Chapter-1

Introduction

1.1 Nanotechnology

Recently, nanotechnology has attracted great interest in the chemistry due to their contribution in the improvement and revolutionizing of different fields. The list of benefits and uses of nanotechnology are increasing very fast from last two decades. Nobel Prize laureate Richard Feynman, who is often considered the father of modern nanotechnology, introduced the specific concept of nanotechnology in 1959. The term of nanotechnology was used and defined by Norio Taniguchi in 1974 who stated, ‘‘nano-technology mainly consists of the processing of separation, consolidation, and deformation of materials by one atom or one molecule.’’ [1-2].

Significance of nanotechnology can also understand from that the Noble prize (2023) in Chemistry are awarded to **Moungi Bawendi, Louis Brus and Aleksey Yekimov** for the discovery and development of nanotechnology's smallest components – quantum dots and their application in various branches Figure 1.1.

Fig. 1.1. Scientists awarded Noble prize in Chemistry (2023).

Before the 1980s, nanotechnology remained only an area for discussion, but the concept of nanotechnology was seeded in the minds of researchers with the potential for future development. This technology can be change of matter on a near-atomic scale and also manipulation of the unique properties of materials at the nanoscale to produce new structures, materials and devices. Nanotechnology has gained popularity in several industries as it offers better built and smarter products, and has also significantly improved drug delivery system due to pharmacokinetic changes in the drug, increasing the duration of the drug in the bloodstream, reducing toxicity, and increasing the half-life of the drug. Definitions and descriptions of terms associated with this nanotechnology are provided below Table 1.

Table 1. A description of various terms

Term	Description
❖ **Nanotechnology**	Nanotechnology refers to technology at the nanoscale level in which materials, devices, or systems are developed via controlling matter at the nanoscale length to stimulate the unique properties of the material at the nano-level.
❖ **Nanomaterial**	A material is called a nanomaterial if it has at least one dimension in the nanoscale range of 1–100 nm.
❖ **Nanoparticle**	An object or particle is called a nanoparticle when all of its dimensions are in the nanoscale range .
❖ **Nanoscale**	A scale covering 1–100 nm.

1.2 Nanomaterial

Nanomaterials are usually classified according to structure, composition, area of application or state of aggregation. Each types of nanomaterial have importance in their particular field. In the last century, materials science has great interested in several areas of research due to their various applications but with the introduction of nanotechnology, has raised more interest for scientific community due to their profound properties even a negligible functionalization of a nanomaterial brings about huge changes in its physical and chemical properties.

Nanomaterial's is wide class of material which deals with particles in the range of 1–100 nm and their physical and chemical properties depends on their size and shape [3-4]. Properties of nanomaterial depends on molecular interactions

- **Easy adsorption**
- **Absorption and**
- **Penetration**

1.3 Nanoparticles

Nanoparticles, in particular gold nanoparticles, have been used for eras by women of China and Egypt for both curative and aesthetic purposes. Some artists also used for the making and decoration of glasses and ceramics such as the illustrious Lycurgus cup (fifth century AD). These nanoparticles appeared since the beginning in the 17^{th} century and the 1^{st} scientific report on the effect of light appeared in the middle of the 19^{th} century with Faraday's famous publication, [5] followed only half a century later by Mie's seminal rationalization of the plasmon [6-7].

A nanoparticle or ultrafine particle is usually defined as a particle of matter that is between 1 and 100 nanometers (nm) in diameter [8-9]. The term is sometimes used for larger particles, up to 500 nm, or fibbers and tubes that are less than 100 nm in only two directions [10]. In figure 1.2, some important synthesized nanoparticles with different morphology and properties.

