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"The Evolution Of Nanoparticles: A Review Of Methods, Applications, And Innovations"

Sakshi Waghmode*, Amruta Gaikwad*, Pallavi Pise*, Sanika Shelake*,

Kedar Phadatare*.

Final year bachelor of pharmacy

Mandesh institute of pharmaceutical science and research centre, Mhaswad 415509. Tal-Man, Dist- Satara

Abstract:-

Nanoparticles are materials with unique properties due to their extremely small size, typically ranging from 1 to 100 nanometers. Nanoparticles are very small materials, typically measuring between 1 and 100 nanometers, which give them special properties that aren't found in larger materials. Their small size and large surface area make them unique, allowing them to be useful in many different fields. In this overview, we explore the basic structure and types of nanoparticles, such as metallic nanoparticles, polymeric nanoparticles, lipid nanoparticles, and carbon-based nanoparticles. These particles are often categorized based on their material, shape, and size, which can affect how they behave and interact with their surroundings. These features make nanoparticles useful in a wide range of areas, including medicine, electronics, and environmental science. To better understand and measure nanoparticles, scientists use various techniques such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), dynamic light scattering (DLS), and X-ray diffraction (XRD). These tools help scientists examine their size, shape, and surface properties, as well as their stability. Nanoparticles are made using different methods like chemical vapour deposition, sol-gel techniques, and both top-down and bottom-up approaches, each offering specific benefits in controlling their size and shape. They are used in many applications, including drug delivery, diagnostic tools, cancer treatment, energy storage, environmental clean-up, and sensors. With on-going research and innovation, nanoparticles are becoming increasingly important in improving technology, sustainability, and creating new solutions in various industries.

Keywords: Nanoparticles, Platforms, Classification, Characterisation, Preparation, Synthesis, Application

Introduction:-

Nanoparticles are very tiny particles, usually between 0.1 and 100 nanometers in size, and they have unique properties that are different from larger materials. These tiny particles are being studied for use in diagnosing and treating diseases. In medical imaging, nanoparticles can make images clearer and more precise. They can also be used to deliver medicine directly to specific areas in the body, making treatment more effective. Because nanoparticles are so useful in medicine and biology, CD Bioparticles offers a wide variety of them with different sizes and surface features, to support both research and industry need. Nanoparticles (NPs) are materials that are very small, with at least one dimension being less than 100 nanometers (nm). These tiny materials can have different shapes, like 0D, 1D, 2D, or 3D, depending on their structure. Scientists realized that the size of these particles can affect their properties, such as how they absorb or reflect light (optical properties). For example, gold (Au), platinum (Pt), silver (Ag), and palladium (Pd) nanoparticles all have distinct colors when they are 20 nanometers in size—gold is wine red, platinum is yellowish grey, silver is black, and palladium is dark black. In a study, they showed how the colour of these nanoparticles changes based on their size, shape, and other factors like the thickness of their shell or how much gold is in the mix. This is important because these colour changes and properties can be used in areas like medical imaging to help visualize things at the microscopic level.

Importance:-

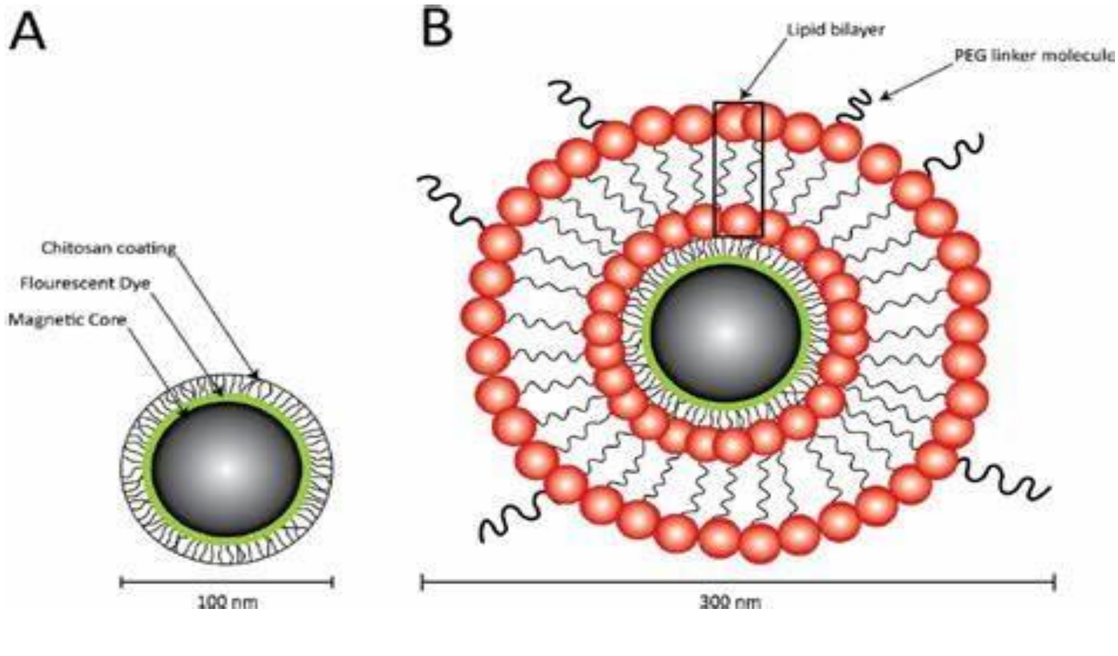
Nanoparticles (NPs) are really tiny materials, usually between 1 to 100 nanometers in size. Because they're so small, they have special physical and chemical properties, like a large surface area, high reactivity, stability, and sensitivity. These features make NPs very useful in many fields, such as medicine, electronics, agriculture, and environmental protection.

1. **Medical Uses**: NPs help in delivering drugs, imaging, and diagnosing diseases. Their tiny size allows them to pass through biological barriers and deliver medicine directly to specific cells, making treatments more effective and reducing side effects.
2. **Environmental Uses**: NPs are used for cleaning water, filtering air, and improving soil. Their high reactivity and large surface area allow them to remove pollutants and contaminants effectively.
3. **Industrial Uses**: NPs are used to create advanced materials like coatings, catalysts, and sensors. Their unique properties improve the performance and efficiency of these materials.
4. **Energy Uses**: NPs are used in devices that store and convert energy, such as batteries, fuel cells, and solar cells. Their large surface area and reactivity enhance the efficiency and capacity of these devices.
5. **Safety and Risks**: It's important to also discuss the potential risks and toxicity of NPs. Understanding how they interact with biological systems and the environment is crucial for their safe and sustainable use.

Structure:-

Nanoparticles (NPs) have a complex structure made up of two or three layers:

1. **Surface Layer:** This is the outermost layer of the nanoparticle. It can have various small molecules, metal ions, surfactants, or polymers attached to it, which can give the particle special properties or help it interact with other substances.
2. **Shell Layer:** This layer can be added intentionally and is different from the core material. Its purpose might be to protect the core or to give the nanoparticle additional functionalities.
3. **Core Material:** This is the central part of the nanoparticle. It's the most important part because it determines most of the nanoparticle's properties and behaviours.



Platforms of Nanoparticles:-

Liposomes: Liposomes are the first type of nanoparticles discovered. They were described in 1965 as a model of cell membranes. Later, they became useful for delivering genes and drugs. Liposomes are small, spherical vesicles made of lipid layers that can form in water. They can be used to target specific cells and increase the concentration of diagnostic and therapeutic agents within those cells. Currently, there are 12 liposome-based drugs that are approved for clinical use.

Albumin-Bound Nanoparticles (NAB): These nanoparticles use the natural pathways of albumin, a protein in the bloodstream that carries hydrophobic (water-repelling) molecules. NAB binds to hydrophobic molecules without forming strong, permanent bonds, which helps avoid toxic effects from solvents in therapeutic drugs. This makes NAB an effective platform for delivering drugs.

Polymeric Nanoparticles:

- **Description:** Made from biocompatible (safe for the body) and biodegradable (can break down naturally) polymers. They are used to carry therapeutic drugs.
- **Structure:** Created using block-copolymers with different levels of water-repellence.
- **Benefits:** Useful for the slow and controlled release of drugs at specific sites in the body.

Quantum Dots (QDs):

- **Description:** Tiny semiconductor particles less than 10 nanometers in size.
- **Properties:** Have unique electronic and optical properties that depend on their size.
- **Common Composition:** Usually consist of a core made of cadmium selenide (CdSe) and a cap or shell made of zinc selenide (ZnS).
- **Uses:** Used in biological research for fluorescent imaging, cell labeling, and tracking biomolecules.

Iron Oxide Nanoparticles:

- **Properties:** Super paramagnetic, meaning they exhibit strong magnetism when an external magnetic field is applied.
- **Structure:** Consist of an iron oxide core with a hydrophilic (water-attracting) coating of dextran or another biocompatible material for stability.
- **Uses:** Mainly used as imaging agents in MRI (Magnetic Resonance Imaging). Two specific agents, ferumoxides (120-180 nm) and ferucarbotran (60 nm), are clinically approved for MRI.

Discovery of Carbon, Silver, Zinc, Copper, and Gold Nanoparticles:-

Carbon Nanoparticles: In 1991, scientists discovered carbon nanoparticles, and in 1993, researchers named Iijima and Ichihashi created a single-wall carbon nanotube that was only 1 nanometer in diameter. Carbon nanotubes, also known as Bucky tubes, are tiny cylinders made from carbon atoms arranged in a hexagonal pattern. They are between fullerenes (which have no dimensions) and graphene (which has two dimensions).

Silver Nanoparticles: M. C. Lea created citrate-stabilized silver colloids (a type of nanoparticle) about 120 years ago. These particles are about 7 to 9 nanometers in size. Modern methods of creating silver nanoparticles are similar, often using silver nitrate and citrate. As early as 1902, scientists also used proteins to stabilize these nanoparticles. Silver nanoparticles known as "Collargol" have been around since 1897 and were used for medical purposes. Collargol has particles about 10 nanometers in size. In 1953, Moudry developed another type of silver nanoparticle stabilized with gelatin, ranging from 2 to 20 nanometers in size.

Gold Nanoparticles: Gold nanoparticles have been around since the Roman era when they were used to colour glassware. The modern study of gold nanoparticles began over 170 years ago with Michael Faraday, who noticed that colloidal gold solutions had different properties than bulk gold. In 1857, Faraday studied how to make these solutions and how they could produce different colours under certain lighting conditions.

Classification of Nanoparticles:-

Type of Nanoparticle	Description	Examples	Key Features	Applications
Organic Nanoparticles	Made from organic materials; biodegradable and non-toxic.	Dendrimers, Micelles, Liposomes, Ferritin	Hollow core (nanocapsules), sensitive to heat and light, good for targeted drug delivery.	**Drug delivery, especially targeted drug delivery.**
Inorganic Nanoparticles	Made from materials that do not contain carbon, including metals and metal oxides.	-	High surface area, reactive to environmental factors, varied shapes and sizes.	**Catalysis, medicine, sensors.**
Metal-based Nanoparticles	Nanoparticles made from metals.	Gold (Au), Silver (Ag), Iron (Fe), Copper (Cu), Zinc (Zn)	Sizes range from 10 to 100 nm, high surface area, spherical/cylindrical shapes, highly reactive.	**Electronics, medicine, materials science.**
Metal Oxide-based Nanoparticles	Nanoparticles made from metal oxides.	Iron Oxide (Fe_2O_3), Zinc Oxide (ZnO), Aluminum Oxide (Al_2O_3)	Enhanced reactivity and efficiency compared to metal nanoparticles.	**Catalysis, medical applications, sensors.**
Carbon-based Nanoparticles	Made entirely of carbon.	Fullerenes, Graphene, Carbon Nanotubes (CNTs), Carbon Nanofibers, Carbon Black	Unique properties like strength, flexibility, conductivity, and lightness.	**Electronics, materials science, energy storage, medicine.**
Fullerenes	Spherical molecules made of carbon atoms.	C60 (Buckminsterfullerene)	Tiny size (4-8 nm), spherical shape.	**Drug delivery, electronics, materials.**
Graphene	A single layer of carbon atoms arranged in a honeycomb lattice.	-	1 nm thick, strong, efficient, and highly conductive.	**Electronics, energy storage, sensors, medical devices.**
Carbon Nanotubes (CNTs)	Hollow tubes made from graphene.	-	Diameters as small as 0.7 nm, long, strong, flexible.	**Electronics, nanocomposites, drug delivery, energy storage.**
Carbon Nanofibers	Similar to CNTs, but shaped like cones or cups.	-	Strong, flexible, unique shapes.	**Strengthening materials, energy storage, filtration.**
Carbon Black	**Fine carbon particles, usually spherical.**	-	**Sizes from 20 to 70 nm, forms aggregates.**	**Pigments, reinforcing fillers in tires, electrical applications.**

Preparation of nanoparticles:-

The preparation of nanoparticles depends on the type of particle product, such as oxides, natural products, or drugs. In this review, we focus on a new method for preparing nanoparticles called the photolysis method.

1. Photolysis method:-

The photolysis method was first introduced by Dr. Hussein Ismail and his student Zaid Hamid in 2015 as part of an MSC thesis titled "Synthesis of Nano ferro Oxide from its Complexes and Salts Using the Photolysis Method." This method has been successful in producing various phases of iron oxide, such as alpha, gamma, and Fe_3O_4. The preparation steps depend on the solution's medium. In a basic solution, the process takes one step, while in acidic or neutral solutions, it requires two steps.

In both cases, the first step involves irradiating ferric salts or complexes with UV light for a short time. When the UV light hits, electrons in the iron ions move from their ground state to an excited state, which requires energy. In a basic medium, hydroxyl ions attack the iron ions, forming iron oxide directly. In neutral or acidic mediums, the iron ions first change to ferrous ions (+2), forming ferrous hydroxide. This product is then heated to a high temperature (calcined) to create iron oxide nanoparticles.

The photolysis method is a "bottom-up" approach. The irradiation system was manually set up by the researchers, using a 125-watt UV light source. The power of the UV light plays an important role in determining how long the irradiation should last. Other researchers have since used this method to create nanoparticles of different oxides like TiO_2, CuO, Cr_2O_3, Ag, and Au.

Compared to methods like sol-gel, co-precipitation, microwaves, ultrasonic, and electric precipitation, the photolysis method is unique in terms of time, cost, size, and energy efficiency. All these factors make the photolysis method a strong alternative for nanoparticle preparation.

2. Co-precipitation:-

This is one of the oldest methods used to make nanoparticles. The good thing about it is that it produces a large number of particles. However, the particles vary greatly in size, and the purity of the product isn't very high. In this method, materials like ammonia or NaOH are slowly added to a salt solution to form a metal hydroxide. Then, the material is heated at 400°C to turn it into an oxide.

3. Sol-Gel:-

In this method, a homogeneous solution is prepared by mixing chemicals like citric acid with salts. When NaOH is added and stirred, a gel forms, and the pH of the solution is adjusted to 7. The gel is then heated at 400°C. This method has similar disadvantages to co-precipitation, like the particles having varying sizes.

4. Electrochemical Precipitation:-

This method is similar to photolysis in oxidation-reduction reactions. It uses two electrodes (cathode and anode) connected to a power supply and placed in an electrolyte solution. The electrodes help control the size of the nanoparticles by adjusting the power. One of the electrodes must be made of the metal that is being turned into an oxide.

5. Extract Method or Green Chemistry:-

This is considered the best method for being environmentally friendly. It doesn't need extra energy, and it uses cheap materials that produce pure nanoparticles with small sizes. In this process, plant extracts help reduce metal ions in a solution, turning them into metal hydroxides. Then, the precipitate is heated to produce oxide nanoparticles.

Characterization of nanoparticle:-

Zeta Potential: The zeta potential of nanoparticles is used to measure their surface charge. It reflects the electrical potential of the particles and depends on their composition and the medium they are in nanoparticles with a zeta potential between -10 and +10 mV are nearly neutral. If the zeta potential is higher than +30 mV or lower than -30 mV, the particles are considered strongly charged (positively or negatively). The zeta potential helps determine whether an active material is trapped inside the nanoparticle or attached to its surface. A higher zeta potential means stronger repulsion between particles, leading to more stable nanoparticles. Here's how stability is classified based on the zeta potential:

- **0-5 mV**: Particles tend to clump together.
- **5-20 mV**: Particles are weakly stable.
- **20-40 mV**: Particles are moderately stable.
- **40+ mV**: Particles are highly stable.

The zeta potential can also change depending on the solution's pH. It is calculated using a formula called the Henry equation.

UV-Visible Absorption Spectroscopy: This technique measures how much light a solution absorbs. A light is passed through the solution, and the absorbance is recorded at different wavelengths. By measuring absorbance, you can determine the concentration of a solution using Beer-Lambert’s law. UV-visible spectroscopy can also identify specific peaks, like the 410 nm peak, which gives insight into the optical properties of nanoparticles.

X-ray Diffraction (XRD) Analysis: XRD is a technique used to study the crystal structure and shape of nanoparticles. It helps determine if the particles are metallic and provides information about the size and shape of the unit cells within the particles. The XRD pattern can be used to calculate the crystallite size using the Scherrer equation, which involves the full width at half maximum (FWHM) of the peaks.

Fourier Transform Infrared (FTIR) Spectroscopy: FTIR measures how infrared light is absorbed by a sample at different wavelengths. It is used to identify the functional groups and structures present in nanoparticles. FTIR helps to analyze how biological materials interact with nanoparticles and to understand their optical properties.

Microscopic Techniques (SEM and TEM): Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) are used to study the size and shape of nanoparticles. These techniques provide detailed images of nanoparticles, helping researchers understand their uniformity and morphology.

Transmission Electron Microscopy (TEM):

TEM is a type of microscope that uses a beam of electrons to go through a very thin sample. As the electrons pass through the sample, they interact with it, creating an image. This image is magnified and can be seen on a screen, photographic film, or detected by a camera. TEM is widely used in different scientific fields like cancer research, studying viruses, materials science, pollution, nanotechnology, and semiconductors.

Scanning Electron Microscope (SEM):

SEM is used to look at the surface of samples and examine their size, shape, and structure. It works like an optical microscope, but instead of using light, it uses electrons. Since electrons can be controlled to have a shorter wavelength, SEM can magnify objects much more, up to 200,000 times. It is used to study particle size and characteristics. Samples are usually coated to be conductive for better analysis, and SEM can detect details as small as 1 nanometer.

Characterization Technique	Description	Key Information/Details
Zeta Potential	Measures the surface charge of nanoparticles, reflecting their electrical potential and stability in a medium.	- Zeta potential between -10 to +10 mV: Neutral particles. - Higher than +30 mV or lower than -30 mV: Strongly charged. - Stability classification based on mV: 0-5 mV (clump), 5-20 mV (weak), 20-40 mV (moderate), 40+ mV (high).
UV-Visible Absorption Spectroscopy	Measures how much light a solution absorbs at different wavelengths. Helps in determining concentration and identifying optical properties of nanoparticles.	- Absorbance recorded at different wavelengths. - Peaks like 410 nm help identify nanoparticles' optical properties.
X-ray Diffraction (XRD) Analysis	Used to study the crystal structure, size, and shape of nanoparticles, especially metallic ones.	- Provides crystallite size using Scherrer equation. - Determines particle shape and crystal structure.
Fourier Transform Infrared (FTIR) Spectroscopy	Measures how infrared light is absorbed at different wavelengths by the sample, used to identify functional groups and structures in nanoparticles.	- Helps identify biological-material interactions. - Used to study the optical properties of nanoparticles.
Scanning Electron Microscopy (SEM)	Examines the surface structure, shape, and size of nanoparticles using electron beams.	- Magnification up to 200,000x. - Detects details as small as 1 nanometer.
Transmission Electron Microscopy (TEM)	Uses electron beams to pass through thin samples, providing highly detailed images of the internal structure and morphology of nanoparticles.	- Magnified images of internal structures. - Used in fields like cancer research, nanotechnology, and materials science.

