Chapter1

1.1. General Introduction of Nanoparticles/Nanocrystals.

Nanotechnology is the branch that agrees with dimensions and tolerances of less than 100 nanometres, and it is also the research of exploiting matter at the atomic and molecular levels. The International Organization for Standardization (ISO), In 2008 well-defined a nanoparticle as a separate Nano-object where all three Cartesian dimensions are less than 100 nm. The ISO standard also explained two-dimensional Nano-objects, this class includes plates-like shapes (i.e. Nano-discs, Nano-plates, graphene, Nano-films, Nano-layers, and Nano-coatings) and one-dimensional Nano-objects (i.e., Nano-fibres Nano-tubes, Nano-rods, and Nano-wires).[1]

However, the Commission of the European Union in 2011 recognized a more-technical but wider-ranging definition: Under that explanation, a Nano-object must have only one of its characteristic dimensions to be in the range of 1–100 nm to be classed as a nanoparticle, even if its additional dimensions are out of that range. (The lower limit of 1 nm should be used because atomic bond lengths are reached at 0.1 nm). According to European Union a natural, manufactured, and incidental material containing particles, in an unbound state, or as agglomerate or as an aggregate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm - 100 nm.[2] By derogation from the above, fullerenes, graphene flakes, and single-wall carbon nanotubes with one or more external dimensions below 1 nm should be considered nanomaterials.

1.2. History of Nanoparticles.

The first engineered nanoparticles are often recognized by the ancient Egyptians, Romans, and Chinese. Despite not having any idea about the scientific suggestions of what they were making, they were effectively able to prepare nanoparticle solutions of precious metals with reasonably precise control over particle size and composition like gold.

These antiquarian gold nanoparticle solutions were dazzlingly coloured (reds and purples) and could be saturated into the glass to make jewellery and stained glass. In addition, many people ingested these synthesized colloidal silver and gold solutions as health tonics specifically to treat high fevers and syphilis. Though it's unlikely that drinking metal nanoparticles has any truly positive aspects for your health, some people still swear by this folk remedy, with often unappetizing, though not necessarily lethal, results.[3]

There is a famous example of ancient artefacts which was created using nanocomposites. The Lycurgus cup is a stunning decorative Roman gem from about AD400; it is made of glass that changes colour when light is shone over it. This glass comprises gold-silver alloyed nanoparticles, which are dispersed in such a way to make the glass look like green in reflected light but, when light passes through the cup, it reveals a brilliant red (Fig.1.1).

Fig.1.1 The stunning Lycurgus cup reveals a brilliant red when light passes through its sections of glass containing gold-silver alloyed nanoparticles. (Source;copyright @ https://www.amusingplanet.com/2016/12/lycurgus-cup-piece-of-ancient-roman.html).

1.3. Source of nanoparticles

Nanoparticles may occur in nature and may also be created as a result of human activities. Some Incidental nanoparticles are called waste particles or anthropogenic, and they are the by-products of human activities which occur because of man-made industrial processes (Fig.1.2). Incidental and natural nanoparticles both may have irregular or regular morphologies and poor size control Generally, engineered nanoparticles on the other hand have regular morphologies and controlled size, and controlled composition like rings, cubes, spheres, quantum dots, etc.

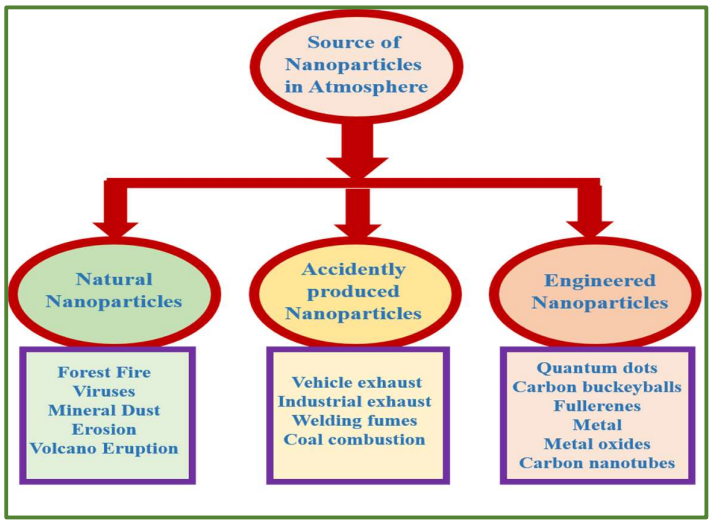


Fig.1.2 Major sources of nanoparticles in the environment.

1.4. Classification of Nanomaterials

The nanomaterials are classified based on the number of dimensions as shown in (Fig.1.3). According to Siegel, nanostructured materials may be classified as:

- Zero-dimensional (0D)
- One-dimensional (1D)
- Two-dimensional (2D)
- Three-dimensional (3D)

Zero-dimensional nanomaterials

All dimensions (x, y, z) of the materials are at the nanoscale, i.e. no dimension of materials are greater than 100 nm. These NPs are point-like particles i.e. as small as a point. The most common examples of these particles are quantum dots (uniform particle arrays), Nano spheres and nanoclusters, hollow spheres fall in this category.

One-dimensional nanomaterials

In one dimension, two dimensions (x, y) are at the nanoscale and the one is outside the nanoscale. This leads to needle-shaped nanomaterials. It includes nanofibres, nanotubes, nanorods, and nanowires.

Two-dimensional nanomaterials

One dimension (x) is at the nanoscale and the other two are outside the nanoscale. The 2D nanomaterials exhibit plate-like shapes. It includes nanofilms, nanolayers, and nanocoatings with nanometre thickness.

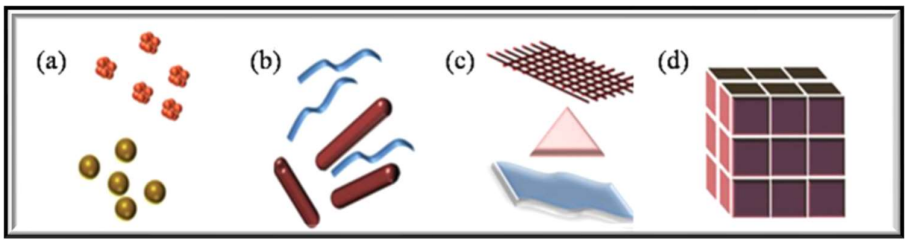


Fig.1.3. Classification of Nanomaterials (a) 0D spheres and clusters; (b) 1D nanofibers, nanowires, and nanorods; (c) 2D nanofilms, nanoplates, and networks; (d) 3D nanomaterials. (sources; Copyright@ https://www.uobabylon.edu.iq/eprints/publication_2_1111_1261.pdf (Ref).[4]

Three-dimensional nanomaterials

Nanomaterials that are not confined to the nanoscale in any dimension and possess three arbitrary dimensions above 100 nm but their components are less than 100 nm in size. The bulk three dimension nanomaterials are composed of multiple organizations of nanosize crystals in different orientations. It includes dispersions of nanoparticles.[5] These materials are usually nonporous. The very common examples of 3D nanomaterials are bundles of nanofibers, nanocomposites, and multi nanolayer-type structures.[3]

Further, nanomaterials are again classified into four types as follows (Fig.1.4).

I. Carbon-based nano-materials
II. Metal-based nano-materials
III. Dendrimers
IV. Composites

Carbon-based nanomaterials

These materials are composed of carbon, and generally have the morphologies like hollow spheres, ellipsoids, or tubes. The spherical and ellipsoidal forms are referred to as fullerenes (Fullerenes C60) while cylindrical forms are known as nanotubes (carbon nanotubes). Other examples of carbon-based materials are carbon black, graphene, carbon nanofibers, etc.

Metal-based or inorganic based Nano-materials

These include metal or metal oxides like quantum dots, gold, silver, copper, and metal oxides like ZnO, ZnS, CuO, TiO_2, etc. A quantum dot is a semiconductor that has a closely packed crystal containing hundreds or thousands of atoms, having a particle size of a few nanometers. Other examples are ceramics and silicon semiconductor nanoparticles fall in this category.

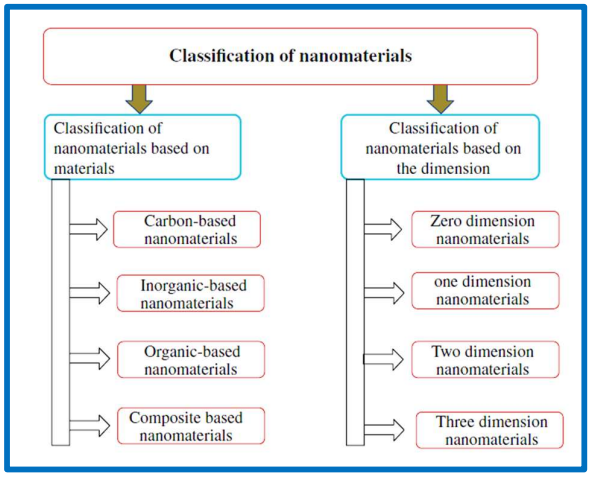


Fig.1.4. The schematic diagram showed the basic classification of nanomaterials. Green Synthesis of Nanomaterials for Bioenergy Applications, First Edition. Edited by Neha Srivastava, Manish Srivastava, P. K. Mishra and Vijai Kumar Gupta. © 2021 John Wiley & Sons Ltd. Published 2021 by John Wiley & Sons Ltd (Ref).[6]

Dendrimers

Dendrimer-based materials are repetitively branched molecules. These nanomaterials are nano-sized polymers made from branched units. Dendrimers are used in nanosensing, molecular recognition, Opto-electrochemical devices, and light-harvesting. They are useful for drug delivery. Dendrimer's surface has numerous chain ends, which can perform specific chemical functions.

