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Toxicological and Life-Cycle Perspectives on Waste-Derived Nanoparticles

Irshad Ahmad[1,2], Md Fahimul Hassan[2], Weqar Ahmad Siddiqui[1]

[1]Department of Applied Science & Humanities, Faculty of Engineering & Technology, Jamia Millia Islamia University, New Delhi, India
[2]Department of Chemistry, C.M. Science College, Lalit Narayan Mithila University, Darbhanga, India
Email: irshadahmad85@gmail.com, irshadalig2005@yahoo.co.in

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Abstract

Many nanoparticles have been created over the last few decades using a variety of techniques and used to develop environmental technology, including water treatment, the detection of persistent contaminants, and soil and water remediation. The studies of alternative inputs for nanoparticle production as well as the use of green synthesis techniques are driven by the field of materials science and engineering's growing interest in increasing the sustainability of the processes involved in their production. In this paper, we begin by providing an overview of the fundamental principles of producing nanoparticles from different sources, such as plastic, electronic, metal, and industrial waste. We elaborate on key facts of waste identification as a workable input for the treatment and recovery of metal and carbon-based nanoparticles. We next go over several controlling factors that play a role in creating nanoparticles, pointing out probable conclusions as we go. Then, we show some instances of waste-derived nanoparticles used in a proof-of-concept experiment of technology for applications in water quality and safety. Before scaling up production and implementing waste-derived nanoparticles, there are several present problems from the toxicological and life-cycle perspectives that must be taken into account.

Keywords

Industrial Waste, Plastic Trash, Metal Waste, Carbon Nanoparticles, Nanoparticle-Enabled Technologies, Electronic-Waste

1. Introduction

The prefix "Nano" in the word "nanoparticle" (NP) refers to a "dwarf" particle that is much smaller than other particles, with a diameter of less than 100 nanometres (10^{-9} m), ranging from 1 to 100 nm [1]. The most notable heavy metals, including nickel, cadmium, manganese, zinc, titanium, gold, antimony, silicon, and their metal oxides, as well as carbon and others that can be intentionally or unintentionally released into the environment, can be categorized as nanomaterials [2]. Designed by humans, NPs have found a number of uses, mostly in the biological sectors, to advance clinical diagnosis and therapy. Several factors can result in the production of incidental NPs [3]. They come from industrial activity and are present there as well as in the surroundings. They are mostly produced by coal, natural gas, and oil-fired power plants [4]. Nano-scale particles may be produced by the burning of fossil fuels, solid waste, or air pollution from vehicles [5]. In these circumstances, NPs may consist of an intricate blend of various chemical compositions. In military shooting ranges, a complex NPs mixture could also form as a result of bomb explosions that generate extremely high temperatures. As a result, all nearby materials—from the rocks to the soil—may be crushed and easily transported as a fine suspension in both air and water [6]. Due to their tiny size and ability to be distributed across the entire environment, insoluble and non-biodegradable particles found in inorganic and metallic powders are frequently created [7].

The main anthropogenic sources of NPs, their release into the environment and at work, and the following occupational or public exposure via a variety of routes of entrance and translocation into the human body are reported in **Figure 1** [8]. The attention on the peculiarities of NPs is due to their nano-scale size, which results in a very high surface area offered to all kinds of reactions. Despite the enthusiastic and promising applications of particular modified NPs in a number of disciplines, a number of negative impacts emerged that have raised concerns [9].

In actuality, both artificially created and accidentally released NPs may have a number of similar harmful impacts on human health [10]. No matter how they are used or where they come from, NPs can infiltrate the human body and build up as foreign substances in the organs and tissues. To research the potentially harmful impacts of nanomaterials on human health and the environment, a new scientific field so called nano toxicology was recently established [11].

This paper aims to assess the special characteristics of nano-scale particles that need to be taken into account to shed light on their hazardous effects [12]. In order to describe their potential hazard and give a fair update on all the key issues associated to their extensive employment, the toxicology of nanoparticles will be summarised here as both technical tools and environmental contaminants [13]. Numerous nanoparticles have been extensively utilised in science and industry due to their huge potential in environmental applications [14]. These applications include, among others, soil and water cleanup, persistent pollutant identification and water treatment [15]. Due to their high surface area to volume ratio, biodegradability, biocompatibility, non-toxicity, simple manufacturing, and ease of isolation from solutions using a magnetic field, these nanoparticles stand out from other materials [16]. Nanoparticle's distinctive properties include their high surface area to volume ratio, biodegradability, biocompatibility, non-toxicity, ease of synthesis, and renewable nature. They are also easily isolated from solutions by the application of an external magnetic field [17]. Therefore, these materials have drawn a lot of attention in industrial applications, both as adsorbents and magnetic carriers (particularly magnetite and its composites) [18].

They have been extensively researched (especially magnetite and its composites) in industrial applications as a combination of adsorption and magnetic carrier technology (MCT), due to their main advantages for the purification of water, which is entirely dependent on the fact that they do not retain magnetism, after the removal of external magnetic field [19]. Many technologies, including ozonation, nano-filtration, reverse osmosis, oxidation, and adsorption, are used to remove toxins (heavy metals) from water, and there are several promising choices available [20]. Only the adsorption method, which is capable of removing toxins (heavy metals) from wastewater due to its aspects of being less expensive, more efficient, and feasible, as well as especially easily-facile operational method, is the most adaptable and widely used method to remove contaminants from aqueous solutions [21].

Nowadays, a variety of adsorbents have been created in order to maximise energy storage, including activated carbon, clay minerals, chelating compounds, chitosan, and natural zeolites. Traditional sorbents could be used to purify water, but their low sorption capacity and efficiency prevent them from being used commercially. Since they can be easily controlled by magnets with external fields, quick kinetics, and small particles, magnetic nanoparticles have gained popularity for application in energy storage processes [22].

Due to their auto-oxidation potential, propensity to aggregate and staining characteristics, the bare magnetite nanoparticles used in water filtering applications are not well suited for practical use. It is feasible to coat silica to increase stability, alter the surface to increase functionality, and use a variety of tiny chemical ligands as well as big macromolecules to adsorb highly specific poisons. Additionally, given their numerous benefits, thermosensitive polymeric adsorbents are particularly appealing [23].

Nanoparticles present a viable answer to these issues as a novel and potential replacement for hazardous substances in water. Comprehensive research has been done over the past few decades on magnetite (Fe_3O_4) nanoparticles with distinctive physicochemical characteristics [24]. With the development of modern nanoscience and nanotechnology, there are tremendous opportunities for the repair of ecological problems. Nano-structured sorbents are unique in that they have qualities that rely on size and shape separate toxic pollutants from energy storage to a higher degree than predictable sorbents [25]. Dissolved contaminants are typically repulsive; therefore, an external magnetic field cannot attract them. Molecularly Imprinted (MI) [26] characteristics in nanoparticles have the potential to be used to purify water due to their bulky surface areas, magnetic properties, and ability to be customized with ligands with affinity for certain toxic pollutants. Recent studies

[27] have focused on utilising MI (molecularly imprinted) magnetite nanoparticles (Fe_3O_4-NPs) and composites to recover dirty elements from water storage purification. The preparation of MI magnetite nanoparticles and its composites has involved both physical and chemical techniques. It has been said that nanotechnology holds great promise for biomedicine, drug design, molecular imaging, biosensing, opto-electronics, the hydrophobic/hydrophilic properties of their reactive surface groups, and their resistance to biological attack, among other fields [28]. The co-precipitation technique is used by researchers to create colloidal magnetite nanoparticles [29]. It is less expensive and simpler to put into practise. This approach is the most often used because it makes it simple to control various synthesis-related variables like temperature, pH, sonication, and contact time. To avoid agglomeration, polyethylene glycol and oleic acid can be used in addition to surfactants, which are added to minimise particle size [30]. High purity, stoichiometric, sphere-shaped metal oxides are created using the chemical co-precipitation technique [31]. It was discovered that nanoparticles with the required size, shape, and magnetic characteristics could be produced when reaction parameters such as temperature, the pH of the solution, the mixing rate, the concentration of the solute, and the concentration of the surfactants were carefully regulated [32].

Silica (SiO_2) was coated onto magnetite and utilized to remove hazardous pollutants from the environment by using TEOS (Tetra Ethyl Ortho Silicate) to be hydrolysed in a sol-gel and the EDTA (Ethelene Di-amine Tetra Acetic-acid) to be functionalized [33]. The removal of hazardous contaminants from the environment and industrial effluent was shown to be most effective using nanocomposite silica-coated magnetite [34]. The sol-gel approach is the most typical technique for coating magnetite nanoparticles with silica [35]. Kolbe discovered how to create silica core-shell nanoparticles by reacting TEOS with an alkali solution in water while employing certain bases [36]. The synthesis process can produce colloidal particles with a variety of compositions, from spherical particles to agglomerates forming complex structures, although a narrow particle size distribution and excellent purity are required for the production of silica nanoparticles [37]. This study sought to determine how different solvents affected the creation of monodispersed silica (SiO_2) coatings on the surface of magnetite (Fe_3O_4) nanoparticles [38].

1.1. Effects of Coating on Magnetite by the Silica (Fe_3O_4@SiO_2) Nanoparticles

The development of silica shells on iron oxide nanoparticle surfaces was mediated by a process catalysing the hydrolysis of TEOS and subsequent condensation of silica (SiO_2) onto iron oxide nanoparticle (Fe_3O_4-NPs) surfaces [39]. This is made feasible by the fact that silica shells on top of magnetite nanoparticles generate negative charges on their surfaces, which enables them to create extremely stable dispersions in water without the need for additional surfactants [40].

Iron oxide nanoparticles and TEOS were combined in a way that was optimised to prevent homogenous spheres [41]. The growth time, the concentration of the ammonia catalyst, the concentration of water, and other factors can all be altered to control the thickness of the silica shells; however, the simplest and most repeatable method to do so is to change the ratio of the concentration of the TEOS precursor to the concentration of the magnetite nanoparticles [42]. **Figure 1** explains the method of synthesizing silica-coated magnetite ($Fe_3O_4@SiO_2$) nanocomposites [43].

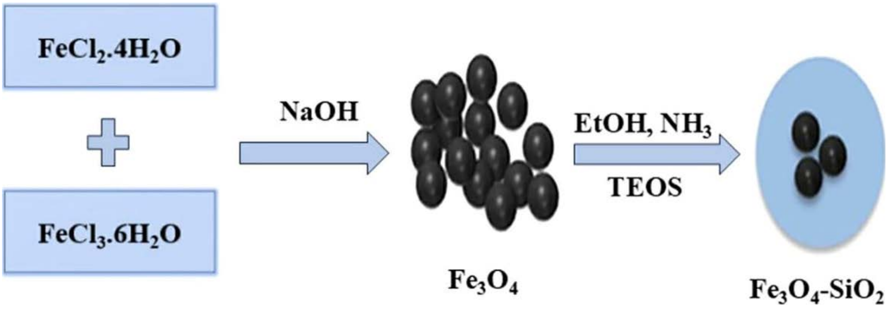

Figure 1. Synthetic route for the silica-coated magnetite ($Fe_3O_4@SiO_2$) nanoparticles [43].

1.2. Molecularly Imprinted (MI) Nanoparticles ($Fe_3O_4@SiO_2$/Thermosensitive/EDTA)

Molecularly imprinted (MI) magnetite samples ($Fe_3O_4@SiO_2$/thermosensitive) were heated for 8 hours at 60˚C~65˚C in the presence of 40 ml of ethanol ($C_2H_5.OH$), under N_2 atmosphere, and then were made into thermosensitive agents by adding 1 g of n-vinyl caprolactam ($C_8H_{13}NO$) to the procedure [44]. Then, 6.25 ml of an aqueous solution of ethylene di-amine tetra acetic acid (EDTA) at 3.3% was added to this suspension. A 15 m-mole solution of acetic

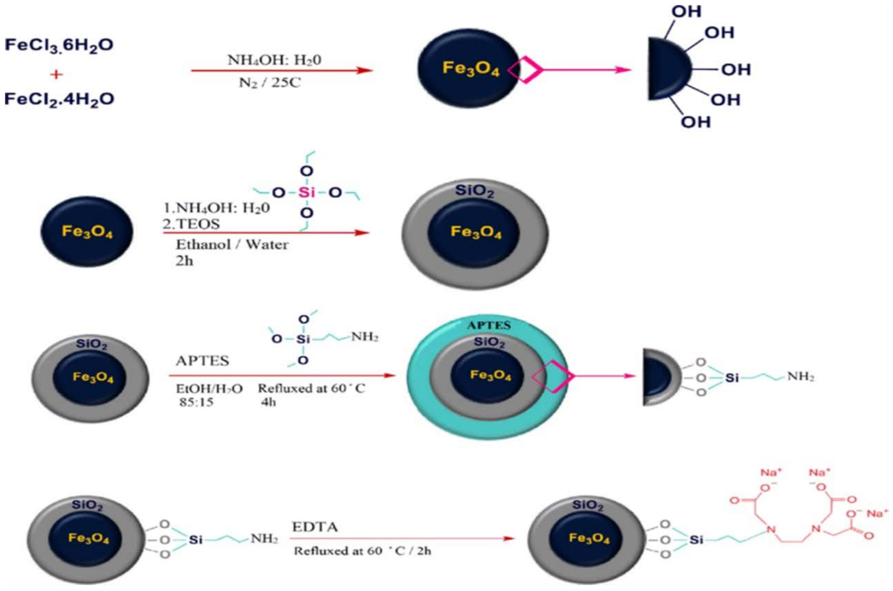

Figure 2. A schematic mechanism of the reaction of EDTA-functionalized silica-coated magnetite nanoparticles ($Fe_3O_4@SiO_2$/Thermosensitive/EDTA) [46].

acid is required to maintain the reaction medium's pH between 4.5 and 5. The molecularly imprinted (MI) magnetite (Fe_3O_4) nanoparticles were then vacuum dried at room temperature after being washed multiple times with ethanol [45]. Azo-bis-isobutyro nitrile was applied as an activator of radicals. As a result, the ideal ratio of silica coated magnetite to EDTA (2:1) is achieved for homogenous homogeneous functionalization of EDTA as shown in **Figure 2** [46].

2. Distinctive Synthetic Approach of Molecularly Imprinted (MI) Magnetite Nanoparticles

A clearly described viewpoint mechanism for molecularly imprinting has been devised by Wulff and colleagues in their paper, "The Synthesis route for Silica coated magnetite ($Fe_3O_4@SiO_2$) nanomaterials" [47]. They were dry at room temperature after being washed twice with TNT (Tri Nitro Toluene) and $C_2H_8O_2$ (Ethanol-water) on the modified Silica coated magnetite ($Fe_3O_4@SiO_2$) is shown in **Figure 3** [48]. Due to its unique characteristics, including magnetic behaviour, biocompatibility, chemical inertness, and low toxicity, Molecularly Imprinted (MI) Silica Coated Magnetite ($Fe_3O_4@SiO_2$) Nanoparticles provide a significant potential in terms of water quality metrics. In this paper, we will look at how molecularly imprinted nanoparticles can remove pollutants from the environment under various experimental conditions [49].

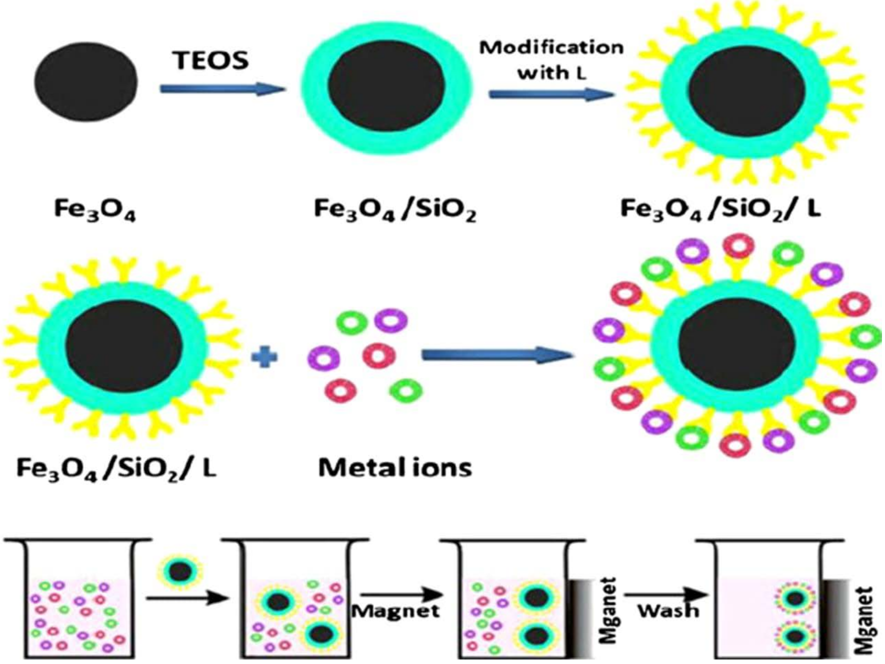

Figure 3. A Schematics representation of the Molecularly Imprinted (MI) