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# A review on the classification, characterisation, synthesis of nanoparticles and their application

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**Abstract**. As per ISO and ASTM standards, nanoparticles are particles of sizes ranging from 1 to 100nm with one or more dimensions. The nanoparticles are generally classified into the organic, inorganic and carbon based particles in nanometric scale that has improved properties compared to larger sizes of respective materials. The nanoparticles show enhanced properties such as high reactivity, strength, surface area, sensitivity, stability, etc. because of their small size. The nanoparticles are synthesised by various methods for research and commercial uses that are classified into three main types namely physical, chemical and mechanical processes that has seen a vast improvement over time. This paper presents a review on nanoparticles, their types, properties, synthesis methods and its applications in the field of environment.

## 1. Introduction

Nanotechnology has gained huge attention over time. The fundamental component of nanotechnology is the nanoparticles. Nanoparticles are particles between 1 and 100 nanometres in size and are made up of carbon, metal, metal oxides or organic matter [1]. The nanoparticles exhibit a unique physical, chemical and biological properties at nanoscale compared to their respective particles at higher scales. This phenomena is due to a relatively larger surface area to the volume, increased reactivity or stability in a chemical process, enhanced mechanical strength, etc. [2]. These properties of nanoparticles has led to its use various applications.

The nanoparticles differs from various dimensions, to shapes and sizes apart from their material [3]. A nanoparticle can be either a zero dimensional where the length, breadth and height is fixed at a single point for example nano dots, one dimensional where it can possess only one parameter for example graphene, two dimensional where it has length and breadth for example carbon nanotubes or three dimensional where it has all the parameters such as length, breadth and height for example gold nanoparticles.

The nanoparticles are of different shape, size and structure. It be spherical, cylindrical, tubular, conical, hollow core, spiral, flat, etc. or irregular and differ from 1 nm to 100 nm in size. The surface can be a uniform or irregular with surface variations. Some nanoparticles are crystalline or amorphous with single or multi crystal solids either loose or agglomerated [4].

Numerous synthesis methods are either being developed or improved to enhance the properties and reduce the production costs. Some methods are modified to achieve process specific nanoparticles to increase their optical, mechanical, physical and chemical properties [3]. A vast development in the instrumentation has led to an improved nanoparticle characterisation and subsequent application. The nanoparticles are now used in every objects like from cooking vessel, electronics to renewable energy and aerospace industry. Nanotechnology is the key for a clean and sustainable future.

## 2. Classification of Nanoparticles

The nanoparticles are generally classified into the organic, inorganic and carbon based.

### *2.1. Organic nanoparticles*

Dendrimers, micelles, liposomes and ferritin, etc. are commonly knows the organic nanoparticles or polymers. These nanoparticles are biodegradable, non-toxic, and some particles such as micelles and liposomes has a hollow core (Figure1), also known as nanocapsules and are sensitive to thermal and electromagnetic radiation such as heat and light [5]. These unique characteristics makes them an ideal choice for drug delivery. The drug carrying capacity, its stability and delivery systems, either entrapped drug or adsorbed drug system determines their field of applications and their efficiency apart from their normal characteristics such as the size, composition, surface morphology, etc. The organic nanoparticles are most widely used in the biomedical field for example drug delivery system as they are efficient and also can be injected on specific parts of the body that is also known as targeted drug delivery.

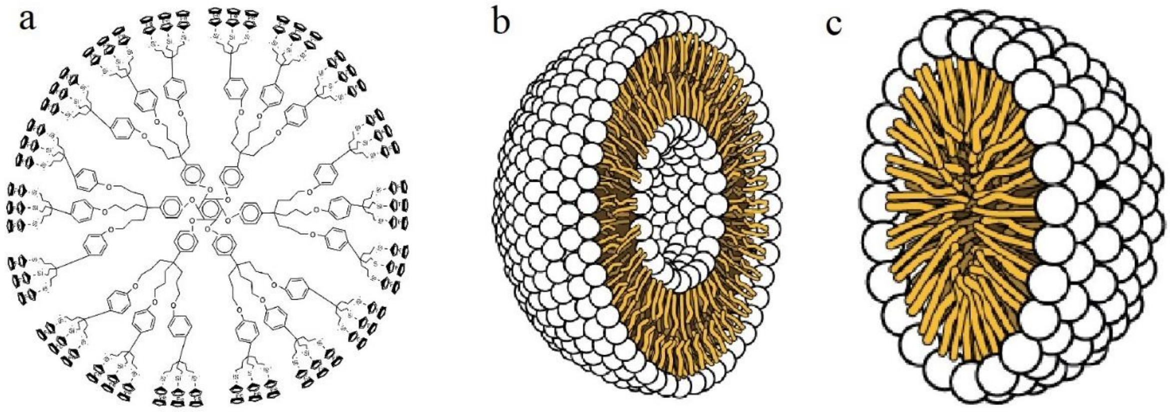


**Figure 1.** Organic nanoparticles: a – Dendrimers, b – Liposomes and c – micelles.

### *2.2. Inorganic nanoparticles*

Inorganic nanoparticles are particles that are not made up of carbon. Metal and metal oxide based nanoparticles are generally categorised as inorganic nanoparticles