Composites

Composites are a multiphase combination of nanoparticles with other nanoparticles or with larger, or complicated structures or bulk-type materials. The composites can be in combination with metal-based, carbon-based, or organic-based.

In the past few decades, there has been an exponential growth of research in the field of nanomaterials. Several reviews, research articles, and books have been published on

different aspects of different types of nanomaterials. These materials may be metals, semiconductors, metal oxides, organic materials, or composites. Amongst the various types of nanomaterials, metal-based semiconductor nanoparticles have been widely investigated. This is quite understandable because Semiconductors have been useful in making devices.[7] Semiconductor NCs are a promising material because they can control their optical and electronic properties which can be exploited for a diverse range of applications, such as catalysis[8], light-emitting diodes[9], bio-labels[10], sensors[11], and solar cells.[12] Semiconductor nanocrystals (NCs) are made from a variety of different compounds.

They are stated to as

Group IV: elemental and compound semiconductors for examples silicon and germanium are in this category.

III-V: III-V semiconductors crystallizing with a high degree of stoichiometry have high carrier mobilities and direct energy gaps, so they are useful in optoelectronics. They may be n-type or p-type. Examples are GaN, GaP, GaAs, InP and InAs etc.

II-VI: they include ZnS, CdS, CdTe, CdSe, usually they are p-type, except ZnO and ZnTe which is n-type. [13]

IV-VI: PbS, PbSe, PbTe, etc.

I-VI: Cu_2S

I-VII: CuCl

II-V: Cd_3P_2, Cd_3As_2, Zn_3P_2, Zn_3As_2 etc.

Oxides: Cu_2O, TiO_2 (rutile), TiO_2 (brookite), SnO_2, UO_2, Bi_2O3, $BaTiO_3$, $SrTiO_3$, $LiNbO_3$, La_2CuO_2, $CuFeO_2$ etc.

1.5. Synthesis of nanoparticles.

Two methods (Fig.1.5) are used for the synthesis of nanomaterials:

(1) Bottom-up Method and (2) Top-down method.

(1) In the first approach, molecular components arrange themselves into complex assemblies atom-by-atom, molecule-by-molecule, and cluster-by-cluster from the bottom (e.g., growth of a crystal).[14]

Some of the methods used in the bottom-up approach include the chemical vapor deposition process (CVD), plasma arcing, metal-organic decomposition, molecular beam epitaxy, laser pyrolysis, sol-gel method, self-assembly processes, and wet synthesis (solvothermal and hydrothermal).[15] Reduction in Gibbs free energy is the main driving force behind the bottom-up approach. Hence, the products produced are close to their equilibrium state. This

approach has been common to chemists for a long period. There are so many advantages of the bottom-up approach like

- It produces nanostructures with fewer defects and a more homogenous chemical composition.
- It plays a crucial role in preparing nanomaterials having a precise small size.
- Narrow size distribution
- It is the cost-effective technique

Disadvantages

- **Large-scale production is difficult.**
- **Chemical purification of nanoparticles is required.**

(2) While the second approach is the top-down approach, nanoscale devices are created by using larger, externally-controlled devices to direct their assembly. The top-down approach often uses the traditional microfabrication methods and workshops in which externally-controlled tools are used to mill, cut, and shape materials into the wanted shape and order. Etching, sputtering, electro-explosion, lithography, Attrition, and milling are typical top-down processes.

Advantages

- Top-down approaches are good for producing structures with long-range order and for making macroscopic connections
- Some techniques in the top-down approach such as lithography, significant crystallographic defects can be introduced.
- Despite the defects, the top-down approach also plays a significant role in the Fabrication and synthesis of nanomaterials.

Disadvantage

- **The top-down process cannot deal with very tiny objects.**
- **Broad size distribution (10-1000 nm).**
- **Impurities like stresses, defects, and imperfections get introduced.**
- **It is an expensive technique.**

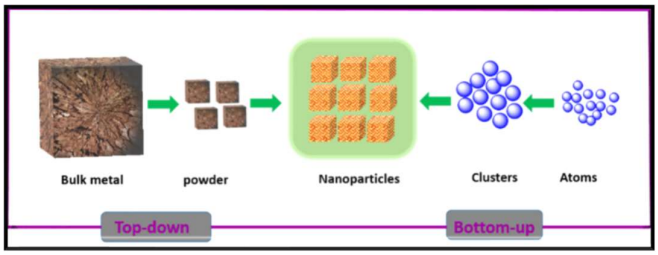


Fig.1.5. Synthesis route to nanoparticles.

1.6. Properties of Nanoparticles

The fundamental properties like optical, biological, electronic, chemical, and mechanical of semiconductor NPs can be different at the nanoscale from the bulk material's mainly for two reasons:

Surface Area (Size matters)

Surface area is the first considerable reason, Off course, it should be counted because most of the chemical reactions involving solids occur at the surfaces, nanomaterials have a comparatively larger surface area when it is compared to the same mass of bulk material. This is the main reason which becomes them more chemically reactive (in some cases materials that are inert in their larger form are reactive when produced in their nanoscale form) and affects their strength or electrical properties (Fig.1.6).

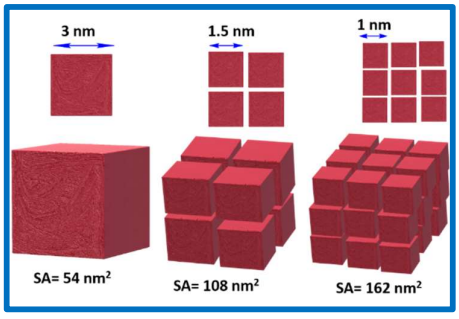


Fig.1.6. Surface area versus particle size.

Quantum Size Effects

As the particle size of the semiconductor material decreases below the Bohr exciton radius (a_o), the electron in the particle becomes more confined. This leads to a rise in the bandgap energy Furthermore, the valence and conduction bands spilitted into quantized or discrete energy levels. This phenomenon is known as quantum confinement. Therefore, the optoelectronic properties of semiconductor NCs become strongly size-dependent, which

makes semiconductor materials possible to tune the photoluminescence properties through a wide spectral window by choosing the composition, shape, and size. Narrower the E_g, larger a_o as a result of this semiconductor NCs experience quantum confinement.[16] (Fig.1.7) shows five colloidal dispersions of CdSe QDs of different sizes, under a UV excitation lamp in the dark. The color of the photoluminescence changes from red to blue as the quantum dot diameter is reduced from 6 to 2 nm.

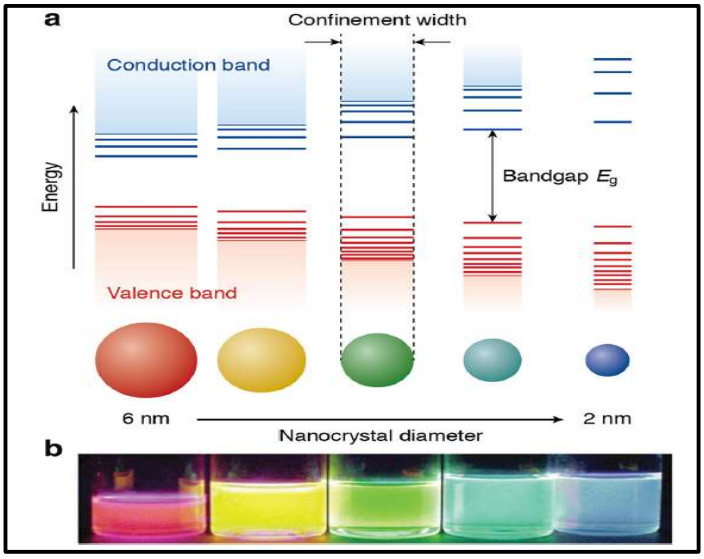


Fig. 1.7. Illustration of Quantum confinement effect in the semiconductor. Source; Celso de Mello Donega, copyright @ Chemical Society Reviews 2011 (Ref [16]).

Morphology (Shape/Morphology Matters)

The surface features like surface energies and electronic structures of synthesized nanomaterials also determined the chemical and physical properties of nanomaterials. Facets with characteristic crystallographic features possess different atomic terminated characters. As the shape of the material is changed the pattern of molecular bonds varies, although they are made up of the same atoms, hence they show different behaviour toward catalysis and sensings.[17–19] It is well understood that particles with smaller sizes have a larger number of surface atoms, however, it is not always true that smaller particles display better performance[20] The efficiency of the catalyst can be tuned by shape control as the numbers of atoms located at edges, surfaces, and corners depend on the shape.[21,22] A polyhedral catalyst with highly reactive surfaces would exhibit higher catalytic activity than the common ones. It is remarkable that, although high index facets that have plentiful unsaturated active sites and high index atomic edges with corners are favorable for catalysis

and sensing applications, [23–26] but by simple chemicals (Fig.1.8) the method they hardly obtained because surfaces with high reactivity usually vanished rapidly during the crystal growth process as a result of the minimization of surface energy.

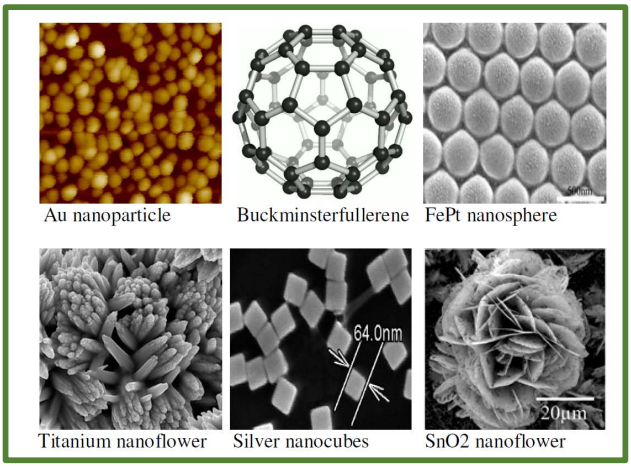


Fig. 1.8. Morphologies of some nanomaterials. Source;
https://www.uobabylon.edu.iq/eprints/publication_2_1111_1261.pdf (Ref [4]).

1.7. Application

The Significance of the Nanoscale – Why Does Nanotechnology Matter

At the nanoscale level, numerous Strange properties such as physical, chemical, and biological can emerge. These properties may differ in significant ways from the properties of single atoms, bulk materials, and molecules (Fig.1.9).

For example, metals having a grain size of around 10 nm are as much as seven times tougher than their normal complements with grain sizes in the hundreds of nm. The causes of these extreme changes stem from the strange world of quantum physics. The bulk properties of the material are just the average of all the quantum forces affecting all the atoms. As we make things smaller and smaller, we eventually reach a point where the averaging no longer works.

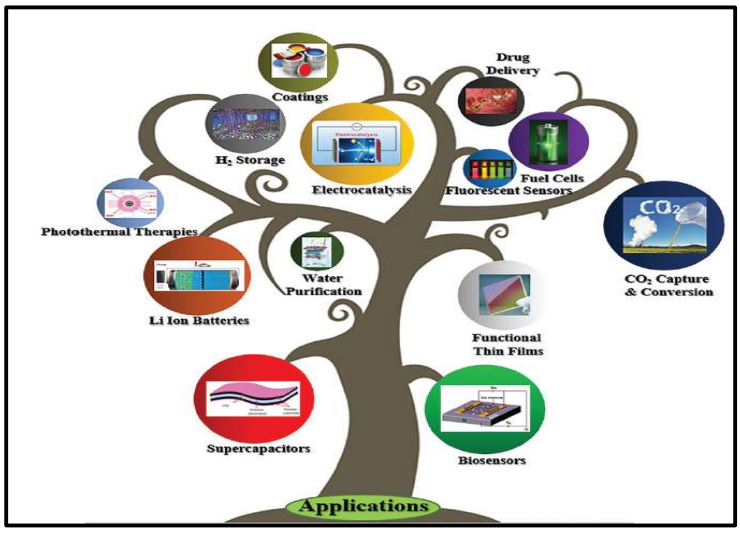


Fig.1.9. A schematic representation of applications of nanomaterials. Source; Irshad et al. copyright @ Materials Advances 2021 (Ref). [27]

Catalysis

The basic principle of photo catalyst

Before we go for diverse catalysis applications of semiconductor materials, let us see the phenomenon that happens on the surface of the semiconductor oxide nanomaterials.

The photocatalytic effect on the surface of semiconductors was first reported by Fujishima and Honda in 1972 for water splitting reactions.[28] When a semiconductor is irradiated with UV light or solar light, one electron (e^-) from the VB is jumped to the Conduction band leaving a hole as presented (Fig.1.10). The concentration of these generated electron-hole pairs in a semiconductor depends on the intensity of the incident light and the electronic properties of the semiconductor. The corresponding minimum (i.e. threshold) wavelength is required for excitation of a semiconductor is governed by the following equation:

$$E(ev) = \frac{1240}{\lambda} nm$$

If there are no suitable electron-hole scavengers, the photo-generated electron-hole pairs may recombine and disperse the input energy as heat within a few nanoseconds. Thus, the electron acceptors are essential for the photocatalytic process to make catalyst efficient, so electrons can be promptly removed by an electron acceptor.

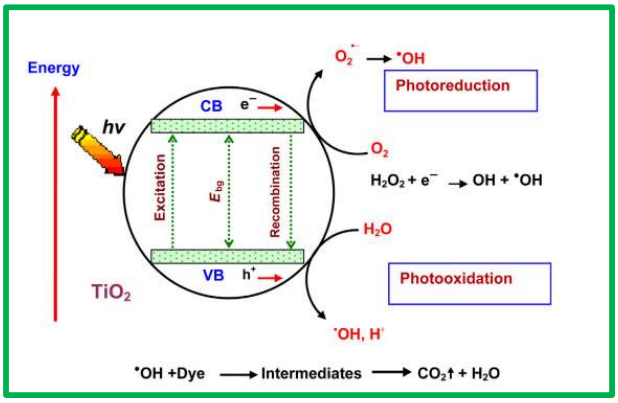


Fig.1.10. Electron hole pair generation in an illuminated semiconductor particle and consecutive reactions for degradation. Source; Swaminathan, Meenakshisundaram copyright @ Handbook of Nanomaterials for Industrial Applications 2018 (Ref).[29]