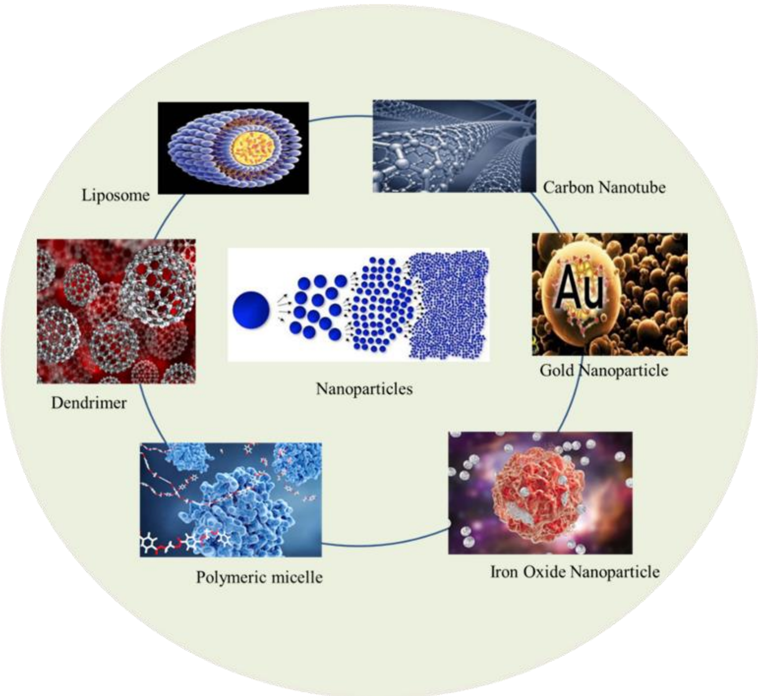


Fig. 1.2. Synthesized nanoparticles with different morphology.

1.4 Nano-catalysis as a tool for green chemistry

As nano catalysis, the first papers were published in 1941 on poly(vinyl) alcohol-protected palladium and platinum nanoparticle [11] and this research was reminding of the work by Paul Sabatier (Chemistry Nobel Prize in 1912), who discovered catalyzed hydrogenation using finely divided nickel particles [12].

Nano-catalysis is an important and necessary tools for sustainable and green chemistry due to use of

- ✓ **Green reagents**
- ✓ **Avoid the use of harmful and toxic chemicals,**
- ✓ **Solvent free reactions conditions which reduce the effluent treatment capacity**
- ✓ **Moderate reaction conditions, provide simple and eco-friendly methods**
- ✓ **Less reaction time**
- ✓ **Reusability of the catalysts.**

These above features of the nanocatalyst provide their various applications in organic transformations (Figure 1.3) [13–18].

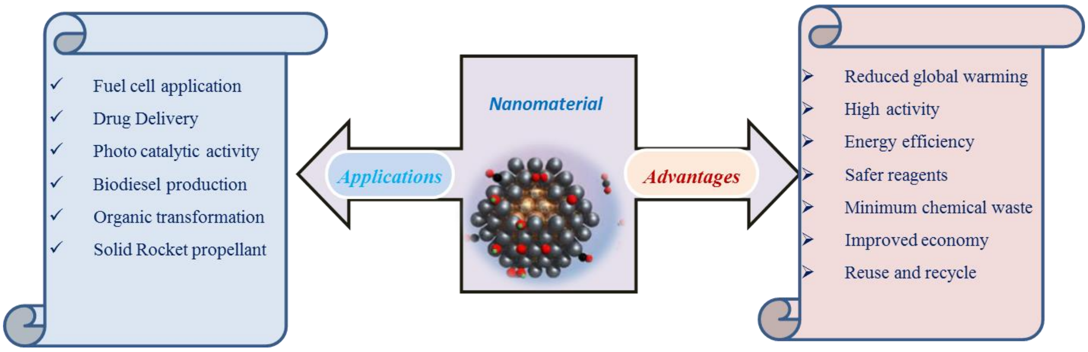


Fig. 1.3. Applications and advantages of nanocatalyst in various fields.

1.5 Magnetic Nanoparticle

In recent decade, particularly magnetic nanoparticles (MNPs, Fe_3O_4, Fe_2O_3) a nanoscale material, with unique magnetic properties have gained huge interest due to their applications in biomedical, heterogeneous and homogenous catalysis, cancer theranostics, magnetic fluids, data storage, magnetic resonance imaging (MRI), and environmental remediation such as water decontamination etc (Figure 1.4). These magnetic nanoparticles can be produced by using magnetic fields with controlled surface engineering for the design of multi-functional MNPs which is energetic for achieving desired application [19-20].