Characteristics of nanoparticles:-

Nanoparticles are tiny particles that range in size from 1 to 100 nanometers. Because of their small size and large surface area, they have unique properties compared to larger materials. Here's a simpler breakdown of the key characteristics of nanoparticles:

1. **Size and Surface Area**
   - **Size**: Nanoparticles are very small, between 1 and 100 nanometers. This small size gives them special properties that are different from those of larger materials.
   - **Surface Area**: Since they are so small, nanoparticles have a lot of surface area compared to their volume. This high surface area makes them more reactive and active in biological processes.
2. **Shape and Form**
   - Nanoparticles can have different shapes, like spheres, rods, cylinders, or irregular forms. Their shape affects how they interact with living cells, how strong they are, and how they are used in different fields like medicine. For example, gold nanoparticles are often spherical or rod-shaped, which changes how they interact with light.
3. **Surface Charge**
   - Nanoparticles can carry a positive, negative, or neutral charge on their surface. This charge affects how they interact with biological cells and how stable they are in liquids. Positive nanoparticles are often more easily taken up by cells because they attract the negatively charged cell membranes.
4. **Optical Properties**
   - Nanoparticles can have unique optical features, like the surface plasmon resonance **(**SPR**)** seen in gold and silver nanoparticles, or quantum effects seen in materials like quantum dots. SPR happens when the electrons on the surface of the nanoparticles vibrate together. This property is useful for sensing and detecting diseases.
5. **Magnetic Properties**
   - Some nanoparticles, like iron oxide, are magnetic and show superparamagnetism. This means they can be controlled by a magnetic field and do not stay magnetized when the magnetic field is turned off. These properties are useful in medical imaging (MRI) and targeted drug delivery.
6. **Chemical Reactivity**
   - Nanoparticles can be more chemically reactive than larger particles due to their large surface area. This reactivity can be helpful in processes like cleaning up pollution or speeding up chemical reactions in industries.
7. **Biocompatibility and Toxicity**
   - For medical use, nanoparticles must be safe for the body and not cause harm like inflammation or cell damage. However, their small size can sometimes lead to toxicity, depending on their material, charge, or size. Research is still working to better understand and reduce these risks.
8. **Stability and Aggregation**
   - Nanoparticles can clump together (aggregate) because of forces between them. To prevent this, they are often coated with special chemicals to keep them stable. This is important for making sure they work properly in applications like drug delivery.
9. **Synthesis and Fabrication**
   - Nanoparticles can be made in two ways:
     - **Top-down**: Breaking down larger materials into smaller pieces, like grinding or laser cutting.
     - **Bottom-up**: Building nanoparticles from smaller units, like atoms or molecules, coming together.
   - The method used to make the nanoparticles affects their size, shape, and surface features.
10. **Applications**
    - **Medical**: Nanoparticles are used for delivering drugs, imaging, cancer treatment (e.g., using gold nanoparticles to treat tumors), and diagnosing diseases.
    - **Environmental**: They are used to clean water, control pollution, and for environmental sensing.

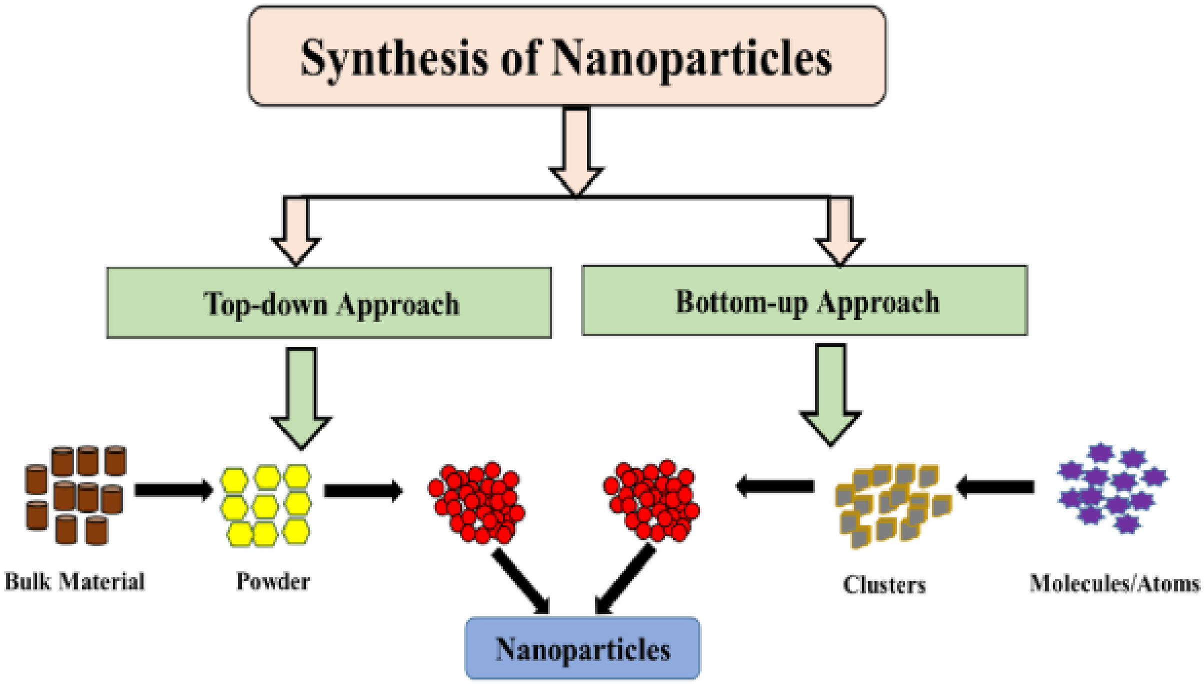
- **Electronics**: Nanoparticles help in creating smaller, flexible electronics, sensors, and memory devices.
- **Catalysis**: Nanoparticles are used to speed up chemical reactions in industries, making processes more efficient.

Synthesis of nanoparticles:-

Nanotechnology is changing the way materials are made and how devices are built. A key part of nanotechnology is making nanomaterials, which involves controlling several factors during the process. These factors include temperature, reactant concentrations, reaction time, and pH levels. Research shows that adjusting the pH of the solution can affect the size and shape of the nanoparticles being produced. Specifically, higher pH values tend to create smaller particles, while lower, acidic pH levels usually result in larger particles.

Reaction time also plays a critical role in making nanoparticles. In some cases, nanoparticles can form very quickly, within just 2 minutes, as the reaction takes place rapidly. Temperature is another important factor in nanoparticle production. It affects how many nanoparticles are produced, as well as their size and shape. Controlling these factors can help improve the quality, purity, and consistency of the nanoparticles.

Nanoparticles can have different shapes, such as hexagonal, circular, triangular, or even chain-like structures. There are two main ways to make nanoparticles: the "top-down" method, where larger pieces are broken down into smaller ones, and the "bottom-up" method, where smaller building blocks come together to form the particles. Both of these methods are shown in the diagram.