Oxygen is usually used as an electron acceptor. It may react with a photo-generated electron at the surface of semiconductors via the given equations:

$$O_2(ads) + e^- \rightarrow O_2^{\bullet-}(ads)$$

$$O_2^{\bullet-}(ads) + H^+ \rightarrow HO_2^{\bullet}(ads)$$

$$HO_2^{\bullet} + HO_2^{\bullet} \rightarrow H_2O_2 + O_2$$

$$H_2O_2 + O_2^{\bullet-} \rightarrow {}^{\bullet}OH + OH^- + O_2$$

The holes generated on the surface, having an affinity for electrons, are very powerful oxidizing agents. Holes after migrating to the surface of the semiconductor, oxidize the adsorbed water molecule or hydroxide ion to form hydroxyl radicals.

$$h^+ + H_2O(ads) \rightarrow {}^{\bullet}OH + H^+$$

$$h^+ + {}^-OH(ads) \rightarrow {}^{\bullet}OH$$

This photo-generated hydroxyl radical is a highly reactive species, due to its very high oxidation potential (i.e. 2.8 eV), it can easily oxidize non-selectively any kind of organic contaminants in wastewater into carbon dioxide and their mineral acids. Therefore, the overall photocatalytic process can be concise by the below reaction.

$$\text{Organic pollutants} + O_2 \xrightarrow[\text{UV/solarlight}]{\text{Semiconductor}} CO_2\uparrow + H_2O + \text{mineral acid}$$

The mechanism, mentioned above, is very well established for the mineralization of organic pollutants using semiconductor oxide as a photo-catalyst.[29]

As Electrocatalyst

With a rising global warming, impending climate change, and increasing energy demands major distresses have been raised. Thus the development of innovative catalysts for effective electrochemical energy conversion is a demand now a day. Many technologies to improve the dependence on fossil fuels have attracted significant interest in the last decades.

Electro-catalysts play an energetic role in the above energy conversion processes because they can lower the reaction kinetic barriers and thus can boost the efficiency and selectivity of the chemical transformations involved.[30] Although noble metal-based catalyst of Rh, Pt, and Pd has been used widely as electrocatalysts in fuel cells.[31] Hence the search for cost-effective and earth-abundant catalysts has brought perovskites for electrochemical energy conversion reactions such as reduction of NOx [32] and oxidation of toxic hydrocarbons and CO [33] and use of sustainable fuels.[34] M. Tavakkoli et al has been introduced effective and low-cost pseudo-atomic-scale dispersion i.e. individual atoms or sub-nanometer clusters of Pt on the sidewalls of single-walled carbon nanotubes (SWNTs) by using a simple and readily up-scalable electroplating deposition method (Fig.1.11).

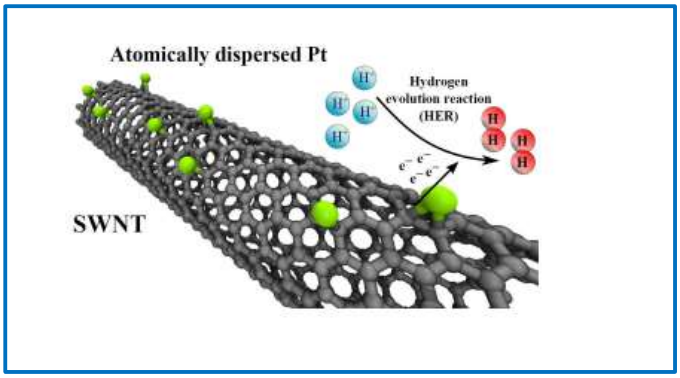


Fig.1.11. DFT (density functional theory) proposes that carbon nanotubes stabilize single platinum atoms and that hydrogen evolution reaction takes place more efficiently on their surfaces, compared to conventional platinum nanoparticles. Source; copy right M. Tavakkoli et al. copyright @ ACS Catalysis 2017 (Ref).[35]

As a photo-catalyst in Water purification

Nanomaterials due to their small sizes and high specific surface areas, nanomaterials have high reactivity and strong adsorption capacities. Based on various studies, nanomaterials show great potential for applications in wastewater treatment.[36] Nanomaterials have fast dissolution, strong sorption, and discontinuous properties such as super-paramagnetism, localized surface Plasmon resonance, and quantum confinement effect which allow them as an efficient catalyst for wastewater treatment processes. TiO_2 has an advantage due to its low price, inertness, high availability, and broad-spectrum effect on the chemical degradation of the micro-organisms and the majority of organic contaminants (Fig.1.12).[37]