The upper layer chemistry of the superparamagnetic magnetite (Fe_3O_4) can be controlled by changing its physicochemical properties and applied in different fields such as Hyperthermia, magnetic resonance imaging (MRI), immunoassays, drug and cell separation [21].

Recently, iron oxide MNPs are receiving tremendous attention due to-

- ✓ **High biocompatibility**
- ✓ **Low toxicity**
- ✓ **Smaller sizes**
- ✓ **High surface area,**
- ✓ **Metal-rich moieties**
- ✓ **Tunable structures**

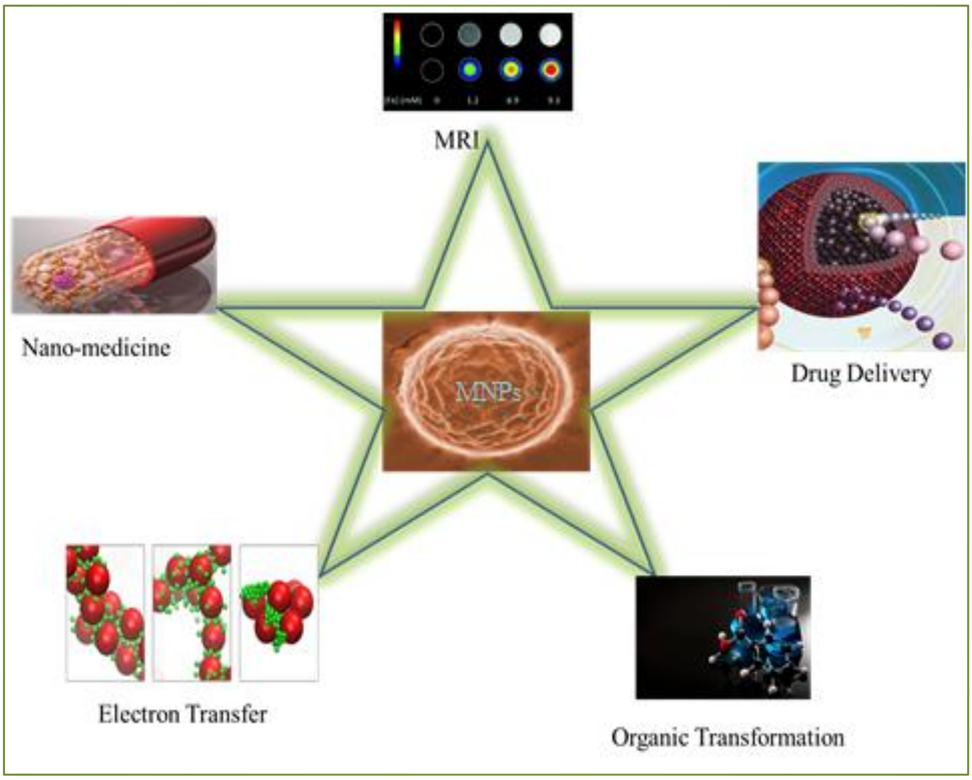
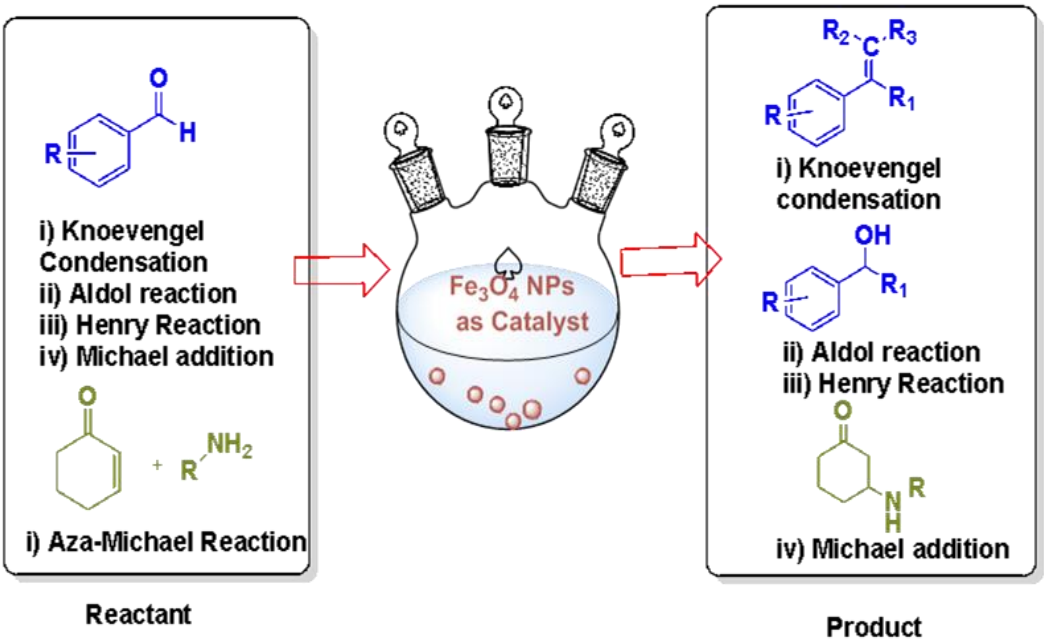