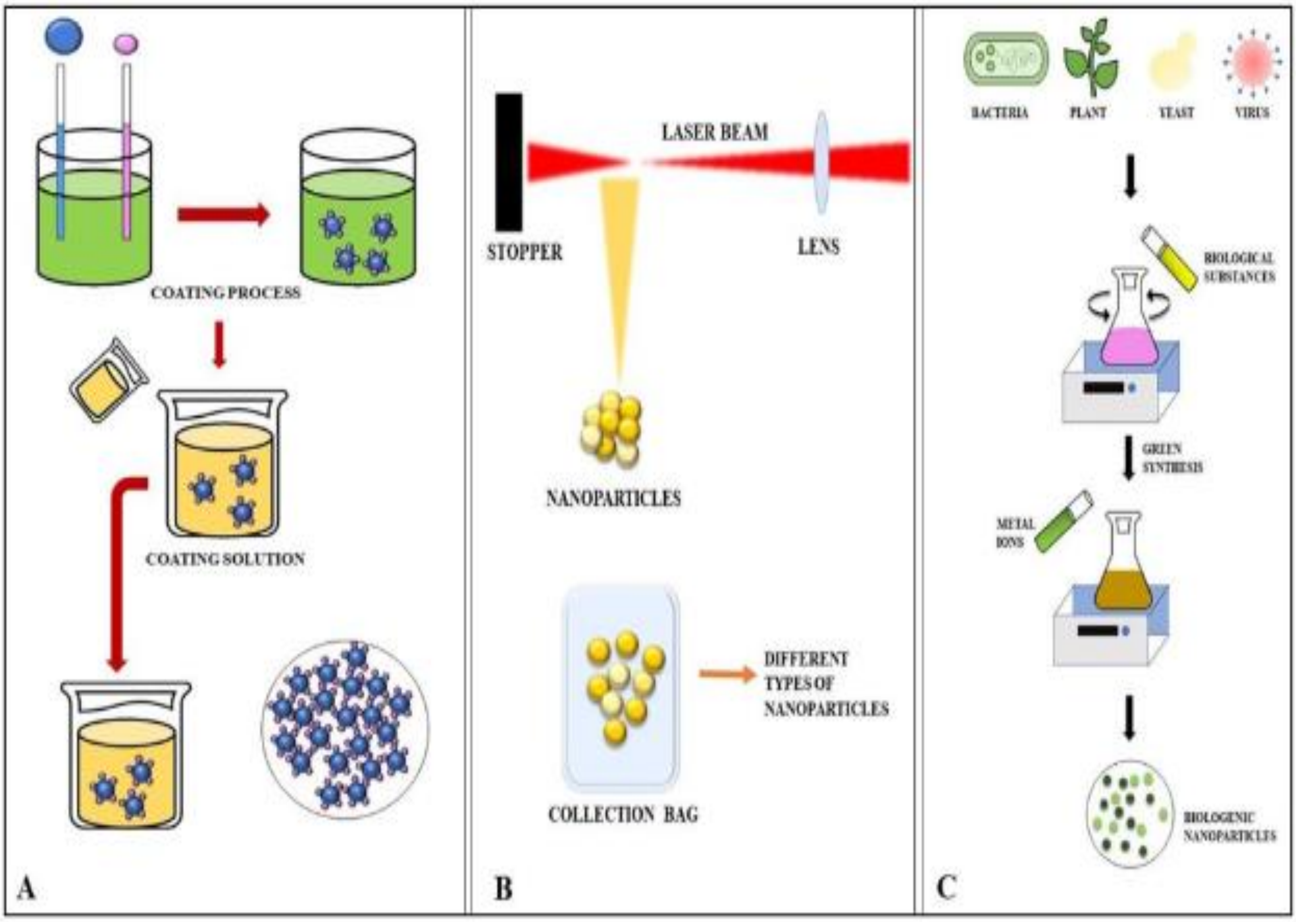


Top-down approach:-

The "top-down approach" is a way of making things by starting with a large piece of material, which is the same as the base material. This method breaks the large material into smaller pieces using physical processes like crushing, milling, or grinding. Top-down methods are usually simpler and focus on removing or shrinking the bulk material to create the desired shape and properties. This method is an improvement over older techniques used to make tiny particles. However, one major problem is that the surface of the material often ends up flawed. In many industries, the top-down approach is the most common method used for creating man-made materials. It mainly focuses on techniques like attrition, as well as more advanced methods such as microfluidics and lithography. A good example is the semiconductor industry, where photolithography is used to create tiny features on silicon wafers for MOSFETs (metal oxide semiconductor field-effect transistors). In the top-down approach, larger structures are used and can be controlled during processing, such as in ball milling or plastic deformation. However, the main issue is that the surface of the material often becomes rough and may have contaminants or other flaws

Bottom-up approach:-

The bottom-up approach involves building materials from the smallest components, like atoms or molecules, to create nanostructures. This method is popular for making nanosized materials because they have unique properties that differ from larger materials. It is also more cost-effective and produces less waste compared to other methods. In this approach, materials are created molecule by molecule or atom by atom, which helps in making uniform shapes and sizes of materials. For example, this method is used to create nanoparticles like zinc oxide, magnetite, and titanium dioxide using wet chemical techniques. The process can create particles with a narrow size range. Titanium dioxide nanoparticles were also made using a bottom-up method called sol-gel synthesis, and their environmental impact was assessed using tools like Life Cycle Assessment (LCA) and Environmental Assessment Tool for Organic Syntheses (EATOS). One of the challenges with this method is ensuring the surface layer sticks well to the base material. Bottom-up techniques are widely recognized for creating luminescent nanoparticles. This approach to nanofabrication advances miniaturization, offering almost endless possibilities for designing and creating functional nanomaterials. Additionally, it has the potential to be much more cost-effective compared to top-down nanofabrication methods.



Different Methods for Creating Nanoparticles:-

There are several ways to make nanoparticles, including chemical, physical, and biological methods. While chemical and physical methods are commonly used, they have limitations, such as the use of toxic chemicals and lower yields. Biological methods, which are safer and simpler, are becoming more popular. Nanoparticles have unique properties that make them useful in many industries and for medical purposes.

Physical Methods of Nanoparticles Synthesis:-

Physical methods have been traditionally used to create nanoparticles. These methods use heat, high-energy radiation, or mechanical pressure to create particles. They are better than chemical methods in some ways, such as not contaminating the materials with solvents. Physical methods are also "top-down" processes, meaning they break down larger materials into nanoparticles without using chemicals. These methods produce uniform and high-quality nanoparticles. Some common physical methods include:

1. Inert Gas Condensation (IGC)

This method is used to make various types of nanoparticles, such as metals, semiconductors, and alloys. The size of the nanoparticles can be controlled by adjusting factors like pressure, gas type, and temperature. Inert gas condensation is efficient for producing high-quality nanoparticles, such as silver and platinum.

2. Laser Ablation

In this method, a powerful laser is used to remove material from a solid surface. This causes the material to evaporate and form nanoparticles. Laser ablation is used to create materials like zinc and lead sulfide nanoparticles, but it can be expensive and challenging to control the shape and size of the particles.

3. Physical Vapour Deposition (PVD)

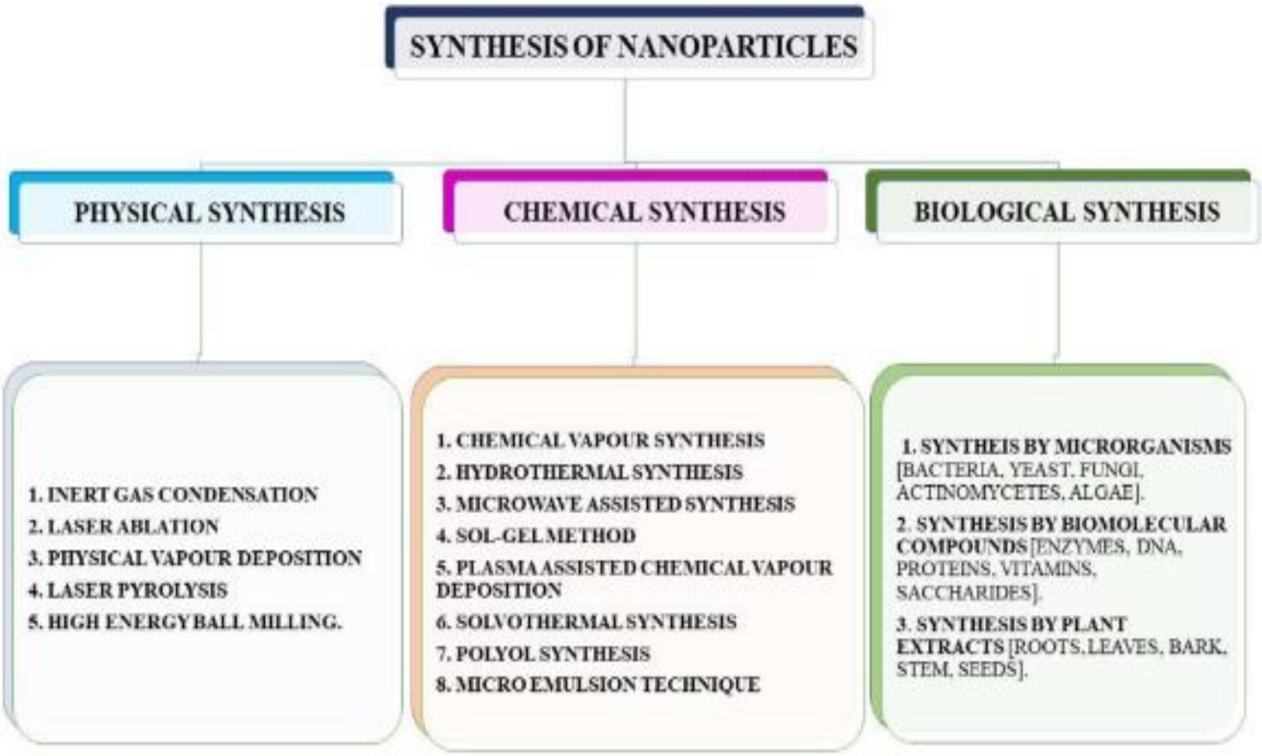
This technique uses vacuum to deposit thin layers of material onto a surface. It is a "green" process because it produces little pollution. The most common PVD method for making nanoparticles is sputtering, which involves shooting particles at a target material. This technique is often used to improve the hardness and wear resistance of materials.

4. Laser Pyrolysis

In laser pyrolysis, a CO_2 laser is used to break down gases or liquids into nanoparticles. This process is scalable, but the equipment is expensive. Laser pyrolysis can be used to make a variety of nanoparticles, such as silicon and molybdenum disulfide.

5. High-Energy Ball Milling (HEBM)

Ball milling is a simple method where materials are crushed into smaller particles by high-energy ball movement. This method has been used to make nanoparticles from various materials, including iron, zinc oxide, and calcium carbonate. The size and properties of the particles depend on factors like milling speed, time, and the type of materials used.



Chemical Methods of Nanoparticle Synthesis:-

Chemical methods use both inorganic and organic reducing agents to create nanoparticles. These agents reduce ions, leading to metal formation and the creation of clusters that eventually form nanoparticles. To prevent these nanoparticles from clumping together, protective agents like polyethylene glycol (PEG), polymethylmethacrylate (PMMA), polyvinyl pyrrolidone (PVP), and poly (methacrylic acid) (PMAA) are often added. These agents stabilize the nanoparticles and keep them dispersed. Some of the common chemical methods for making nanoparticles include microwave-assisted synthesis, hydrothermal synthesis, polyol synthesis, microemulsion technique, solvothermal synthesis, and chemical vapour deposition. These are considered "bottom-up" methods, where nanoparticles are built from smaller components.

1. Chemical Vapour Synthesis (CVS): Chemical Vapour Synthesis involves chemical reactions at high temperatures to deposit solid films from vapour. In this method, volatile precursors react in a reactor to form nanoparticles. It's often used in the semiconductor industry and can produce high-performance thin films. The process can be adjusted by controlling the temperature, precursor concentration, and other factors. It's useful for producing materials like Ni/NiO nanostructures.

2. Hydrothermal Synthesis: Hydrothermal synthesis uses high-pressure water to create nanoparticles with controlled size and shape. By adjusting factors like temperature, pressure, and solvents, the size, surface properties, and crystal structure of the nanoparticles can be controlled. This method is simple, cost-effective, and can produce nanoparticles from materials like ZnO, $FeWO_4$, and Ag.

3. Microwave-Assisted Synthesis: Microwave-assisted synthesis uses microwave radiation to create nanoparticles quickly. It allows for efficient heating and fast synthesis of nanomaterials without the need for long heating periods. This method has been used for nanoparticles like TiO_2, ZnO, and CuS, which have applications like photocatalysis and antimicrobial activity.

4. Sol-Gel Method: The sol-gel process involves turning a liquid precursor into a gel, which is then dried to form nanoparticles. This technique is mainly used to produce metal oxides. After mixing and setting the precursor, it can be used to create films or powders. The sol-gel method has been used to create nanoparticles like Fe_3O_4 and TiO_2.

