiconductors:

1. Semiconductor acts like an insulator at Zero Kelvin. On increasing the temperature, it works as a conductor.
2. Due to their exceptional electrical properties, semiconductors can be modified by doping to make semiconductor devices suitable for energy conversion, switches, and amplifiers.
3. Their resistivity is higher than conductors but lesser than insulators.
4. The resistance of semiconductor materials decreases with the increase in temperature and vice-versa.

Types of Semiconductors:

Intrinsic Semiconductor

- An **intrinsic type of semiconductor material** is made up of only a single type of element.
- Germanium (Ge) and Silicon (Si) are the most common type of intrinsic semiconductor elements.
- They have four valence electrons (tetravalent).
- They are bound to the atom by covalent bond at absolute zero temperature.
- When the temperature rises, due to collisions, few electrons are unbounded and become free to move through the lattice, thus creating an absence in its original position (hole).
- These free electrons and holes contribute to the conduction of electricity in the semiconductor. The negative and positive charge carriers are equal in number.



Extrinsic Semiconductor

- The conductivity of semiconductors can be greatly improved by introducing a small number of suitable replacement atoms called **impurities**.

- The process of adding impurity atoms to the pure semiconductor is called **doping**.

. An extrinsic semiconductor can be further classified into:

- **N-type Semiconductor**
- **P-type Semiconductor**

N-Type Semiconductor

- When a pure semiconductor (Silicon or Germanium) is doped by pentavalent impurity (P, As, Sb, Bi) then, four electrons out of five valence electrons bonds with the four electrons of Ge or Si.
- The fifth electron of the dopant is set free. Thus, the impurity atom donates a free electron for conduction in the lattice and is called “**Donar**”.
- Since the number of free electron increases by the addition of an impurity, the negative charge carriers increase. Hence, it is called n-type semiconductor.
- As conduction is due to a large number of free electrons, the electrons in the n-type semiconductor are the majority carriers

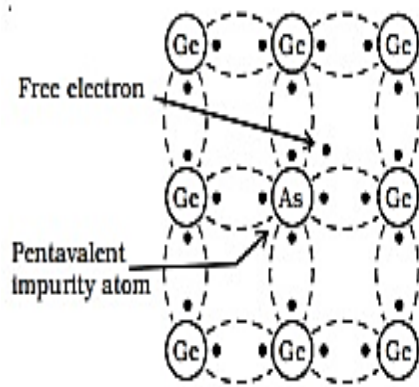


Fig a N-type semiconductor

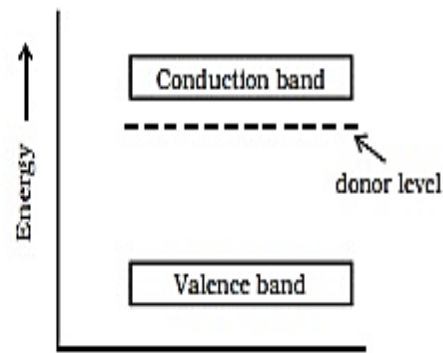
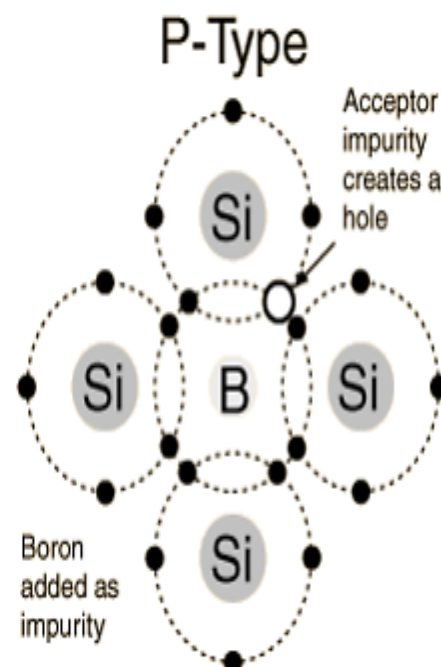
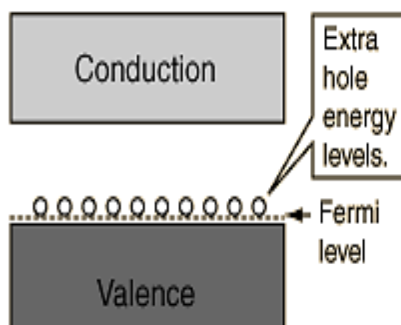