*2.2.1. Metal based*. Nanoparticles that are synthesised from metals to nanometric sizes either by destructive or constructive methods are metal based nanoparticles. Almost all the metals can be synthesised into their nanoparticles [6]. The commonly used metals for nanoparticle synthesis are aluminium (Al), cadmium (Cd), cobalt (Co), copper (Cu), gold (Au), iron (Fe), lead (Pb), silver (Ag) and zinc (Zn). The nanoparticles have distinctive properties such sizes as low as 10 to 100nm, surface characteristics like high surface area to volume ratio, pore size, surface charge and surface charge density, crystalline and amorphous structures, shapes like spherical and cylindrical and colour, reactivity and sensitivity to environmental factors such as air, moisture, heat and sunlight etc.

*2.2.2. Metal oxides based*. The metal oxide based nanoparticles are synthesised to modify the properties of their respective metal based nanoparticles, for example nanoparticles of iron (Fe) instantly oxidises to iron oxide ($Fe_2O_3$) in the presence of oxygen at room temperature that increases its reactivity compared to iron nanoparticles. Metal oxide nanoparticles are synthesised mainly due to their increased reactivity and efficiency [7]. The commonly synthesised are Aluminium oxide ($Al_2O_3$),

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Cerium oxide ($CeO_2$), Iron oxide ($Fe_2O_3$), Magnetite ($Fe_3O_4$), Silicon dioxide ($SiO_2$), Titanium oxide ($TiO_2$), Zinc oxide (ZnO). These nanoparticles have possess an exceptional properties when compared to their metal counterparts.

*2.3. Carbon based*

The nanoparticles made completely of carbon are knows as carbon based [8]. They can be classified into fullerenes, graphene, carbon nano tubes (CNT), carbon nanofibers and carbon black and sometimes activated carbon in nano size and are presented in Figure2.