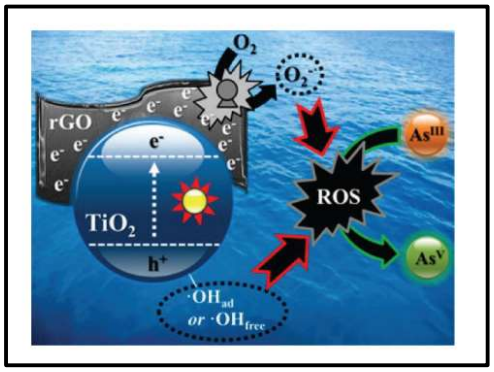


Fig.1.12. Schematic presentation of the mechanism of TiO_2 as photo catalyst. Source; copyright @ Gun-hee Moon et. al. Environmental Science Technology 2014 (Ref).[38]

The use of magnetic nanoparticles such as magnetite Fe_3O_4 for removing water pollutants has already been recognized in groundwater remediation, in specific for the removal of arsenic.[39] In recent years, numerous zero-valent metal nanoparticles, such as Al, Fe, Zn, and Ni, in water contamination treatment have drawn extensive research attention. The standard reduction potentials of Al, Fe, Ni, and Zn are listed in Table 1.1.

Nano-zero-valent Al has a high reductive ability, which makes Al thermodynamically unstable in the presence of water, which allow the formation of oxides/hydroxides on the surface of Al, impeding the transfer of electrons from the metal surface to the pollutants.[40] Al has a less negative standard reduction potential compared to Fe and Ni, indicating a lower reducing ability. Fe and Zn have moderate standard reduction potential, hence both have good potential to act as reducing agents compared to numerous redox-labile contaminants. Fe possesses dominant advantages compared to nano-zero-valent Zn such as precipitation, excellent adsorption properties, and oxidation (in the presence of dissolved oxygen) in water

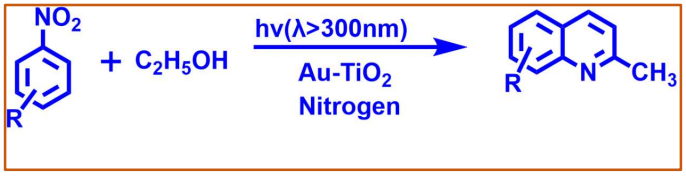
pollution treatment because it has a weaker reduction ability, Therefore, zero-valent Fe nanoparticles have been the most broadly studied.[36]

Table 1.1 The standard reduction potential of metals. (data adapted from Steven G. Bratsch Ref). [41]

Metal	Standard reduction potential (E^0/V)
Fe	−0.440
Zn	−0.762
Al	−1.677
Ni	−0.236

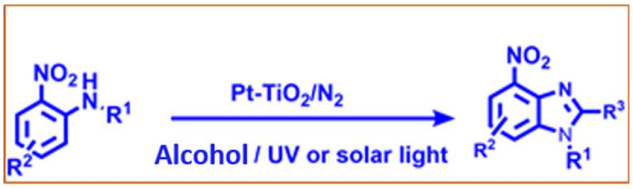
As Photo-catalysts in Organic Synthesis

Selvam and Swaminathan developed a protocol for the synthesis of quinaldines from nitrobenzene and alcohols by using $AuTiO_2$ under UV irradiation in a nitrogen atmosphere Scheme 1.1.



Scheme 1.1 synthesis of quinaldines. Source; copyright K. Selvam et.al. copyright @ Tetrahedron letter 2010 (Ref).[42]

Selvam and Swaminathan also reported a one-pot synthesis of disubstituted benzimidazoles from N-substituted 2-nitro aniline or 1,2-diamines using 312-nm-sized platinum particles loaded on the TiO_2 using solar light and UV-A light by collective redox photocatalytic reaction, condensation and catalytic dehydrogenation on Pt metal Scheme 1.2.



Scheme 1.2 synthesis of benzimidazoles. Source; K. Selvam et.al. copyright @ Tetrahedron Letter 2011 (Ref).[43]

Photothermal therapy:

There is rising interest in battling cancer with nanoparticle-based therapeutics. Nano-particles upon photo-induced heating using near-infrared (NIR) light to destroy cancer cells have been revealed to be a potentially effective technique to target cell death without injuring surrounding healthy tissue.[44,45] For this purpose the nanoparticles should have smaller than about 50 nm or so, should be non-toxic, and have surfaces that can be functionalized with cell recognition moieties. Furthermore, the nanoparticles should answer powerfully to light excitation with wavelengths in the range of 650 to 950 nm. Because Human tissue, blood, and water have high transparency in this range of wavelengths.[46]

A wide range of nanomaterials,[47] polymers,[48] noble metal nanostructures,[49] carbon-based organic dyes, and semiconductor nanomaterials [46,50,51] have been explored as NIR-responsive photothermal agents. Among them, semiconductor photothermal nanomaterials of metal oxides[52] and chalcogenides,[50,53] as a new type of photothermal agent have made remarkable progress in recent years. Because semiconductor photothermal nanomaterials embrace facile synthesis and particularly low cost (Fig.1.13).[54]