Fig b Energy band diagram of N-type semiconductor

P-Type Semiconductor

- When a pure semiconductor is doped with a trivalent impurity (B, Al, In, Ga) then, the three valence electrons of the impurity bonds with three of the four valence electrons of the semiconductor.
- This leaves an absence of electron (hole) in the impurity. These impurity atoms which are ready to accept bonded electrons are called “**Acceptors**”.
- With the increase in the number of impurities, holes (the positive charge carriers) are increased. Hence, it is called p-type semiconductor.
- As conduction is due to a large number of holes, the holes in the p-type semiconductor are majority carriers



NON-ELEMENTAL SEMICONDUCTING MATERIALS (Compound Semiconductors):

Besides Si and Ge, many intermediate and ceramic compounds exhibit semi conductivity. These compounds may be grouped into (1) **Stoichiometric semiconducting compounds** are intermediate compounds having an average movement of positive electric charge four valence electrons per atom and possess crystal structures and band structures similar to those of Si and Ge. Such intermediate semiconducting compounds may be prepared by the combining

- (1) elements of group III (e.g., Ga, In) and group V (eg P. As, Sb),
- (2) elements of group II (eg, Cd. and group VI (eg., S, Se, Te).

For example, gallium arsenite GaAs is a III-V groups combination. The $4S^2, 4P^1$ level of Ga and $4S^2, 4P^3$ level of As overlap to yield a hybrid band. GaAs compound has a wide energy gap (E) of 135 eV and this can be used as a semiconductor with a wider range of temperature than the elemental semiconductor Si or Ge. It may be pointed here that GaAs can also be doped to yield n-type or p-type semiconductors.

The energy gap in the stoichiometric semiconductors can be reduced by substituting one of its elements by an element of higher atomic number belong to the same group this can be observed in the below table.

Compound	GaP	GaAs	GaSb	InSb	CdS	CdSe	PbS	PbTe
Groups	III-V	III-V	III-V	III-V	II-VI	II-VI	II-VI	II-VI
Energy gap (E _g) in eV	2.24	1.35	0.67	0.36	2.42	1.74	0.37	0.25

Applications of Semiconductors:

- Semiconductors are used in almost all electronic devices. Without them, our life would be much different.
- Temperature sensors are made with semiconductor devices.
- They are used in 3D printing machines
- Used in microchips and self-driving cars
- Used in calculators, solar plates, computers and other electronic devices.