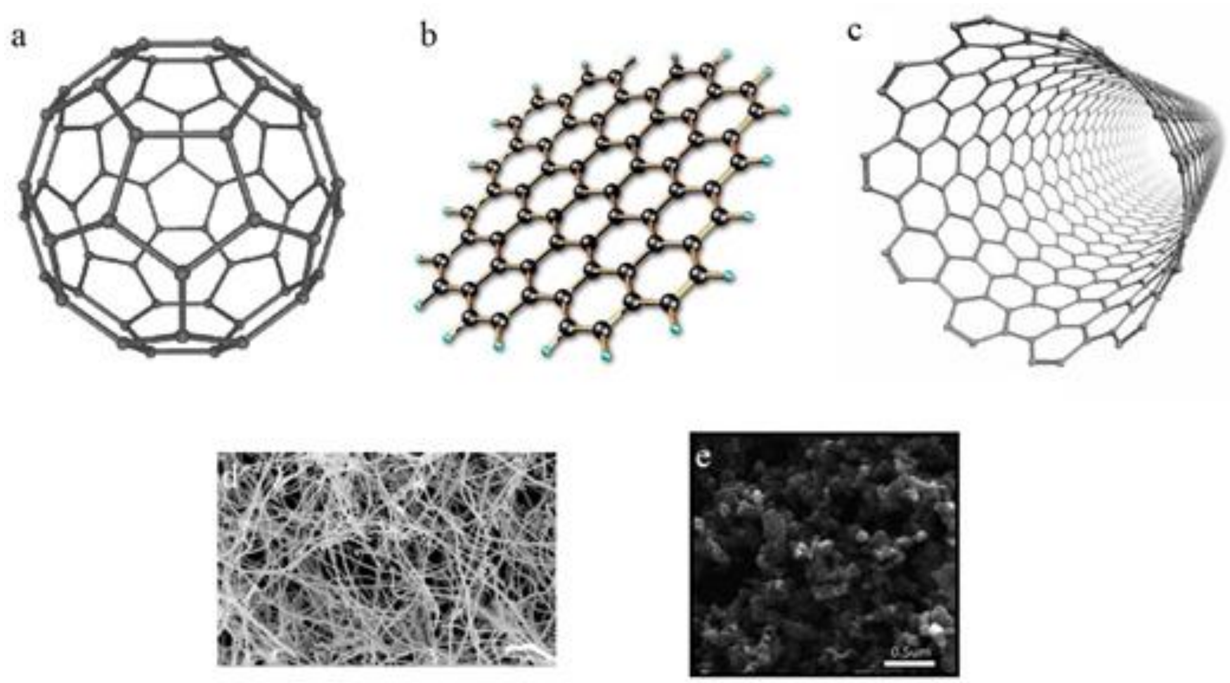


**Figure 2.** Carbon based nanoparticles: a – fullerenes, b – graphene, c – carbon nanotubes, d – carbon nanofibers and e – carbon black

*2.3.1. Fullerenes*. Fullerenes ($C_{60}$) is a carbon molecule that is spherical in shape and made up of carbon atoms held together by $sp^2$ hybridization. About 28 to 1500 carbon atoms forms the spherical structure with diameters up to 8.2 nm for a single layer and 4 to 36 nm for multi-layered fullerenes.

*2.3.2. Graphene*. Graphene is an allotrope of carbon. Graphene is a hexagonal network of honeycomb lattice made up of carbon atoms in a two dimensional planar surface. Generally the thickness of the graphene sheet is around 1 nm.

*2.3.3. Carbon Nano Tubes (CNT)*. Carbon Nano Tubes (CNT), a graphene nanofoil with a honeycomb lattice of carbon atoms is wound into hollow cylinders to form nanotubes of diameters as low as 0.7 nm for a single layered and 100 nm for multi-layered CNT and length varying from a few micrometres to several millimetres. The ends can either be hollow or closed by a half fullerene molecule.

*2.3.4. Carbon Nanofiber*. The same graphene nanofoils are used to produce carbon nanofiber as CNT but wound into a cone or cup shape instead of a regular cylindrical tubes.

*2.3.5. Carbon black*. An amorphous material made up of carbon, generally spherical in shape with diameters from 20 to 70 nm. The interaction between the particles are so high that they bound in aggregates and around 500 nm agglomerates are formed.

## 3. Synthesis of Nanoparticles

The nanoparticles are synthesised by various methods that are categorised into bottom-up or top-down method. A simplified representation of the process is presented in Figure3.

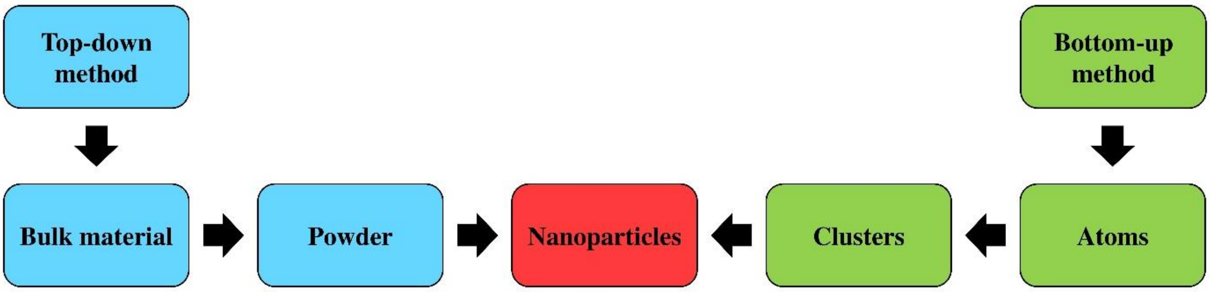


**Figure 3.** Synthesis process.

### *3.1. Bottom-up method*

Bottom-up or constructive method is the build-up of material from atom to clusters to nanoparticles. Sol-gel, spinning, chemical vapour deposition (CVD), pyrolysis and biosynthesis are the most commonly used bottom-up methods for nanoparticle production.

*3.1.1. Sol-gel*. The sol – a colloidal solution of solids suspended in a liquid phase. The gel – a solid macromolecule submerged in a solvent. Sol-gel is the most preferred bottom-up method due to its simplicity and as most of the nanoparticles can be synthesised from this method. It is a wet-chemical process containing a chemical solution acting as a precursor for an integrated system of discrete particles. Metal oxides and chlorides are the typically used precursors in sol-gel process [9]. The precursor is then dispersed in a host liquid either by shaking, stirring or sonication and the resultant system contains a liquid and a solid phase. A phase separation is carried out to recover the nanoparticles by various methods such as sedimentation, filtration and centrifugation and the moisture is further removed by drying [10].