Fig. 1.4. Applications and advantages of magnetic nanoparticles in various fields.

1.5.1 Magnetic Nanoparticle (Iron Oxide Fe_3O_4) as a catalyst

From the last decades, preparation of magnetic nanoparticle (MNPs) and their role in organic transformation as catalysis has carried out by many researchers around the world because of it falls in the twelve principles of green chemistry.



Scheme 1.1. Magnetic Nanoparticles (Iron oxide) as a catalyst in various organic transformations.

Magnetic Nanoparticles are having two part of catalyst in which one is homogeneous another one is heterogeneous catalyst. Furthermore, these magnetic nanoparticles have been layered by organic or inorganic moieties and various transition metals such as Cu, Zn, Co, Cu, Pd, Pt etc. to explore their role in various important organic transformations (Scheme 1.1) [22-24].

1.5.2 Synthesis Methods of Magnetic Nanoparticle (MNPs)

Preparation of MNPs remains challenging as the properties of these nanoparticles are highly depended on the experimental procedure accepted. With this view, it is required to develop different synthetic methods to obtain MNPs of desired size, morphology, stability, and biocompatibility. The synthetic approached of MNPs are categorized into three different methods such as physical methods, chemical methods, and biological methods which are given in below Figure 1.5.

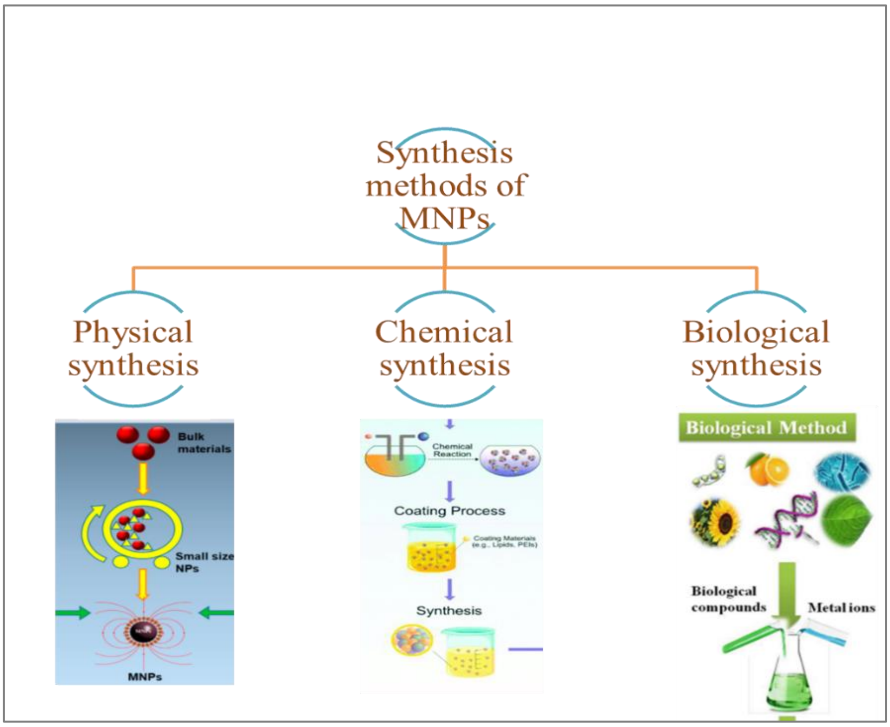


Fig. 1.5. General methods for the preparation of magnetic nanoparticles (MNPs).