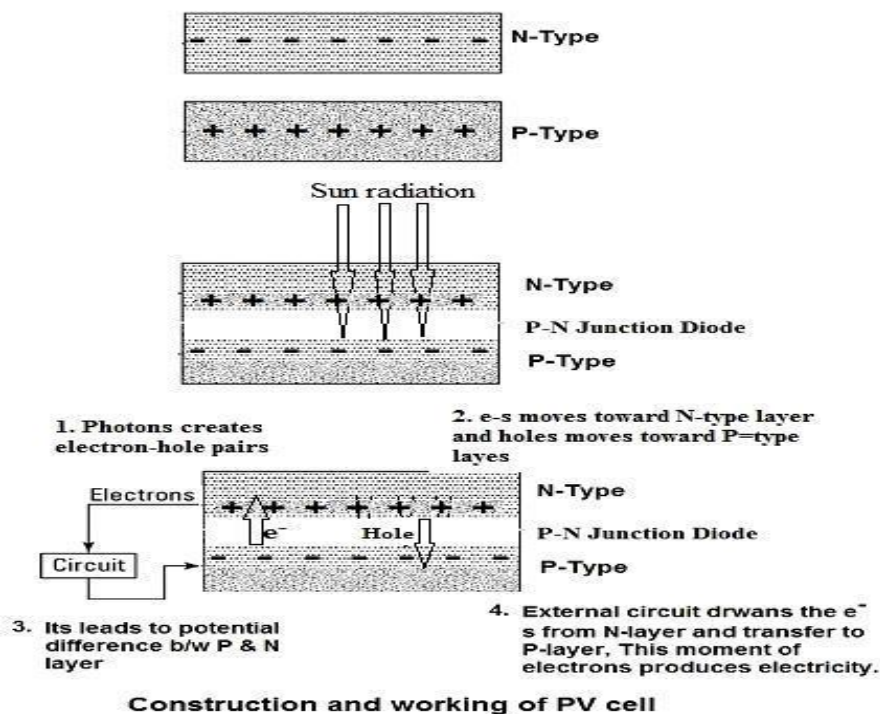
SOLAR CELLS

Photo Voltaic Cell (PV Cell): Photovoltaic cell is a device which **converts the solar radiation into electrical energy** by using the **semiconductor device**.

- The main components of PV cell are semiconductors and solar radiation.
- Solar radiation is energy source and this energy is converted into electrical energy by using semiconductor device.

Construction of PV Cell:

- Photo voltaic cells are made up of semiconductors, such as doped silicon materials.
- There are two types of semiconductor material, called positive (P-type) and negative (N-type) semiconductors.
- P-type is made by doping of pure Si with 13 group elements (Ex: Boron) and creates more **positively charged holes** on it.
- N-type is made by doping of pure Si with 15 group elements (Ex: Phosphorous) and creates more **negatively charged electrons** on it.
- When P,N layers are placed together, and the physical boundary between them is called the P-N junction diode.
- This P-N junction diode arranged to expose to sun light.
- Two electrodes (metal electrodes) are connected to upper and lower layer of PV cell.



Working of PV cell:

- When enough sunlight is irradiated on PV cell, it reaches to P-N junction diode and creates **electron-hole pairs**.
- Electrons are tends to move towards N-type layer and positive holes move towards P-type layer.
- Due to this separation of charges **potential difference exit between the two layers**.
- When both p and n layers are connected through an external circuit, **electrons are moved from N-layer to P-layer through external circuit**.
- This moment of electrons produce electricity.

Advantages:

- **Green process**, no hazards gasses released during production of electricity.
- **Renewable process**, the sources of energy is Sun.
- PV arrays can be installed quickly and in any size.

SUPERCONDUCTIVITY

INTRODUCTION

In 1908, a Dutch physicist, Kammerlingh Onnes studied the variation of electrical resistance of metals at low temperatures. He discovered that, the electrical resistance of highly purified mercury dropped abruptly to zero at 4.15K. He called this new phenomenon, superconductivity. Subsequently, this was discovered in Lead (Pb), Tin (Sn), Zinc (Zn), Aluminum (Al), other metals and alloys.

SUPERCONDUCTIVITY

The sudden disappearance of electrical resistance in materials when cooled below a certain temperature is called superconductivity and the temperature at which a normal material turns into a superconductor is called the **critical temperature (or transition temperature) T_C** .

GENERAL FEATURES

- The transition temperature is different for different substances
- Superconductivity is found to occur in metallic elements with valence electrons between 2 and 8
- Transition metals having odd number of valence electrons are unfavourable to exhibit superconductivity, while metals with even number of valence electrons are unfavourable.
- There is no change in the crystal structure at superconducting state as revealed by x-ray diffraction.
- The superconducting property of a superconductor is not lost by adding impurities to it, but the critical temperature is lowered.
- Ferromagnetic and anti ferromagnetic materials are not superconductors
- The magnetic flux lines are rejected out of the superconductor

MEISSNER EFFECT:

The expulsion of magnetic lines of force from the body of the superconductor when it is cooled below its transition temperature is known as Meissner Effect.

TYPE-I & TYPE-II SUPERCONDUCTORS:

Superconductors are divided into two types depending upon the way in which the transition from superconducting state to normal state takes place, when the magnetic field exceeds the critical value H_C i.e. based on the diamagnetic response of the substance in an external magnetic field.