*3.1.2. Spinning*. The synthesis of nanoparticles by spinning is carried out by a spinning disc reactor (SDR). It contains a rotating disc inside a chamber/reactor where the physical parameters such as temperature can be controlled. The reactor is generally filled with nitrogen or other inert gases to remove oxygen inside and avoid chemical reactions [7]. The disc is rotated at different speed where the liquid i.e. precursor and water is pumped in. The spinning causes the atoms or molecules to fuse together and is precipitated, collected and dried [11]. The various operating parameters such as the liquid flow rate, disc rotation speed, liquid/precursor ratio, location of feed, disc surface, etc. determines the characteristics nanoparticles synthesised from SDR.

*3.1.3. Chemical Vapour Deposition (CVD)*. Chemical vapour deposition is the deposition of a thin film of gaseous reactants onto a substrate. The deposition is carried out in a reaction chamber at ambient temperature by combining gas molecules. A chemical reaction occurs when a heated substrate comes in contact with the combined gas [8]. This reaction produces a thin film of product on the substrate surface that is recovered and used. Substrate temperature is the influencing factor in CVD. The advantages of CVD are highly pure, uniform, hard and strong nanoparticles. The disadvantages of CVD are the requirement of special equipment and the gaseous by-products are highly toxic [12].

*3.1.4. Pyrolysis*. Pyrolysis is the most commonly used process in industries for largescale production of nanoparticle. It involves burning a precursor with flame. The precursor is either liquid or vapour that is fed into the furnace at high pressure through a small hole where it burn [13]. The combustion or by-product gases is then air classified to recover the nanoparticles. Some of the furnaces use laser and plasma instead of flame to produce high temperature for easy evaporation [14]. The advantages of pyrolysis are simple, efficient, cost effective and continuous process with high yield.

*3.1.5. Biosynthesis*. Biosynthesis is a green and environmental friendly approach for the synthesis of nanoparticles that are nontoxic and biodegradable [15]. Biosynthesis uses bacteria, plant extracts, fungi, etc. along with the precursors to produce nanoparticle instead of convention chemicals for bioreduction and capping purposes. The biosynthesised nanoparticles has unique and enhanced properties that finds its way in biomedical applications [1].

### *3.2. Top-down method*
Top-down or destructive method is the reduction of a bulk material to nanometric scale particles. Mechanical milling, nanolithography, laser ablation, sputtering and thermal decomposition are some of the most widely used nanoparticle synthesis methods.

*3.2.1. Mechanical milling*. Among the various top-down methods, mechanical milling is the most extensively used to produce various nanoparticles. The mechanical milling is used for milling and post annealing of nanoparticles during synthesis where different elements are milled in an inert atmosphere [16]. The influencing factors in mechanical milling is plastic deformation that leads to particle shape, fracture leads to decrease in particle size and cold-welding leads to increase in particle size .

*3.2.2. Nanolithography*. Nanolithography is the study of fabricating nanometric scale structures with a minimum of one dimension in the size range of 1 to 100 nm. There are various nanolithographic processes for instance optical, electron-beam, multiphoton, nanoimprint and scanning probe lithography [17]. Generally lithography is the process of printing a required shape or structure on a light sensitive material that selectively removes a portion of material to create the desired shape and structure. The main advantages of nanolithography is to produce from a single nanoparticle to a cluster with desired shape and size. The disadvantages are the requirement of complex equipment and the cost associated [18].

*3.2.3. Laser ablation*. Laser Ablation Synthesis in Solution (LASiS) is a common method for nanoparticle production from various solvents. The irradiation of a metal submerged in a liquid solution by a laser beam condenses a plasma plume that produces nanoparticles [19]. It is a reliable top-down method that provides an alternative solution to conventional chemical reduction of metals to synthesis metal based nanoparticles. As LASiS provides a stable synthesis of nanoparticles in organic solvents and water that does not require any stabilising agent or chemicals it is a ‘green’ process.

*3.2.4. Sputtering*. Sputtering is the deposition of nanoparticles on a surface by ejecting particles from it by colliding with ions [20]. Sputtering is usually a deposition of thin layer of nanoparticles followed by annealing. The thickness of the layer, temperature and duration of annealing, substrate type, etc. determines the shape and size of the nanoparticles [21].

*3.2.5. Thermal decomposition*. Thermal decomposition is an endothermic chemical decomposition produced by heat that breaks the chemical bonds in the compound [6]. The specific temperature at which an element chemically decomposes is the decomposition temperature. The nanoparticles are produced by decomposing the metal at specific temperatures undergoing a chemical reaction producing secondary products. Table 1 lists some of the nanoparticles synthesised from these methods.

**Table 1.** Categories of the nanoparticles synthesised from the various methods

| Category | Method | Nanoparticles |
|---|---|---|
| Bottom-up | Sol-gel | Carbon, metal and metal oxide based |
| | Spinning | Organic polymers |
| | Chemical Vapour Deposition (CVD) | Carbon and metal based |
| | Pyrolysis | Carbon and metal oxide based |
| | Biosynthesis | Organic polymers and metal based |
| Top-down | Mechanical milling | Metal, oxide and polymer based |
| | Nanolithography | Metal based |
| | Laser ablation | Carbon based and metal oxide based |
| | Sputtering | Metal based |
| | Thermal decomposition | Carbon and metal oxide based |

## 4. Properties of Nanoparticles

The properties of nanoparticles are generally categorised into physical and chemical. The properties of few common nanoparticles are given in Table 2.

**Table 2.** Physical and chemical properties of different nanoparticles

| Nanoparticles | Properties | Reference |
|---|---|---|
| | **Carbon based nanoparticles** | |
| Fullerenes | Safe and inert, semiconductor, conductor and superconductor, transmits light based on intensity | [40] |
| Graphene | Extreme strength, thermal, electrical conductivity, light absorption | [41] |
| Carbon Nano Tubes (CNT) | High electrical and thermal conductivity, tensile strength, flexible and elastic | [42] |
| Carbon Nanofiber | High thermal, electrical, frequency shielding, and mechanical properties | [43] |
| Carbon Black | High strength and electrical conductivity, surface area; resistant to UV degradation | [44] |
| | **Metal based nanoparticles** | |
| Aluminium | High reactivity, sensitive to moisture, heat, and sunlight, large surface area | [45] |
| Iron | Reactive and unstable, sensitive to air (oxygen) and water | [46] |
| Silver | Absorbs and scatters light, stable, anti-bacterial, disinfectant | [18] |
| Gold | Interactive with visible light, reactive | [47] |
| Cobalt | Unstable, magnetic, toxic, absorbs microwaves, magnetic | [48] |
| Cadmium | Semiconductor of electricity, insoluble | [49] |
| Lead | High toxicity, reactive, highly stable | [50] |
| Copper | Ductile, very high thermal and electrical conductivity, highly flammable solids | [51] |
| Zinc | Antibacterial, anti-corrosive, antifungal, UV filtering | [52] |

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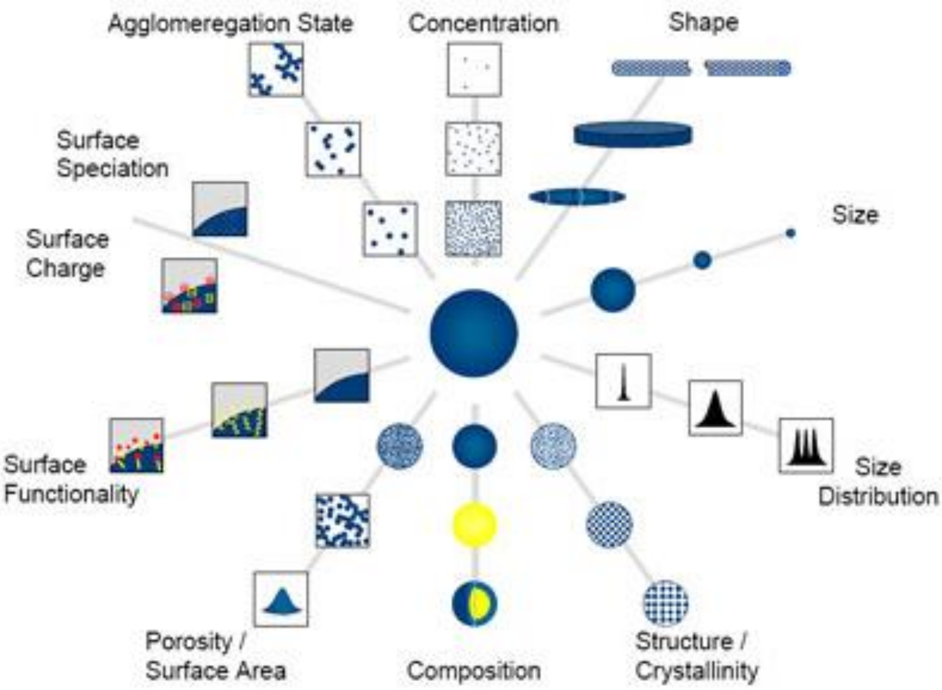
| Metal oxide based nanoparticles | | |
|---|---|---|
| Titanium oxide | High surface area, magnetic, inhibits bacterial growth | [35] |
| Iron oxide | Reactive and unstable | [53] |
| Magnetite | Magnetic, highly reactive | [54] |
| Silicon dioxide | Stable, less toxic, able to be functionalize many molecules | [55] |
| Zinc oxide | Antibacterial, anti-corrosive, antifungal and UV filtering | [56] |
| Cerium oxide | Antioxidant, low reduction potential | [57] |
| Aluminium oxide | Increased reactivity, sensitive to moisture, heat, and sunlight, Large surface area | [58] |

### *4.1. Physical*
The physical properties include optical such as the colour of the nanoparticle, its light penetration, absorption and reflection capabilities, and UV absorption and reflection abilities in a solution or when coated onto a surface. It also includes the mechanical properties such as elastic, ductile, tensile strengths and flexibility that play a significant factor in their application. Other properties like hydrophilicity, hydrophobicity, suspension, diffusion and settling characteristics has found its way in many modern everyday things. Magnetic and electrical properties such as conductivity, semi conductivity and resistivity has led a path for the nanoparticles to be used in modern electronics thermal conductivity in renewable energy applications.

### *4.2. Chemical*
The chemical properties such as the reactivity of the nanoparticles with the target and stability and sensitivity to factors such as moisture, atmosphere, heat and light determine its applications. The anti-bacterial, anti-fungal, disinfection, and toxicity, properties of the nanoparticles are ideal for biomedical and environmental applications. Corrosive, anti-corrosive, oxidation, reduction and flammability characteristics of the nanoparticles determine their respective usage.

## 5. Characterisation
The unique characteristics determines the potential and application of a nanoparticle. The nanoparticle characterisation is carried out by various measurement techniques that is summarised in Table 3 and illustrated in Figure4.




**Source:** ***Hassellöv & Kaegi, 2009***

**Figure 4.** Nanoparticle characterisation

**Table 3.** Various characterisation methods for nanoparticle in solid, liquid and gaseous phase

| Characteristics | Solid | Liquid | Gaseous |
|---|---|---|---|
| Size | Electron microscope and laser diffraction for bulk samples | Photon correlation spectroscopy and centrifugation | SMPS and optical particle counter |
| Surface area | BET Isotherm | Simple titration and NMR experiments, | SMPS, DMA |
| Composition | XPS and Chemical digestion followed by wet chemical analysis for bulk samples. | Chemical digestion for mass spectrometry, atomic emission spectroscopy and ion chromatography | Particles are collected for analysis by spectrometric or wet chemical techniques |
| Surface morphology | Image analysis of electron micrographs | Deposition onto a surface for electron microscopy | Capture particles electrostatically or by filtration for imaging using electron microscopy |
| Surface charge | Zeta potential | | DMA |
| Crystallography | Powder X-ray or neutron diffraction | - | - |
| Concentration | - | - | CPC |

BET – Brunauer–Emmett–Teller model, CPC – Condensation Particle Counter, DMA – Differential Mobility analyser, NMR – Nuclear Magnetic Resonance Spectroscopy, SMPS – Scanning Mobility Particle Sizer, XPS – X-ray Photoelectron Spectroscopy

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### *5.1. Size*
The particle is one of the most basic and important measurement for nanoparticle characterisation. It determines the size and distribution of the particle and whether it falls under nano or micro scale. The particle size and distribution is most commonly measured using electron microscopy. The images of Scanning Electron Microscope (SEM) and Transmission Electron Microscope (TEM) are used for the measurement of particles and clusters whereas laser diffraction methods are used for measuring bulk samples in solid phase [22]. The particles in liquid phase are measured using photon correlation spectroscopy and centrifugation. The particles in gaseous phase are difficult and irreverent to use the imaging techniques and hence a Scanning Mobility Particle Sizer (SMPS) is used which provides a fast and accurate measurements compared to other methods.

### *5.2. Surface area*
The surface area is also a significant factor in nanoparticle characterisation. The surface area to volume ratio of a nanoparticle has a huge influence on its performance and properties. The surface area is most commonly measured using BET analysis. A simple titration is sufficient for the surface area analysis of particles in liquid phase, but it is a labour intensive process. Hence nuclear magnetic resonance spectroscopy (NMR) is used. A modified SMPS and differential mobility analyser (DMA) is used for the measurement of surface are of nanoparticles in gaseous phase.

### *5.3. Composition*
The chemical or elemental composition determines the purity and performance of the nanoparticle. Presence of higher secondary or undesired elements in the nanoparticle may reduce its efficiency and also lead to secondary reaction and contamination in the process. The composition measurement is usually carried out by X-ray photoelectron spectroscopy (XPS) [23]. Some techniques involve chemical digestion of the particles followed by wet chemical analysis such as mass spectrometry, atomic emission spectroscopy and ion chromatography. The particles in gaseous phase are collected either by filtration or electrostatically and spectrometric or wet chemical techniques are used for the analysis [24].

### *5.4. Surface morphology*
The nanoparticles possess various shapes and surface structures that plays a key role in exploiting its properties. Some of the shapes include spherical, flat, cylindrical, tubular, conical and irregular shapes with surface like crystalline or amorphous with uniform or irregularities on the surface. The surface is generally determined by electron microscopy imaging techniques like SEM and TEM [25]. The particles in liquid phase are deposited on a surface and analysed whereas the particles in gaseous phase are capture electrostatically or by filtration for imaging using electron microscopy.

### *5.5. Surface charge*
The surface charge or the charge of a nanoparticle determines its interactions with the target. Generally a zeta potentiometer is used for the measurement of surface charges and its dispersion stability in a solution [22]. A Differential Mobility Analyser (DMA) is used for the charge determination of nanoparticles in gaseous phase.

### *5.6. Crystallography*
Crystallography is the study of atoms and molecules arrangement in crystal solids. The crystallography of nanoparticles are carried out by a powder X-ray, electron or neutron diffraction to determine the structural arrangement [26].

### *5.7. Concentration*
The concentration of nanoparticles in gaseous phase is measured to determine the volume of air or gas required for the process. The concentration, size and distribution of nanoparticles in a unit volume of

air or gas marks the performance or its efficiency. The concentration measurements are usually made through a Condensation Particle Counter (CPC).

## 6. Applications
Below are some of the significant applications of nanoparticles.

### *6.1. Cosmetics and Sunscreens*
The conventional ultraviolet (UV) protection sunscreen lacks long-term stability during usage. The sunscreen including nanoparticles such as titanium dioxide provides numerous advantages. The UV protection property of titanium oxide and zinc oxide nanoparticles as they are transparent to visible light as well as absorb and reflect UV rays found their way to be used in some sunscreens. Some lipsticks use iron oxide nanoparticles as a pigment [27].

### *6.2. Electronics*
The higher necessity for large size and high brightness displays in recent days that are used in the computer monitors and television is encouraging the use of nanoparticles in the display technology. For example nanocrystalline lead telluride, cadmium sulphide, zinc selenide and sulphide, are used in the light emitting diodes (LED) of modern displays [28].

The development in portable consumer electronics such as mobile phones and laptop computers led to the enormous demand for a compact, lightweight and high capacity batteries. Nanoparticles are the ideal choice for separator plates in batteries. A considerable more energy can be stored compared to traditional batteries due to their foam like (aerogel) structure. Batteries made from nanocrystalline nickel and metal hydrides, due to their large surface area require less recharging and last longer [29].

The increase in electrical conductivity of nanoparticles are used to detect gases like $NO_2$ and $NH_3$ [30]. This is due to increase in the pores of nanoparticles due to charge transfer from nanoparticles to $NO_2$ as the gas molecules bind them together making them a better gas sensors.

### *6.3. Catalysis*
Nanoparticles contain high surface area that offers higher catalytic activity. Due to their extremely large surface to volume ratio the nanoparticles function as efficient catalyst in the production of chemicals [31]. One of the important application is the use of platinum nanoparticles in the automotive catalytic converters as they reduce the amount of platinum required due to very high surface area of the nanoparticles thus reducing the cost significantly and improving performance. Some chemical reactions for example, reduction of nickel oxide to metal nickel (Ni) is performed using nanoparticles.

### *6.4. Medicine*
Nanotechnology has improved the medical field by use of nanoparticles in drug delivery. The drug can be delivered to specific cells using nanoparticles [32]. The total drug consumption and side effects are significantly lowered by placing the drug in the required area in required dosage. This method reduces the cost and side effects. The reproduction and repair of damaged tissue (Tissue engineering) can be carried out with the help nanotechnology. The traditional treatments such as artificial implants and organ transplants can be replaced by tissue engineering. One such example is the growth of bones carbon nanotube scaffolds [33]. The use of gold in medicine is not new. In Ayurveda an Indian medical system, gold is used in several practices. One common prescription is the use of gold for memory enhancement. To enhance the mental fitness of a baby gold is included in certain medical preparations [34].

### *6.5. Food*
The improvement in production, processing, protection and packaging of food is achieved by incorporating nanotechnology. For example a nanocomposite coating in a food packaging process can directly introduce the anti-microbial substances on the coated film surface [35]. One of the example is

the canola oil production industry includes nanodrops, an additive designed to transfer the vitamins and minerals in the food.

*6.6. Construction*

Nanotechnology has improved the construction processes by making them quicker, inexpensive and safer. For example when nanosilica ($SiO_2$) is mixed with the normal concrete, the nanoparticles can improve its mechanical properties, and also improvements in durability [36]. The addition of haematite ($Fe_2O_3$) nanoparticles increases the strength of the concrete. Steel is the most widely available and used material in the construction industry. The properties of steel can be improved by using nanotechnology in steel for example in bridge construction the use of nano size steel offers stronger steel cables [36]. The other important construction material is glass. Extensive research is being performed on the application of nanotechnology in construction glass. Since titanium dioxide ($TiO_2$) nanoparticles has sterilizing and anti-fouling properties and catalyse powerful chemical reaction that breakdown volatile organic compound (VOV) and organic pollutants it is used to coat glazing [37]. The use of nanotechnology provides a better blocking of light and heat penetrating through the windows. The paints with self-healing abilities and corrosion resistance and insulation are obtained by adding nanoparticles to the paints. The hydrophobic property of these paints repels water and hence can be used to coat metal pipes to offer protection from salt water attack. The addition of nanoparticles in paints also improves its performance by making them lighter with enhanced properties [38] so when used for example on aircraft, it might reduce their overall weight and the amount of paint required, which is favourable to the environment as well the company to improve cost savings.

*6.7. Renewable energy and environmental remediation*

The unique physical and chemical properties of nanoparticles has made them an ideal choice to be used nowadays in environmental remediation to enhancing the performance in renewable energy sector [39]. Nanoparticles occur in nature themselves and some of them are found to cure the environment.

Environmental remediation using nanoparticles or nanoremediation is successfully being used to treat or decontaminate the air, water and soil for over a decade [2]. Nanoremediation is one of the effective solutions as it offers *in situ* treatment eliminating the necessity of pumping the ground water out for treatment and the need for excavation to reach the target destination. The nanoparticles are injected into the desired location and gets carried along the groundwater flow and decontaminates the water by immobilising the contaminants. The general mechanism involving in decontamination is the redox reactions.

The nanoparticles are used to treat the surface water by disinfection, purification and desalination. Some of the contaminants are most likely to be heavy metals, pathogens and organic contaminants. It has proven to be efficient and eliminating the need for chemicals that may sometime produce secondary reaction products.

Oil spill is one of the major problem worldwide as it may spread over very long distances. Cleaning them by conventional methods is difficult and time consuming that makes the situation worse as it may spread more. The nanoparticles are also used to clean-up oil spills and has also established to be effective method.

The major use of nanoparticles are to treat municipal and industrial wastewater as well as the sludge produced. The replacement of nanoparticles for conventional chemicals is due to less cost, higher efficiency and lower quantity required for treatment. Nanofiltration is a recent membrane filtration system for water purification widely used in food and dairy industries.

Soil contamination is also an increasing concern. Contaminated soil is cleaned or treated using nanoparticles by injecting the nanoparticles into specific target locations for heavy metal contamination, toxic industrial waste, etc. The higher surface area of certain nanoparticles has been used as a nanocatalyst in gaseous reactions. The most widely used area is in industrial stacks to reduce the contaminant level to prescribed limits or to remove completely that reduces the air pollution.

Extensive research is being carried out in the use of nanoparticles for renewable energy. Higher light and UV absorption with a very low reflection coatings in solar cells has improved their efficiency by considerable extent. The hydrophobic property of some nanoparticles has led to self-cleaning solar cells. High thermal conductivity and heat absorption capacity of certain nanoparticles are used to coat boilers and solar concentrators to improve their thermal efficiency.

## 7. Conclusion

Nanotechnology is improving our everyday lives by enhancing the performance and efficiency of everyday objects. It provides a clean environment by providing safer air and water, and clean renewable energy for a sustainable future. Nanotechnology has gained a wide attention where more investment is made for the research and development by top institutions, industries and organisations. Nanotechnology has established to be an advanced field of science where extensive research is carried out to implement the technology. It is being tested for various new applications to increase the efficiency and performance of the object or process and subsequently reduce the cost so that it is accessible for everyone. The nanotechnology has a great future due to its efficiency and environmental friendly property.

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