1.5.2.1 Physical Synthesis of Magnetic Nanoparticle (MNPs)

The physical methods of magnetic nanoparticle consist of "top-down" and "bottom-up" approaches are mentioned in below table

Method	Description
Ball Milling Method/Mechanical Method	This process is a top-down approach of producing MNPs from the bulk material. **Disadvantage:** Having contamination of the many products [25-26].
Laser Evaporation	This process related to bottom-up approach in which nanoparticles are formed through condensation from liquid or gaseous phase and this method is also suitable for preparation of iron oxide MNPs [27-28]. **Disadvantage:** In this technique high energy laser is applied for production of MNPs.

3. Wire Explosion Method	This process is having a new physiochemical technique which is a one-step highly productive process due to easy separation of NPs from solution [29-30]. **<u>Disadvantage</u>:** The NPs produced through this method are not monodispersed.

1.5.2.2 Biological Synthesis of Magnetic Nanoparticle (MNPs)

In this method, MNPs synthesized by using living organisms such as plant, fungi, viruses, bacteria etc. The synthesized MNPs from this method are used in the biomedical field. This method is more efficiency, eco-friendly, and clean process compare to others. The main disadvantage is its poor dispersion of the NPs [31-32].

1.5.2.3 Chemical Synthesis of Magnetic Nanoparticle (MNPs)

This method contains of different bottom-up approaches compared to others methods. Chemical methods are preferred by researcher because of shape and size of NPs in nanometer range can be controlled and achieved by adjusting different conditions of reaction Figure 1.6 [33].

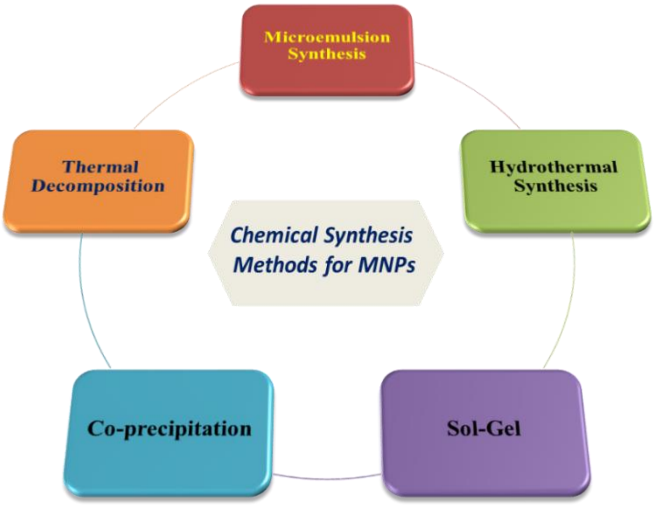


Fig. 1.6. Chemical methods for the preparation of magnetic nanoparticles (MNPs).

1.5.2.3.1 Thermal decomposition method

In this process, organometallic precursors such as Fe_3O_4 is used under the presence of organic surfactants to produce MNPs. Currently, this method has been reported as one of the best methods to prepared MNPs due to following major **advantage** such as

- ✓ **High crystallinity,**
- ✓ **Desirable size and well-defined shape.**
- ✓ **Controlled temperature and reaction time.**
- ✓ **Easy selection of surfactants and solvents.**
- ✓ **large scale production in uniform size and homogeneous shape.**

Major Disadvantage of this method is production of **toxic organic-soluble solvents** in high quantity which limits its application in the biomedical field and medicine chemistry [34-35].

1.5.2.3.2 Microemulsion synthesis method

This is turbid systems of lipophilic and hydrophilic phases which is divided into three parts based on liquid system such as [36].

1) Oil in water (O/W), (water as dominant phase)
2) Water in oil (W/O) (oil as a dominant phase)
3) Both oil and water.

The risk factor related with this method is production of MNPs in **low quantity**.