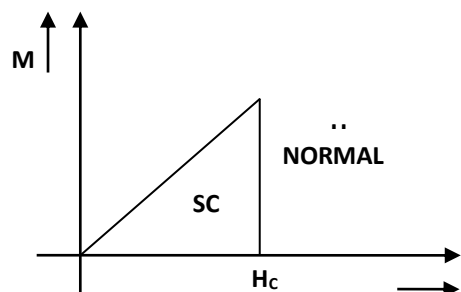
They are **Type-I or soft superconductors**

Type-II or hard superconductors

Type – I Superconductors

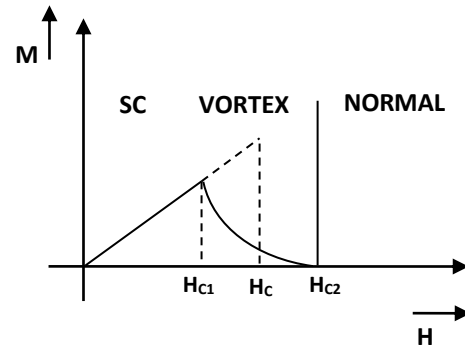
Superconductors exhibiting a complete Meissner effect (perfect diamagnetism) are called type-I superconductors. When the magnetic field strength is gradually increased from its initial value $H < H_C$, at H_C , the diamagnetism abruptly disappear and the transition from superconducting to the normal state is sharp. These are also referred to as soft superconductors.

E.g. Al, Zn, Hg and Sn (pure specimens)



Type – II Superconductors

In type-II, up to a field H_{C1} , called the **lower critical field**, the specimen is in the superconducting state. The magnetic flux lines are rejected. When the field is increased beyond H_{C1} , flux lines start penetrating. Between H_{C1} & H_{C2} the specimen is in a mixed state (neither superconducting state nor normal state). This H_{C2} is called the **upper critical field**. Above H_{C2} , the specimen is in a normal state. This means that, the Meissner effect is incomplete in the region between H_{C1} & H_{C2} . This region is called **vortex region**. These are also called hard superconductors. These are of great practical interest because of the high current densities that can carry. E.g.: Ta, V, Nb and Yttrium barium copper oxide (1:2:3) .



Difference between Type-I and Type-II Superconductors:

Type-I Superconductor

1. These are usually elements in their pure form.
2. Transition to normal state occurs abruptly at the critical field H_C
3. Value of H_C is usually small.
4. These exhibit complete Meissner effect. Hence perfectly diamagnetic up to H_C .
5. Example: Al, Zn, Pb, Hg, Sn etc.

Type-II Superconductor

1. These are impure elements, alloys or compounds.
2. Transition to normal state begins at H_{C1} and is completed only at H_{C2} .
3. Value of H_{C1} is small, where H_{C2} is quite large.
4. These are not obeying the Meissner effect between H_{C1} and H_{C2} and become normal at H_{C2} .
5. Example: Alloys consist of Ta, V, Nb

APPLICATIONS OF SUPERCONDUCTORS:

1. **Magnetic Resonance Imaging (MRI):** Superconducting magnets are vital components in MRI machines due to their ability to generate strong and stable magnetic fields for high-resolution imaging.
2. **Electric Power Infrastructure:** Superconductors can be used in power transmission lines, enabling the efficient transport of electricity without significant losses that occur in conventional systems.
3. **Particle Accelerators:** Superconducting materials are used to create powerful magnetic fields in particle accelerators, enabling the manipulation and acceleration of particles for research in physics and medicine.
4. **Maglev Trains:** Superconductors are used in magnetic levitation (maglev) train systems to create the magnetic fields that lift and propel the train above the tracks, reducing friction and enabling high-speed, efficient transportation.
5. **Electronics and Computing:** Superconducting materials hold promise in creating more efficient and faster electronic circuits, such as superconducting quantum interference devices (SQUIDS) for highly sensitive measurements and quantum computing applications.
6. **Medical Devices:** Superconductors are utilized in devices like superconducting quantum interference devices (SQUIDS) for highly sensitive measurements in medical diagnostics and research.
7. **Research and Science:** They are crucial in scientific research for generating high magnetic fields for studying materials, condensed matter physics, and other scientific experiments.