5. Plasma-Assisted Chemical Vapour Deposition (PECVD): PECVD is a method where plasma enhances the chemical vapour deposition process to create thin films and nanoparticles. It's widely used in electronics and microelectronics. By controlling plasma conditions, nanoparticles like silica and carbon nanotubes can be formed.

6. Solvothermal Synthesis: Solvothermal synthesis is similar to hydrothermal synthesis, but it uses solvents other than water. It allows for better control over the nanoparticles' size, shape, and crystallinity. This method has been used to create nanoparticles like $CuFe_2O_4$ and $MgMn_2O_4$.

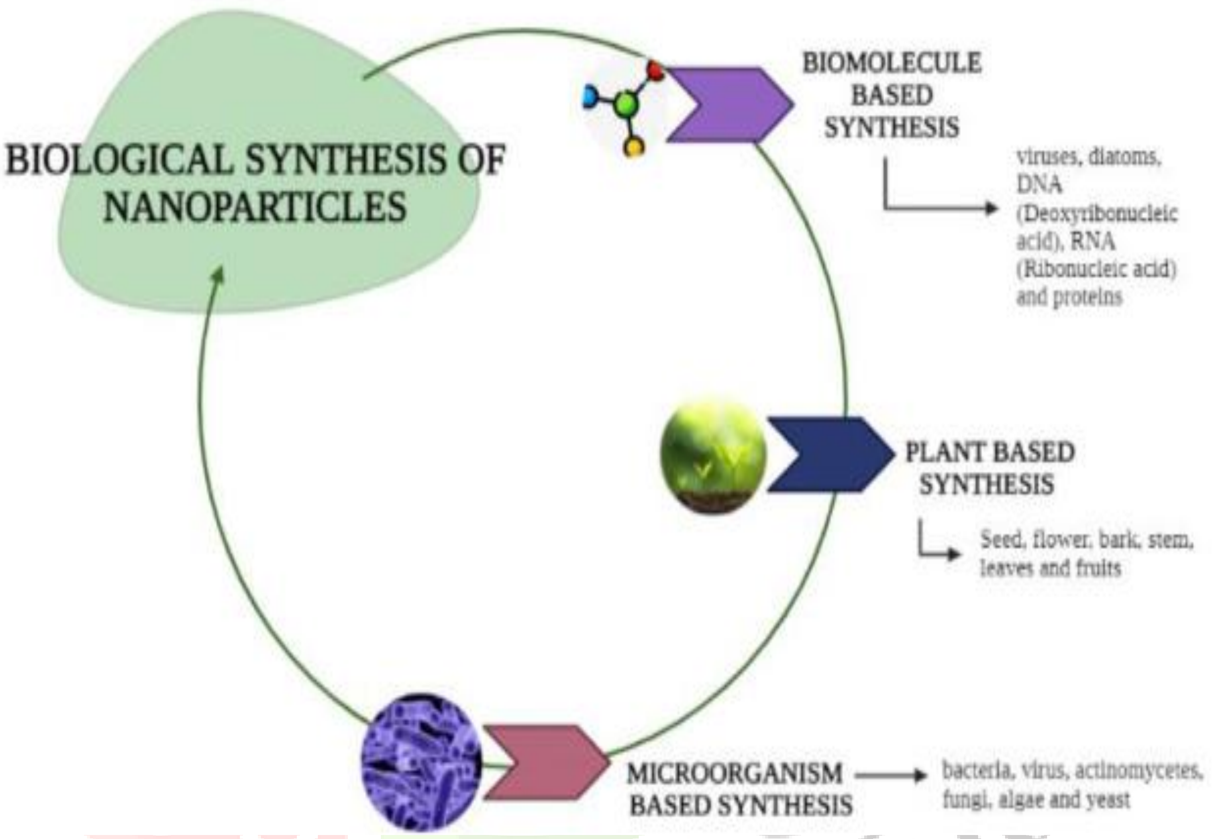
7. Polyol Synthesis: Polyol synthesis uses a solution where a metal precursor reacts with a polyol (like polyethylene glycol) to create nanoparticles. This method is especially useful for producing magnetic nanoparticles and noble metal particles. The polyol acts as a solvent and a reducing agent. It's used to make nanoparticles like Fe_3O_4 and $CuInS_2$.

8. Microemulsion Technique: Microemulsion involves creating stable dispersions of tiny droplets in water or oil. This technique can produce well-crystallized nanoparticles. The process allows for the creation of nanoparticles of different sizes and materials, but it has some limitations in terms of flexibility in size and shape. Examples of nanoparticles made using this technique include ZnO and silica-coated magnetite nanoparticles.

Biological Methods for Synthesizing Nanoparticles:-

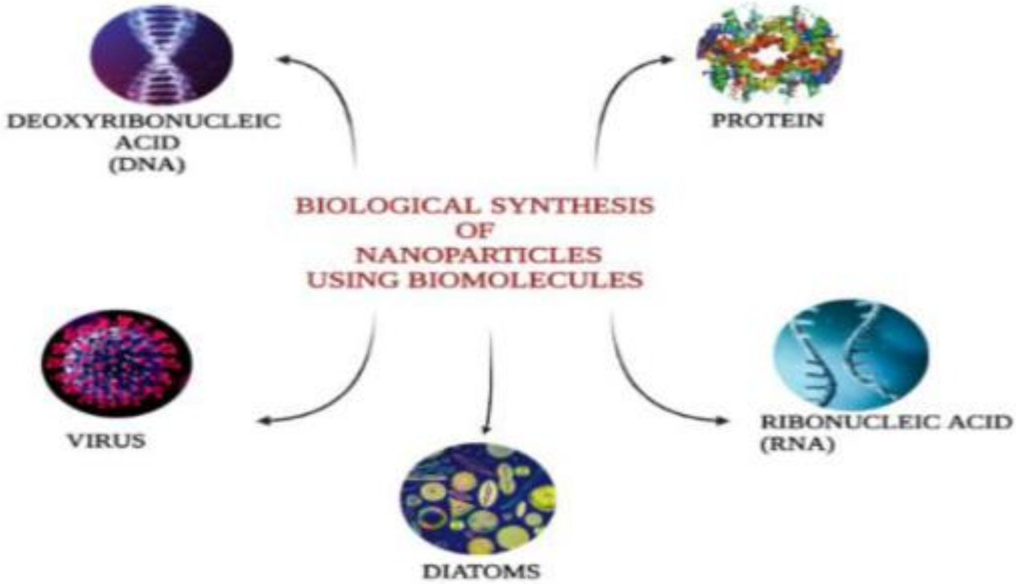
While physical and chemical methods for making nanoparticles are effective, they come with some drawbacks. These include long synthesis times, higher costs, difficulties with purification, and the production of harmful by-products. Chemical methods can also lead to toxic substances being adsorbed, which can be problematic for medical applications. On the other hand, biological (green) synthesis methods have several advantages. They are more environmentally friendly and use non-toxic agents. In these methods, nanoparticles are made inside or outside living organisms through their natural processes. This combination of biology and nanotechnology is known as nanobiotechnology, and it involves living entities like plants, bacteria, fungi, and viruses.

The biological methods used for nanoparticle synthesis generally follow a "bottom-up" approach, which involves reactions such as oxidation or reduction. These biological systems include fungi, bacteria, viruses, and plant extracts, which can convert metal ions into nanoparticles. Biological methods of synthesis can be categorized into three types:



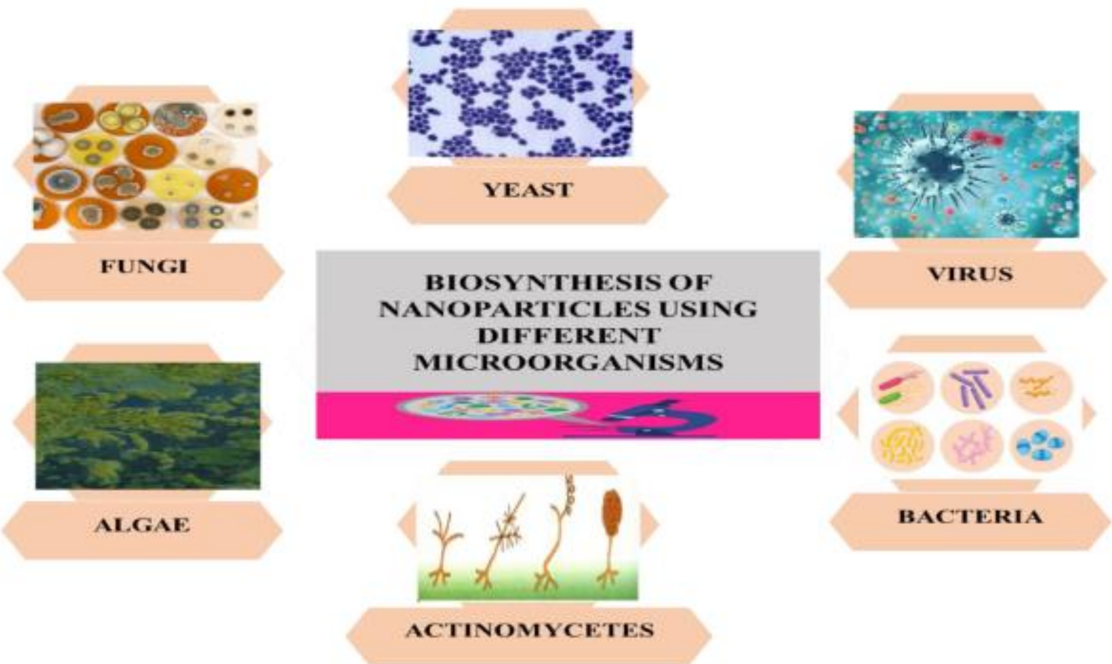
1. Biological synthesis of nanoparticles using biomolecules:-

Biomolecules such as viruses, diatoms, DNA, RNA, and proteins are natural nanostructures used as templates for nanoparticle creation. For example, DNA is an excellent template due to its strong ability to attract metal ions. The amino acids in enzymes can act as reducing agents for metal nanoparticles, while the protein chains help stabilize these particles. DNA can be used to create nanoparticles like metal-graphene oxide heterostructures. For instance, DNA can direct the synthesis of silver nanoparticles, which can then be used to reduce the growth of harmful bacteria on plants. Researchers have also developed nanoplatforms using DNA aptamers conjugated with magnetic graphene oxide to target and destroy antibiotic-resistant bacteria. These nanoparticles are biocompatible and can be activated by light to treat infections.