1.5.2.3.3 Hydrothermal (solvothermal) synthesis method

This method is carried out at high pressure and temperature using aqueous solution in which hydrolysis and oxidation reaction takes place to produce MNPs. The properties like morphology and crystallinity of synthesized MNPs depend on the reaction parameters such as solvent, time, amount of pressure, and temperature. Mainly advantages of this method to obtained **desirable shape, size, with high crystallinity** and **consistent composition** [37-38]. This process is required **high temperature and pressure** which is major demerits for this method.

1.5.2.3.4 Sol-Gel synthesis method

In this process gel prepared at room temperature through hydrolysis and polycondensation reactions of metal alkoxides whereas sol is formed in water by using metallic salt. This method is suitable in the formation of iron oxide MNPs and silica-coated MNPs Figure 1.7 [39-41].

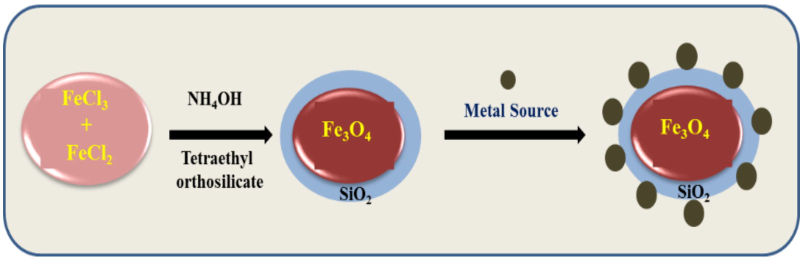


Fig. 1.7. General synthesis process for $Fe_3O_4@SiO_2$ and $Fe_3O_4@SiO_2@M$.

Some **advantage** of this method are given below

- **Produced in large quantities with control size and well-defined shape**
- **Cheaper technology**
- **Controlling the composition**
- **Material highly pure with good crystallinity and tunability**

In some cases, impurities comes in results due to by-product reaction which is create problem to obtain pure product and require further more process to obtain pure MNPs. Other **disadvantages** of this process are to require prolong reaction time and involve toxic organic solvents.

1.5.2.3.5 Coprecipitation method

This method is commonly used by researcher for producing MNPs of controlled size with good magnetic properties [42]. MNPs produced in this method by using various metal ions in a solvent. Some benefit of this method such as

- **Using less harmful materials and procedures which offers widely practiced in biomedical**
- **Controlled size with good magnetic properties.**
- **Very convenient and facile**
- **Obtain uniformly dispersed small size NPs**

In this process, various factors like pH, metal ions, concentrations, the nature of salt, reaction temperature can affect properties of MNPs [43-46]. For example, Fe^{2+} and Fe^{3+} ions are coprecipitated to get Fe_3O_4 (Figure 1.8). Moreover, this process is preferred over other methods but, the major drawback of coprecipitation method is to get MNPs with desired shape.

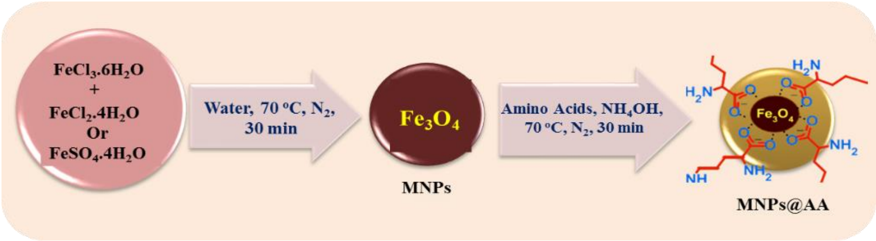


Fig. 1.8. General synthesis process for amino acid capped Fe_3O_4 nanoparticles

This has motivated researchers in the field to develop and design of a new ways to obtain magnetic nanoparticles with desired properties which so-called **greener process**, having more advantages from the existing systems.

This greener approaches are the most widely accepted which is environment friendly, easy and safe due to

- **Relatively safe reagents**
- **Low temperature**
- **Solvent free condition**
- **Shorter reaction time**

These new syntheses have some benefits such as

- **Cost effectiveness**
- **More activity, selectivity and efficiency in term of catalysis**
- **Reusability and recyclability**

In this direction, some approaches are reported regarding to synthesis of amino acid capped Fe_3O_4 nanoparticles by using green process and their applications in various fields such as heterogeneous catalyst for organic transformation, biomedical, and drug delivery etc (Figure 1.9).

Naturally available amino acids are good choice to work as a capping agent due to contain functional groups such as **acids (-COOH) and amines (-NH2)** which are helped to simply bonding with magnetic iron oxide nanoparticles that can change the morphology of nanoparticles. From large scale point of view, amino acids are first choice for synthesis of magnetic iron oxide nanoparticles due to their **easy availability** and **low cost**.

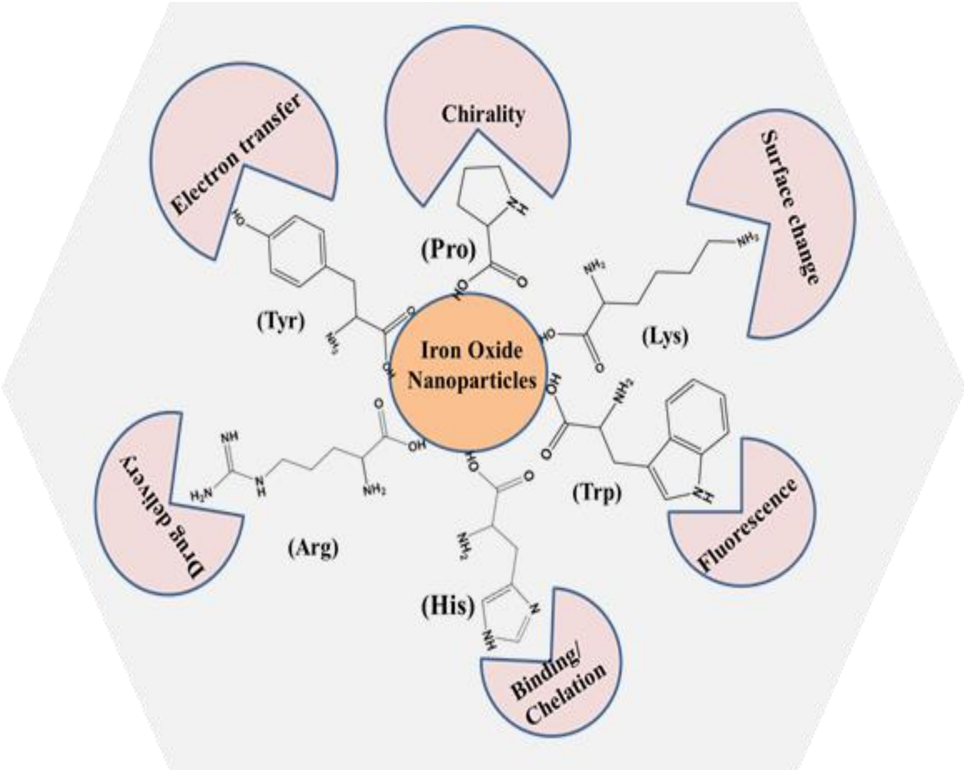


Fig. 1.9. Applications of amino acids capped MNPs in various fields

In this thesis, we have summarized our research work in four chapters. In chapter 2 & 3, we have studied Fe_3O_4 NPs with transition metal dopant ions have capped with amino acid molecules to tune magnetism. Furthermore, to adjust the solubility and toxicity parameters, as-synthesized NPs were encapsulated with Pluronic F127 block copolymeric micelle (M^{2+}/Fe_3O_4@AA/P), to load the hydrophobic anti-cancer (and in one case anti-malarial) drugs and used as targeted delivery platforms for various cell-lines. In chapter 4, we have reported the synthesis of iron oxide nanoparticles using three amino acids (AA-L-Tyrosine, L-Proline and L-Histidine) as a capping agent. Pluronic- F127, a surfactant triblock co-polymer, was used to encapsulate the AA/Fe_3O_4 NPs.

In chapter 5, we have adopted the green chemistry approach and carried out Knoevenagel reaction without any solvent. Fe_3O_4 NPs with different amino acids as capping ligands have used as catalyst for organic transformation.

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