The field of superconductivity continues to advance, and ongoing research and technological developments are likely to expand the range of applications further in various industries.

NANO MATERIALS

Nanomaterials:

- Nanomaterials are one of the main products of nanotechnologies having nano-scale particles, tubes, rods, or fibres.
- Nanoparticles are normally defined as being smaller than 100 nanometres in at least one dimension.
- Nano materials in one dimensional are layers like thin films or surface coatings. One dimensional nano structures offer unique opportunities to control the density of semiconductors.
- Nano materials in two dimensions are tubes like nano tubes and nano wires. Nanowires are considered as building blocks for the next generation of electronics, photonics, sensors and energy applications.
- Nano materials in three dimensions are particles like precipitates, colloids and quantum dots. A quantum dot is a particle having an approximate size of one nanometre which has display properties of a semiconductor.

Metal and metal oxide nanoparticles are nanoscale materials composed of either metallic elements or metal oxides, which are compounds formed by the combination of metals with oxygen. These nanoparticles have gained significant attention in various fields due to their unique properties and potential applications. Here's a brief introduction to both types:

1. Metal Nanoparticles:

Metal nanoparticles are extremely small particles, typically ranging from 1 to 100 nanometers in size.

They exhibit unique properties compared to their bulk counterparts, such as enhanced catalytic activity, surface plasmon resonance, and increased surface area.

These properties make metal nanoparticles valuable in applications like catalysis, electronics, sensors, and medical diagnostics.

Common metal nanoparticles include gold, silver, platinum, and copper nanoparticles.

2. Metal Oxide Nanoparticles:

Metal oxide nanoparticles are composed of metal atoms bonded with oxygen atoms to form various compounds.

Examples of metal oxide nanoparticles include titanium dioxide (TiO₂), zinc oxide (ZnO), and iron oxide (Fe₃O₄ or Fe₂O₃).

They possess unique properties, such as semiconductor behavior, photocatalytic activity, and magnetic properties, depending on the specific metal oxide.

Applications of metal oxide nanoparticles range from photovoltaics, photocatalysis, drug delivery, to environmental remediation.

Both types of nanoparticles are synthesized using various methods, including chemical reduction, sol-gel processes, and physical vapor deposition. Their small size and high surface area-to-volume ratio contribute to their versatility and usefulness in diverse technological and scientific advancements.

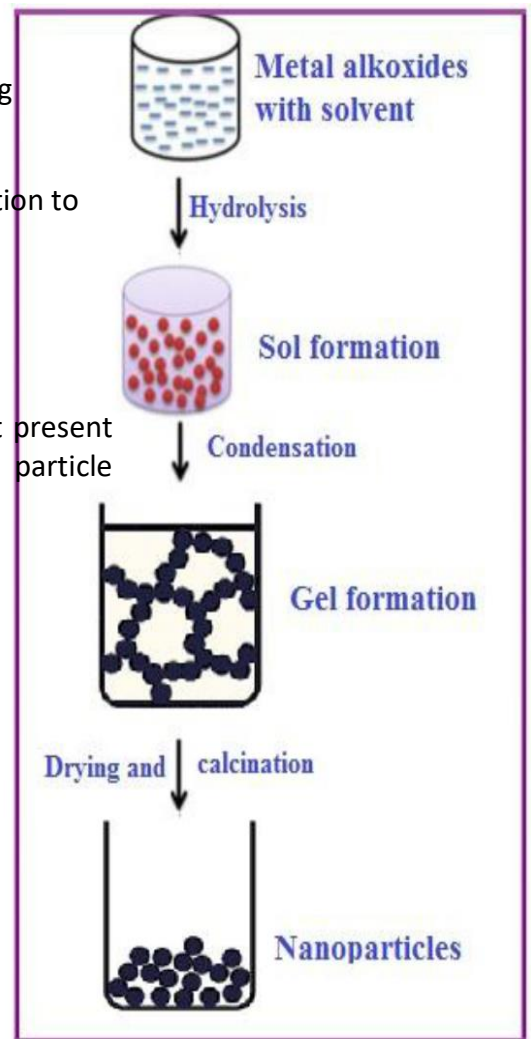
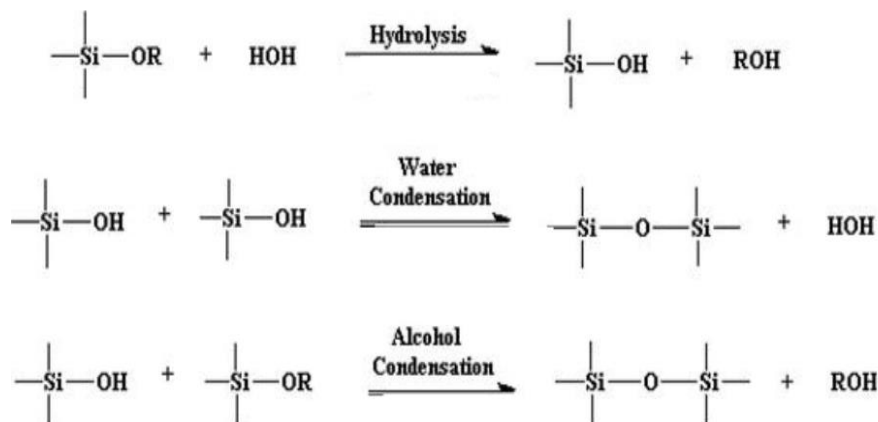
Sol-Gel Process:

The sol-gel process, as the name implies, **the transition of a liquid colloidal solution (sol) to a solid three-dimensional network (gel).**

It involves several steps, such as **hydrolysis and polycondensation**, gelation, aging, drying, calcination. A **sol** is a type of colloid in which very small solid ionic particles are suspended in a liquid. A **gel** is a semi rigid mass which is obtained after poly condensation of particles present in the sol. During this process the ions present in the sol, arranged in continuous 3-D network in gel.

Process:

- ❑ Metal alkoxide or metal chlorides are generally taken as starting materials for this process.
- ❑ They undergo hydrolysis to form sol and followed by condensation to form gel.
- ❑ Here, metal oxide networks formed due to formation of bonds between metal centers with -O or -OH groups.
- ❑ These are subjected to drying process for evaporating solvent present in the gel and followed by calcination and it results nano particle powders.



Chemical precipitation method:

Chemical precipitation method is a common technique for synthesizing nanoparticles. Here's a basic overview of the process:

1. **Precursor Solutions:** Two separate precursor solutions: one containing the cation (positively charged ion) and another containing the anion (negatively charged ion) of the desired nanoparticle material.
2. **Mixing:** These solutions are mixed under controlled conditions, such as temperature and pH. The mixing should be done slowly to allow the nanoparticles to form.
3. **Nucleation:** Initially, nucleation occurs, where small clusters of atoms or ions begin to form nanoparticles.
4. **Growth:** As the reaction progresses, these clusters continue to grow by attracting more ions from the solution.
5. **Filtration and Washing:** Once the desired particle size is achieved, the nanoparticles are typically separated from the solution through filtration. They are then washed to remove any impurities or unreacted chemicals.
6. **Drying:** The collected nanoparticles are dried to remove any remaining solvent.

This method allows for control over the size and composition of the nanoparticles by adjusting parameters like temperature, pH, and the concentration of precursor solutions. It's commonly used for the synthesis of various types of nanoparticles, including metal nanoparticles like gold and silver, as well as metal oxides like iron oxide nanoparticles.

The synthesis of silver nanoparticles using the chemical precipitation method :

1. **Precursor Solutions:** prepare two precursor solutions

Solution A: Contains a silver salt, such as silver nitrate (AgNO_3), which serves as the source of silver ions (Ag^+).

Solution B: Contains a reducing agent, such as sodium borohydride (NaBH_4), which will reduce the silver ions to form silver nanoparticles.

2. **Mixing:** Solution A (AgNO_3) and Solution B (NaBH_4) are slowly mixed under controlled conditions. The mixing must be gentle to facilitate the formation of nanoparticles.

3. **Nucleation:** As the two solutions combine, silver ions from Solution A come into contact with the reducing agent in Solution B. Nucleation begins, and small clusters of silver atoms start forming.

4. **Growth:** These clusters continue to grow as more silver ions are reduced by the NaBH_4 , causing the nanoparticles to increase in size.

5. **Filtration and Washing:** Once the desired size and concentration of silver nanoparticles are achieved, the solution is typically filtered to separate the nanoparticles from the remaining solution. The collected nanoparticles are then washed to remove any impurities or unreacted chemicals.

6. **Drying:** The washed silver nanoparticles are dried to remove any residual solvent, resulting in a dry powder or suspension of silver nanoparticles.

The size and shape of the silver nanoparticles can be controlled by adjusting factors like the concentration of AgNO_3 , the rate of addition of NaBH_4 , and the reaction temperature. This method is widely used in applications such as antimicrobial coatings, catalysis, and electronics.

Green synthesis Method or Biological Method:

Green synthesis methods for nanoparticles involve using environmentally friendly and sustainable processes. Here's a general outline of a green synthesis method for preparing nanoparticles:

1. **Selection of Precursor:** Choose a biocompatible or eco-friendly precursor material. This can be a metal salt (e.g., silver nitrate, gold chloride) for metallic nanoparticles or a metal oxide (e.g., iron oxide) for oxide nanoparticles.

2. **Choice of Reducing Agent:** Opt for a green reducing agent, such as plant extracts, microbial cells, or environmentally benign chemicals like vitamin C or glucose. These agents help convert the metal ions into nanoparticles.

3. **Stabilizing Agent:** Use a natural polymer or stabilizing agent like chitosan, starch, or cellulose to prevent agglomeration of nanoparticles and improve stability.

4. **Reaction Conditions:** Maintain mild reaction conditions, typically at room temperature or lower. Avoid the use of toxic solvents or excessive heat.

5. **Biological Methods:** Consider using biological entities like bacteria, fungi, or plant extracts. They can act as both reducing and stabilizing agents. For example, the fungus *Fusarium oxysporum* is used to produce silver nanoparticles.

6. **Control and Characterization:** Ensure control over particle size and shape through reaction time, pH, and temperature. Characterize the nanoparticles using techniques like UV-Vis spectroscopy, X-ray diffraction (XRD), and electron microscopy.

7. **Safety and Waste Management:** Follow safety protocols and dispose of waste in an environmentally responsible manner.

Green synthesis methods offer advantages like reduced toxicity, energy efficiency, and sustainability. However, the specific method can vary depending on the type of nanoparticles (e.g., gold, silver, iron, quantum dots) and the chosen green synthesis approach.

Example of a green synthesis method for preparing silver nanoparticles using a plant extract:

Green Synthesis of Silver Nanoparticles using Gigantic Swallow Wort:

1. **Precursor:** Start with a silver salt, such as silver nitrate (AgNO_3).

2. **Plant Extract:** Obtain fresh gigantic swallow-wort leaves extract. This extract contains compounds like which act as reducing agents like alkaloids, flavonoids, terpenoids.

3. **Reaction Setup:** Mix a solution of silver nitrate with the gigantic swallow-wort extract. The compounds in the gigantic swallow-wort will reduce the silver ions into silver nanoparticles.

4. **Stabilizing Agent:** The gigantic swallow-wort extract also acts as a stabilizing agent due to its natural alkaloids, flavonoids, terpenoids preventing agglomeration of the nanoparticles.

5. **Reaction Conditions:** Keep the reaction at room temperature to minimize energy consumption.

6. **Characterization:** Characterize the synthesized silver nanoparticles using techniques like UV-Vis spectroscopy, X-ray diffraction (XRD), and transmission electron microscopy (TEM) to confirm their size, shape, and purity.

This method is environmentally friendly, as it uses a natural reducing agent and stabilizing agent, avoiding the need for toxic chemicals or high-temperature processes.

Properties of Nano Particles:

Nanoparticles have various unique properties due to their extremely small size, typically in the range of 1 to 100 nanometers. Some key properties include:

1. **Size-dependent properties:** Nanoparticles exhibit size-dependent properties, such as enhanced reactivity and unique optical, electronic, and magnetic properties, which differ from bulk materials.

2. **High surface area:** Nanoparticles have a high surface area-to-volume ratio, making them ideal for various applications in catalysis, drug delivery, and sensors.

3. **Quantum effects:** At the nanoscale, quantum effects become significant, influencing the behavior of particles. This can lead to quantum confinement effects in semiconducting nanoparticles, for example.

4. **Enhanced reactivity:** Nanoparticles often exhibit higher chemical reactivity due to their high surface area, which makes them useful in catalysis and chemical reactions.

5. **Improved mechanical properties:** Nanoparticles can enhance the mechanical properties of composite materials, making them stronger and more durable.

6. **Optical properties:** Nanoparticles can interact with light in unique ways, resulting in phenomena like plasmon resonance and tunable optical properties, making them useful in imaging and photonic applications.

7. **Magnetic properties:** Magnetic nanoparticles can exhibit superparamagnetism and are used in applications like magnetic data storage and medical diagnostics.

8. **Drug delivery:** Nanoparticles can be designed to encapsulate drugs and deliver them to specific targets in the body, improving drug efficacy and reducing side effects.

9. **Thermal properties:** Nanoparticles can have different thermal conductivity and heat dissipation properties, which are important in applications like thermal management.

10. **Biological interactions:** Nanoparticles can interact with biological systems, making them valuable in fields like nanomedicine, where they can be used for imaging, drug delivery, and diagnostics.

It's important to note that the properties of nanoparticles can vary based on their composition, size, and shape, making them versatile for a wide range of applications across various fields.

Applications of Nano Materials:

Nanomaterials have a wide range of applications in catalysis, medicine, sensors, and other fields due to their unique properties. Here are some examples of how nanomaterials are utilized in these areas:

1. Catalysis:

Catalyst support: Nanomaterials like metal nanoparticles or metal oxides are used as catalyst supports due to their high surface area and reactivity. They enhance catalytic reactions in various industries, including petrochemical and environmental applications.

Enzyme immobilization: Nanoparticles are employed to immobilize enzymes, improving their stability and activity in biocatalysis processes.

Selective catalysis: Tailored nanocatalysts can enable highly selective reactions, reducing unwanted byproducts and increasing the efficiency of chemical processes.

2. Medicine:

Drug delivery: Nanoparticles can encapsulate drugs, genes, or therapeutic agents, enabling targeted delivery to specific cells or tissues, reducing side effects, and improving treatment efficacy.

Imaging agents: Nanoparticles with unique optical or magnetic properties are used in imaging techniques such as MRI, CT scans, and fluorescence imaging to enhance contrast and visualization of tissues or diseases.

Theranostics: Combining diagnostic and therapeutic capabilities, nanomaterials allow for personalized medicine approaches, where diagnosis and treatment occur simultaneously.

3. Sensors:

Gas sensors: Nanomaterials like nanowires or nanotubes are used to create highly sensitive and selective gas sensors for detecting pollutants, toxic gases, or specific chemical analytes.

Biosensors: Nanomaterials can be integrated into biosensors for the detection of biomolecules (e.g., glucose, DNA) or pathogens, enabling applications in medical diagnostics and environmental monitoring.

Nanoelectromechanical systems (NEMS): Nanoscale mechanical sensors can detect extremely small forces, making them useful for applications such as atomic force microscopy and biosensing.

4. Energy:

Solar cells: Nanomaterials like quantum dots or nanowires are employed to enhance the efficiency of photovoltaic cells by capturing a broader range of light wavelengths.

Batteries and supercapacitors: Nanomaterials can improve the energy storage capacity and charge-discharge rates in batteries and supercapacitors, leading to longer-lasting and faster-charging energy storage devices.

5. Environmental remediation:

Water purification: Nanomaterials are used to remove contaminants from water through adsorption, catalysis, or filtration processes.

Air pollution control: Nanocatalysts can be applied in catalytic converters to reduce harmful emissions from vehicles and industrial processes.

6. Electronics and optics:

Nano-electronics: Nanomaterials enable the development of smaller and more efficient electronic components, such as transistors and memory devices.

Plasmonics: Nanoparticles exhibit unique plasmonic properties that can be harnessed for applications in optical data storage, sensing, and imaging.

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