2. Biological synthesis of nanoparticles using microorganisms:-

Microorganisms such as bacteria, fungi, and viruses can also be used to make nanoparticles. These microorganisms can survive in environments with high metal concentrations, which make them effective for synthesizing metal nanoparticles. This method combines nanotechnology and microbiology, forming a field called nanobiotechnology. Many different types of microorganisms—such as bacteria, fungi, and yeasts—have been used to create various nanoparticles, including metals like gold, silver, platinum, and even rare materials like tellurium and palladium. The nanoparticles produced can be used in fields like electronics, bioimaging, and sensor technology. Microorganisms can produce nanoparticles both inside and outside their cells. The extracellular nanoparticles are particularly useful for various applications due to their ease of extraction and wider range of uses.



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A] Bacteria:-

Bacteria are single-celled organisms that grow quickly in warm, moist environments. Many bacteria can produce nanoparticles like silver (Ag), zinc oxide (ZnO), gold (Au), magnesium (Mg), arsenic (As), and iron oxide (FeO) nanoparticles. To reduce the metal ions, bacteria use various components like anionic functional groups, reducing sugars, proteins, enzymes, and other substances found in their biomass. Nanoparticles can be made using both gram-positive and gram-negative bacteria.

Gram-positive bacteria have a cell wall that is rich in anionic groups, made up of peptidoglycan and various acids like lipoteichoic and teichoic acids, along with polysaccharides and proteins. These parts help in the reduction and absorption of cations. For example, the cultural supernatants (liquid left after bacteria are grown) of bacteria like Enterobacter cloacae, Escherichia coli, and Klebsiella pneumoniae are used to make metallic nanoparticles like silver (Ag).

Most metal ions are toxic to bacteria, but to protect themselves, bacteria have developed a defense system to deal with this toxicity. One way they do this is by reducing the metal ions. For instance, Bacillus licheniformis bacteria produce NADPH and enzymes like nitrate reductase, which can reduce silver ions (Ag^+) to silver nanoparticles (Ag^0). Silver nanoparticles can also be made without enzymes by using the bacterial biomass to act as a reducing and capping agent.

Silver nanoparticles made by bacteria like Saccharomyces cerevisiae, Bacillus subtilis, and E. coli has been studied for their effects against various pathogens and their anticancer activity, such as on the MCF-7 cancer cell line. Bacteria are important for nanoparticle synthesis because of their ability to adapt to extreme environments and their diversity. Many studies have been done on bacteria-based nanoparticle synthesis, including for elemental compounds and other materials. Using bacteria as "Nano-factories" could offer a new way to remove harmful metal ions and create materials with unique properties.

B] Fungi:-

Fungi have been used as useful tools for making nanoparticles both outside (extracellular) and inside (intracellular) their cells. The process of making nanoparticles with fungi, using green chemistry, has many benefits. It is cost-effective, allows for higher bioaccumulation, and is easy to scale up because the process and handling of the fungal biomass are simple. Compared to bacteria, fungi can produce more nanoparticles because they secrete more proteins, which leads to higher nanoparticle production.

Fungi can grow in a wide range of conditions, such as varying levels of salt (sodium chloride), pH, and temperature. This makes it easier to adjust the growing conditions to produce consistent nanoparticles. Many studies have shown that fungi can produce silver nanoparticles by reducing silver ions (Ag^+). Several species of the Aspergillus genus, including Aspergillus niger, Aspergillus flavus, Aspergillus terreus, and Aspergillus fumigatus, have been shown to do this. The process involves an enzyme-dependent reaction that requires NADH (a type of energy molecule) to reduce the silver ions to nanoparticles.

Other fungi like Bryophilous rhizoctoni, Pleurotus ostreatus, and Fusarium species have also been reported to produce silver nanoparticles. In some cases, fungi like Penicillium species, including Penicillium brevicompactum, Penicillium fellutanum, and Penicillium citrinum, have been studied for their ability to create metallic nanoparticles.

Fungi can produce a variety of extracellular enzymes, such as glucanases, chitinases, and celluloses, under the right conditions. One example is Fusarium solani, an endophytic fungus (a fungus that lives inside plants), which was used to make gold nanoparticles. These gold nanoparticles showed cytotoxic (cell-killing) effects against different cancer cells.

C] Yeast:-

Yeast is a type of single-celled organism that belongs to the fungus kingdom. Yeast cells can be used as templates for making nanoparticles (NPs) through a process called biomineralization. For example, yeast has been used to make gold nanoparticles (Au NPs) with species like *Thermomonospora fusca*, *Thermomonospora curvata*, and *Thermomonospora chromogena*. Another yeast species, *Yarrowia lipolytica*, has also been used to produce gold nanoparticles.

Research has shown that *Hansenula anomala* can reduce gold salts to make gold nanoparticles. Yeast can also be used to create other types of nanoparticles, such as lead sulfide (PbS) and cadmium (Cd) nanoparticles, using species like *Candida glabrata* and *Rhodosporidium diobovatum*. One yeast strain, BDU-XR1, which was isolated from yogurt, has been shown to produce silver nanoparticles (Ag-NPs) in

Azerbaijan. These silver nanoparticles were made both inside the yeast cells and in the cell walls, depending on how the yeast was prepared.

Studies have also looked at how yeast cells respond when treated with silver nanoparticles. For example, RNA sequencing (RNAseq) showed that certain genes in the yeast cells were activated when they were exposed to silver nanoparticles coated with citrate. Infrared analysis of these nanoparticles showed that they were attached to biomolecules like alcohols, aromatic amines, and carboxylic acids. In 2020, researchers used yeast extract as both a reducing and capping agent to create well-dispersed, spherical silver nanoparticles.

D] Actinomycetes:-

Actinomycetes are microorganisms that share characteristics with both fungi and bacteria. One example, *Thermonospora sp.*, is used to make gold nanoparticles (Au NPs). Gold nanoparticles were also synthesized inside the cells of *Rhodoscoccus sp.*, a species that can tolerate alkali. Research showed that more nanoparticles were found in the cytoplasmic membrane of the cells than in the cell walls.

Actinomycetes have gained attention because they are often underused and could be a great option for making metal nanoparticles. These microorganisms are known for their saprophytic behaviour, meaning they feed on dead organic matter, and are considered important in commercial applications. Actinobacteria, a group that includes actinomycetes, have already been successfully used to create metallic nanoparticles. Because of this, actinomycetes are being increasingly considered for nanoparticle synthesis.

E] Algae:-

Algae, a diverse group of plants, are being studied for their potential uses in nanotechnology. In 2019, Sharma et al. reported that platinum nanoparticles (PtNPs) made from *S. myriocystum* were used as biosensors to measure adrenaline levels in the human body. Adrenaline is a hormone-based drug used to treat asthma, allergies, and heart attacks.

Gracilaria edulis was used to make silver and zinc oxide nanoparticles. Brown algae have been used to produce titanium dioxide (TiO2) and zinc oxide (ZnO) nanoparticles. Another study used *S. muticum* to synthesize zinc oxide nanoparticles.

Silver nanoparticles (Ag-NPs) made from green algae (*Ulva latica*) and red algae (*Hypnea musciformis*) were found to inhibit the growth of fungal strains like *Aspergillus niger*, *Candida parasitosis*, and *Candida albicans*. Similarly, gold nanoparticles (Au-NPs) and silver nanoparticles (Ag-NPs) made from *Neodesmus pupukensis* were tested for antifungal activity.

Silver nanoparticles made from *Microchaeta* showed better dye-removal ability than those made from cyanobacterial extract, particularly in removing "methyl red azo" dye. In a recent study, silver nanoparticles made by *Chlorella ellipsoidea* were found to have high photocatalytic activity, meaning they could break down harmful dyes like methylene orange and methylene blue.

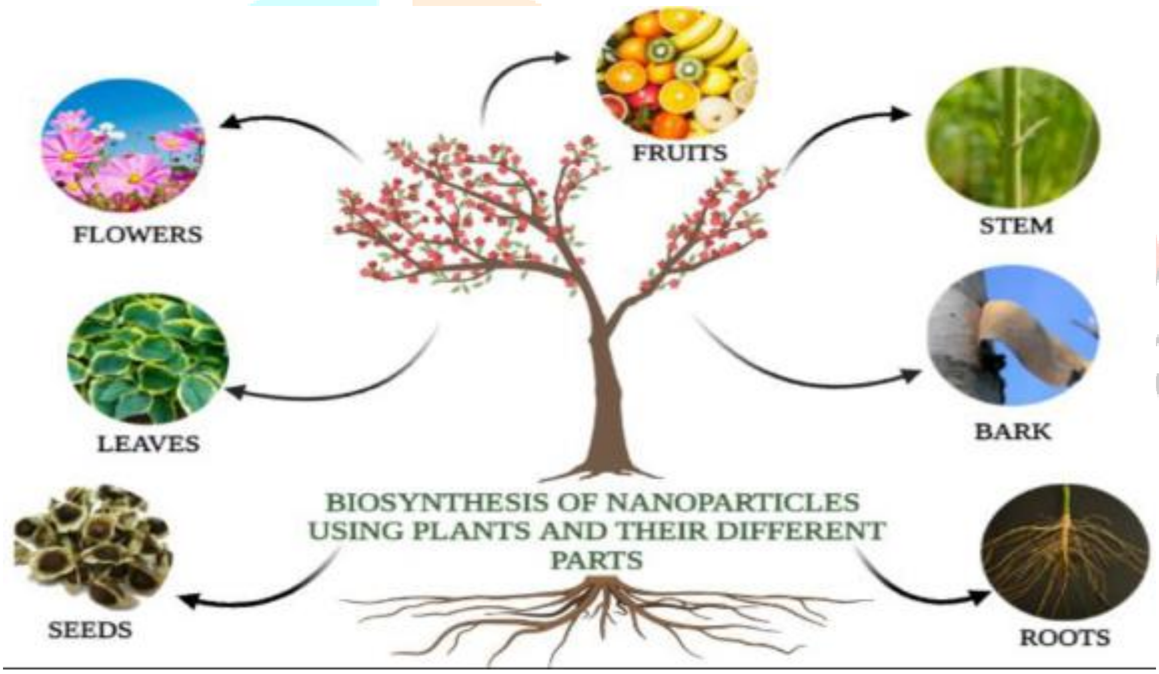
3. Biological synthesis of nanoparticles using plants:-

Plants contain a wide variety of phytochemicals, which are used in the pharmaceutical industry, both directly and indirectly. Plants serve many purposes beyond being medicines, such as in food supplements and nutraceuticals. The medicinal properties of plants have been known since ancient times, and researchers like ethno pharmacologists, botanists, microbiologists, and natural-product chemists have studied them. Plants secrete bioactive molecules that can reduce metal ions, which makes them useful for producing biocompatible nanoparticles.