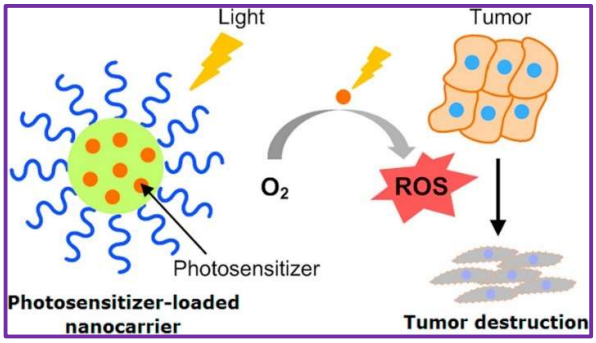


Fig. 1.13. Schematic illustration of photodynamic therapy Source Eun Ji Hong et al. @ copyright Acta Pharmaceutica Sinica B 2016 (Ref).[55]

Supercapacitors

It is of great importance to develop environmentally friendly renewable energy storage systems and energy sources to overcome the fossil fuels correlated problems. Super-capacitors are one of the most important energy storage systems recently used as ultra-capacitors or electrochemical capacitors which can deliver huge amounts of energy in a short time. The foremost benefits of using super-capacitors are their high power density, fast charging-discharging process, long cycle life, and the ability to use in an extensive range of temperatures.[56] Thus, there has been great attention to developing and purifying more

efficient energy storage devices. Super-capacitors, utilize thin electrolytic dielectrics and high surface area electrode materials to attain capacitances numerous orders of magnitude superior to conventional capacitors.

(Fig. 1.14) shows a graph termed a "Ragone plot". This graph represents the power densities of several energy storage devices, measured along the vertical axis, versus their energy densities, measured along the horizontal axis. It is seen from the figure that super-capacitors occupy a state between conventional capacitors and batteries. Despite superior capacitances to conventional capacitors, super-capacitors have yet to match the energy densities o fuel cells and mid to high-end batteries.[57]

Nanomaterials show highly unusual properties and their industrial demand is progressively increasing. The main properties of nanomaterials are:

- High surface-to-volume ratio and surface energy
- High mechanical strength and micro-hardness
- Large specific heat
- Large thermal expansion
- High magnetic susceptibility
- Enhanced self-diffusion
- High sintering rate etc.
- High catalytic activity

hence by incorporating the nanomaterials, the capacitance will be increased.[58]

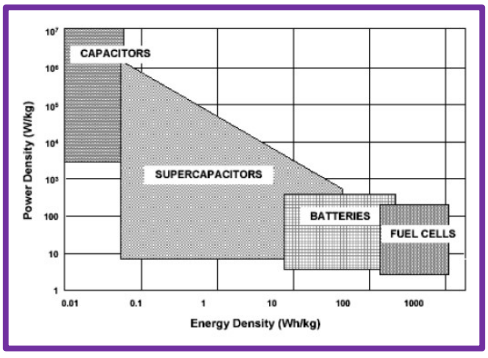


Fig.1.14. The ragone plot of energy storage devices. Source; Mohapatra, S et.al. copyright @ Latin-American Journal of Physics Education 2012 (Ref).[58]

Biosensors

Research on fluorescent semiconductor nanocrystals or quantum dots has progressed over the past few decades from electronic materials science to biological applications. Semiconductor quantum dots have sparked widespread interest in the field of bio-sensing due to their novel and unique properties. The size of semiconductor NCs can be controlled precisely, and by choosing the desired shape and composition of these nanostructures their physicochemical properties and overall behaviour can be controlled. Furthermore, modifications in semiconductor NCs to better suit their incorporation with biological systems led to such exciting properties as enhanced biocompatibility, aqueous solubility, and bio-recognition.[59]

The unique optical properties and high fluorescent properties of semiconductor quantum dots nanocrystals, make them very fascinating fluorophores for equally in vivo and in vitro biological investigations.[60,61] Semiconductor QDs nanocrystals are extremely light-absorbing and luminescent nanoparticles whose absorbance onset and emission maximum alteration to higher energy with decreasing particle size due to quantum size effects. Thus, the wavelength of emission can be regulated by altering their size and by altering the chemical composition, giving rise to an extensive spectrum of emission colors. When semiconductor QDs Compared with molecular dyes, two properties in specific stand out: (1) the ability to size-tune fluorescent emission as a function of nanocrystal size and (2) the broad excitation spectra. Quantum dots can be synthesized from various types of semiconductor materials (II-VI: CdS, CdSe, CdTe III-V: InP, InAs, IV-VI: PbSe, etc.).

1.8. References

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