Plants contain various phytochemicals and metabolites that are useful in nanoparticle synthesis. Using plants for making nanoparticles is a simple, cost-effective process that can be done in one step. Many plants and their different parts are used for this purpose. Some plants are known as "hyper accumulators," meaning they can gather more metals than other plants. Water-soluble phytochemicals like quinines, organic acids, and flavones are responsible for reducing metal ions. Tannic acid, a compound found in many plants, helps stabilize nanoparticles, especially gold nanoparticles.

Researchers have used berry extracts rich in ellagic acid to create silver nanoparticles and studied their antimicrobial properties against dental pathogens like *Candida albicans* and *Enterococcus faecalis*. Plants like *Zanthoxylum armatum* have been used to create zinc oxide nanoparticles (ZnO NPs). In 2020, researchers studied *Cannabis sativa* for its potential as a reducing and stabilizing agent in nanoparticle synthesis. Another study used anthocyanin-rich red cabbage extract for creating stable iron oxide nanoparticles (Fe_3O_4) with antimicrobial and antioxidant properties. The iron oxide nanoparticles (Fe_3O_4 NPs) have shown antimicrobial and antioxidant properties, as well as improved stability. Copper oxide nanoparticles (CuO-NPs) were created using two methods: green synthesis (CuO (G)-NPs) and microwave irradiation (CuO (M)-NPs) with *Zanthoxylum armatum* plant extract. Silver-doped zinc oxide nanoparticles (AgZnO) were made using seed extract from *Moringa oleifera*. *Cannabis sativa* was also used in a green method to create nanoparticles with copper (Cu), magnesium (Mg), and silver (Ag) doping.

Aqueous extracts from three species of *Sideritis*—*S. brevidens*, *S. argyrea*, and *S. lycia*—were used to create silver nanoparticles (AgNPs). The activity of enzymes like cholinesterase (BChE and AChE) and tyrosinase was also tested. Using plants for nanoparticle synthesis is convenient, easy to handle, and offers a variety of metabolites that help in reducing metals. Many natural biomolecules in plants play important roles in reducing metals, forming nanoparticles, and stabilizing them.



Physicochemical properties of Nanoparticles:-

Nanoparticles (NPs) are widely utilized in various fields due to their unique physical and chemical properties, which differ significantly from those of the same materials in larger forms. These distinct properties arise from their small size and large surface area relative to their volume. When materials are reduced to the nanoscale, their characteristics undergo changes that enhance their effectiveness in a wide range of applications.

One of the most important properties of nanoparticles is their increased surface area. Since NPs are so small, even a small amount of material can have a vast surface area, making them highly reactive and allowing them to interact with their environment in ways that bulk materials cannot. This large surface area is particularly advantageous in applications like catalysis and drug delivery, where it enhances the material's effectiveness.

The behaviour of materials also changes as they are reduced to the nanoscale, a phenomenon known as size-dependent properties. At this scale, the physical and chemical properties of materials are different from those of their bulk counterparts. Nanoparticles may exhibit enhanced reactivity, strength, or lightness, making them useful for specific applications that require these traits.

Moreover, the optical properties of nanoparticles can differ greatly from those of larger materials. When reduced to the nanoscale, materials can absorb and reflect light in unique ways, leading to effects like colour changes or enabling applications in areas such as sensors and imaging. Additionally, nanoparticles often show distinct magnetic and electrical properties. For instance, magnetic nanoparticles can be manipulated by an external magnetic field, making them valuable in medical imaging, such as magnetic resonance imaging (MRI), and in targeted drug delivery. Similarly, nanoparticles made from specific metals or semiconductors possess unique electrical properties, making them vital in electronics and energy storage systems.

Finally, the chemical reactivity of nanoparticles is heightened due to their small size and large surface area. This increased reactivity makes them highly effective in chemical reactions, such as catalysis, where they can accelerate processes. Additionally, their reactivity allows nanoparticles to be used for targeted treatments in medical applications, such as attacking specific cells. All these physicochemical properties combined contribute to the versatility and wide range of uses for nanoparticles in various industries.

Mechanical Properties of Nanoparticles:-

Mechanical properties describe how a material behaves under different conditions, such as varying environments or when external forces are applied. For traditional materials, mechanical properties typically include strength, brittleness, hardness, toughness, fatigue strength, plasticity, elasticity, ductility, rigidity, and yield stress. Most non-metallic, inorganic materials are brittle and lack toughness, elasticity, and ductility. On the other hand, organic materials are more flexible and don't typically exhibit brittleness or rigidity.

Nanoparticles (NPs) have different mechanical properties compared to larger materials, mainly because of surface and quantum effects. For example, bulk FeAl (iron-aluminum) powder is brittle, but when it's reduced to ultrafine FeAl alloy powder, it shows a good balance of strength and ductility, as well as increased plasticity. These changes in properties are thought to be caused by the various forces acting between nanoparticles or between nanoparticles and surfaces.

The key forces that influence the mechanical properties of nanoparticles include **van der Waals forces**, which consist of three types: Keesom force, Debye force, and London force. Other important forces include electrostatic forces, electrical double layer forces, capillary forces, and hydration forces.

There are several theories that help explain the mechanical behaviour of nanoparticles. One of them is the **DLVO Theory (Derjaguin–Landau–Verwey–Overbeek Theory)**, which combines van der Waals attraction and electrostatic repulsion to explain the stability of nanoparticles in suspension and how they interact in liquid environments. While the DLVO theory is useful for understanding how nanoparticles behave in suspension, it doesn't fully explain their behaviour when they aggregate.

Another theory is the **JKR Model (Johnson–Kendall–Roberts)**, which is applied to larger bodies that can easily deform and have high surface energies. This model focuses on short-range adhesion forces. On the other hand, the **DMT Model (Derjaguin–Muller–Toporov)** applies to smaller, harder bodies with low surface energies and explains how long-range weak forces cause adhesion. Although these theories are widely used to describe the mechanical properties of nanoparticles, there's still debate about whether traditional continuum mechanics can accurately describe particles at the nanoscale.

Thermal Properties of Nanoparticles:-

Heat transfer in nanoparticles (NPs) mainly happens through the movement of electrons and the vibrations of atoms in the material. The way heat moves in NPs depends on two factors: how electrons conduct heat and the scattering effects that happen with both electrons and vibrations. Key thermal properties of materials include thermal conductivity, thermoelectric power, heat capacity, and thermal stability.

The size of nanoparticles directly affects their thermal and electrical conductivity. As the size of the nanoparticle gets smaller, the surface area compared to its volume becomes much larger. This means there are more electrons available to transfer heat in NPs than in bulk materials. Additionally, when NPs are in a liquid, like in a "nanofluid," heat conductivity can be increased by the random motion of the NPs, also known as Brownian motion. For example, adding copper (Cu) NPs to ethylene glycol can improve the thermal conductivity of the liquid by up to 40%.

Thermoelectric power is another important property, and it depends on the Seebeck coefficient (which measures the voltage created when a material is heated) and electrical conductivity. In some cases, doping (adding) nanoparticles to a material can improve its thermoelectric power. This improvement can come from either an increase in the Seebeck coefficient or better electrical conductivity. For instance, adding small-sized NPs to thermoelectric materials can reduce heat conduction and improve the Seebeck coefficient by filtering electron energy. Depending on the size of the NPs, it can either increase or decrease the electrical conductivity compared to a material without any doping.

When it comes to heat capacity, studies show that nanoparticles often have a heat capacity that is 10% higher than the same material in bulk form. This difference is because the vibration of atoms (phonons) inside the nanoparticle affects its ability to hold heat. NPs also have a lower melting point compared to bulk materials. As the size of the particles decreases, the ratio of surface area to volume increases, which lowers the melting temperature. For example, gold (Au) nanoparticles that are just 3 nanometers in size melt 300 degrees Celsius lower than bulk gold.

Finally, the composition of nanoparticles plays an important role in their thermal stability. For example, a gold-iron (Au-Fe) alloy nanoparticle can have better thermal stability than pure gold nanoparticles. In general, bimetallic nanoparticles (made of two metals) tend to have higher thermal stability and higher melting temperatures than single-metal nanoparticles, thanks to the effects of alloying.

Magnetic Properties of Nanoparticles:-

Most magnetic materials contain elements like iron (Fe), cobalt (Co), or nickel (Ni), which are magnetic at room temperature. However, there are a few exceptions made from non-magnetic elements, like Sc3In or TiBe2-xCux. The behaviour of magnetic materials changes at the nanoscale. Some materials that are not magnetic in bulk form become magnetic when reduced to nanoparticle (NP) size. For example, iron-aluminum (FeAl) is not magnetic in bulk but becomes magnetic when made into nanoparticles. Other examples include palladium (Pd) and gold (Au).

In bulk materials, factors like composition, structure, and defects affect magnetic properties. But for nanoparticles, size and shape become more important. One interesting property that happens with smaller nanoparticles is superparamagnetism. As nanoparticles get smaller, the energy required to keep their magnetic moment (the direction the particle's magnetism points) in place decreases. At a certain size, the magnetic energy becomes equal to the energy from heat, allowing the magnetic moment to flip randomly. At this size, nanoparticles are considered super paramagnetic. This means they only show magnetism when a magnetic field is applied, and once the field is removed, they lose their magnetism.

Superparamagnetism was once thought to only happen in small ferromagnetic or ferromagnetic nanoparticles, but it’s now known that even other paramagnetic materials can show magnetism at the nanoscale.

The size of nanoparticles also affects their magnetic coactivity, which is the resistance of a magnetic material to changes in its magnetization. In larger particles, multiple magnetic domains (regions with different magnetic orientations) exist, but in smaller nanoparticles, the magnetic spins align in one direction. Below a certain size, nanoparticles have a single magnetic domain, and their coactivity increases. Once the nanoparticle reaches a certain critical size, the coactivity starts to decrease, and the particle behaves more like bulk material, even though it has a single domain structure.

The shape of nanoparticles also affects their magnetic properties. While there is less research on the effect of shape, studies show that nanoparticles with different shapes, like spherical or cubic, can have different magnetic behaviours. For example, cubic cobalt-ferrite ($CoFe_2O_4$) nanoparticles have lower coactivity compared to spherical ones due to differences in their surface structure.

Finally, just like bulk materials, the composition of nanoparticles impacts their magnetic properties. Magnetic nanoparticles with different crystalline structures or core-shell designs can behave differently. For example, Copt core-shell nanoparticles show super paramagnetic behaviour with no coactivity at room temperature. The addition of magnetic elements to nanoparticles can significantly change their magnetic properties.

Electronic and Optical Properties of Nanoparticles:-

Metallic and semiconductor nanoparticles (NPs) have special electronic and optical properties that come from their tiny size. These properties include things like absorption of light, emission of light (photoluminescence), and the ability to change light in non-linear ways. These effects happen because of quantum confinement and a phenomenon called Localized Surface Plasmon Resonance (LSPR).

LSPR occurs when light hits nanoparticles, causing the electrons in the metal to move in a collective way. This happens because the frequency of the incoming light matches the natural frequency at which the electrons in the nanoparticle like to oscillate. For noble metals like gold and silver, this causes a strong colour change that depends on the size of the nanoparticles. Bulk metals do not show this effect.

The optical properties of nanoparticles depend on several factors: size, shape, and the surrounding environment. For example, when nanoparticles are irradiated by visible light, the electrons inside the metal start to oscillate. These oscillations create an effect where the surface of the nanoparticle develops areas of positive and negative charge. The oscillations of the electron cloud on the nanoparticle's surface are called surface plasmons, and they have a specific frequency at which they resonate.

Experiments with silver (Ag) nanoparticles show that their optical properties change depending on their size. For example, silver nanoparticles with a radius of 30 nm have an extinction peak (the wavelength where the material absorbs light) at 369 nm, but silver nanoparticles with a 60 nm radius behave differently. The shape of the nanoparticles also affects their properties. If the nanoparticles become more oblong, their resonance shifts to longer wavelengths (redder light). This shows that the shape of the nanoparticle is crucial to its optical behaviour.

The environment around the nanoparticles also influences their optical properties. For instance, the refractive index (how much light bends) of the solvent surrounding the nanoparticles can affect the wavelength of light they absorb. When silver nanoparticles are placed on a mica surface (a type of mineral), their resonance shifts to red compared to when they are not supported on any surface.

Biologically produced nanoparticles can also have different and improved optical properties compared to chemically made ones. For example, nanoparticles of cerium oxide (CeO_2) made using a plant extract showed better crystallinity and higher band-gap energy, which improved their absorption properties. Similarly, zinc oxide (ZnO) nanoparticles produced using a plant extract showed higher photocatalytic activity (ability to break down pollutants in light) than chemically produced ZnO nanoparticles.

Catalytic Properties of Nanoparticles:-

Nano catalysis refers to using nanoparticles (NPs) as catalysts, and it's a rapidly growing area in chemical catalysis. Nanoparticles often show much better or new catalytic properties, like increased reactivity and selectivity, compared to the larger forms of the same materials. The catalytic performance of nanoparticles depends on factors like their size, shape, composition, spacing between particles, oxidation state, and the surface they are supported on.

The relationship between the size of nanoparticles and their catalytic activity is well-known: the smaller the nanoparticles, the more active they are as catalysts. This means that tiny nanoparticles are generally much more effective at speeding up chemical reactions than their larger counterparts. Nanocatalysis is when nanoparticles (NPs) are used to speed up chemical reactions, and it's a rapidly growing field in chemistry.

Nanoparticles often show much better catalytic properties, such as higher reactivity and selectivity, compared to their larger counterparts. The catalytic performance of nanoparticles depends on their size, shape, composition, spacing between particles, oxidation state, and the surface they are supported on.

Studies have shown that smaller nanoparticles are generally more effective at catalyzing reactions. For example, in the oxidation of carbon monoxide (CO), smaller gold nanoparticles (1.5, 4, and 6 nm) showed higher reactivity than larger ones. This trend has been observed in other studies as well. Researchers believe that this behaviour is due to quantum-size effects, where the electrons are confined in smaller spaces, or changes in the electronic structure of the particles that make more active atoms available for reactions.

The shape of nanoparticles also plays a role in their reactivity. For example, hemispherical gold nanoparticles are more active than spherical ones in CO oxidation. Similarly, nanocubes of silver nanoparticles are much more effective than nanoplates or nanospheres in the oxidation of styrene. These differences are due to the changes in the surface area available for reactions or how stable the nanoparticles are in different shapes.

Composition also affects the catalytic properties. Studies have shown that alloying metals in nanoparticles can improve their activity. For example, combining platinum with metals like ruthenium, nickel, or cobalt enhances hydrogenation and oxygen reduction reactions. It can also help reduce poisoning effects that lower the efficiency of the catalyst. However, combining platinum with metals like iron, ruthenium, or palladium can reduce the reactivity for some reactions, such as methanol decomposition. This happens because the added metal atoms occupy surface sites that would otherwise be active for the reaction.

The spacing between nanoparticles also affects their catalytic properties. A study showed that gold nanoparticles on a titanium carbide (TiC) surface had different lifetimes depending on the spacing between them. Smaller spacing led to faster deactivation, while larger spacing helped the nanoparticles last longer.

The oxidation state of nanoparticles can also impact their catalytic activity. For example, ruthenium nanoparticles tend to oxidize under oxygen-rich conditions, forming ruthenium dioxide (RuO_2), which is more reactive for CO oxidation than metallic ruthenium. Similarly, platinum nanoparticles oxidize to form platinum dioxide (PtO_2), which is more active than pure platinum for CO oxidation. These changes in reactivity show that the oxidation process of nanoparticles might not always reduce their catalytic performance, as was previously believed.

Finally, the support material on which nanoparticles are placed is important. For instance, when gold nanoparticles are supported on magnesium oxide (MgO), the support helps improve CO oxidation by controlling the rate of the reaction. Other support materials like cerium oxide (CeO_2) or titanium carbide (TiC) have also been found to enhance the catalytic performance of gold nanoparticles. The support material can also help stabilize nanoparticles by preventing them from breaking down or losing their activity during reactions.

Toxicity:-

Toxicity is an important factor to consider when using nanoparticles (NPs) in various applications like tissue repair, drug delivery, and food packaging. The type of material used affects how toxic the nanoparticles are, and the way they act depends on the specific application. The toxicity of NPs depends on factors like how much is used, how stable they are, how easily they are absorbed into the body, and how likely they are to build up in specific organs or tissues. These factors change depending on the material, size, and surface properties of the nanoparticles.

In general, NPs can cause toxicity by producing reactive oxygen species (ROS), which can damage cells. Inorganic nanoparticles, like metallic NPs, are commonly used in various industries. They can be easily combined with other materials and used in treatments for cancer, antioxidants, and infections. However, too much exposure can lead to harmful effects like oxidative stress, inflammation, and genetic damage.

Silver nanoparticles are often studied for their strong antimicrobial properties and are used in fields like medicine, biotechnology, and environmental science. However, concerns have grown about their potential toxicity to both human health and the environment. The toxicity of silver NPs is influenced by their size, shape, surface charge, coating, and concentration. Their small size and the release of silver ions can make them more reactive, leading to cell damage, oxidative stress, and inflammation. For example, studies on zebra fish embryos have shown that silver NPs can cause harmful effects like increased death rates, delayed hatching, heart problems, and developmental issues.

In another study with rats, silver NPs caused significant damage to organs like the liver, kidneys, and heart. The rats showed signs of oxidative stress, lower antioxidant levels, liver damage, kidney function problems, and heart inflammation.

Gold nanoparticles are also studied for their toxicity. Research on mice has shown that gold NPs of certain sizes (8 to 37 nm) can cause health problems like weight loss, tiredness, and damage to organs such as the lungs, liver, and spleen.

Other nanoparticles, like titanium dioxide (TiO2), have also been tested for toxicity. In mice, TiO2 NPs caused oxidative stress, genetic changes, and organ damage, especially with smaller particle sizes and higher doses.

Conclusion:-

Nanoparticles are tiny materials with special properties that make them incredibly useful in many different areas. Their small size, large surface area, and high reactivity make them perfect for uses in medicine, electronics, cleaning the environment, and energy storage. By controlling their size, shape, and surface features, we can use nanoparticles for things like delivering medicine, treating cancer, and improving diagnostic tools. As scientists develop better ways to make and study nanoparticles, their potential for new uses continues to grow. With on-going research, nanoparticles are expected to play a big role in solving global problems, such as healthcare challenges, environmental protection, and improving industrial processes. In conclusion, nanoparticles hold great promise for the future of science and technology, and their continued development is likely to lead to important breakthroughs and solutions in many industries.

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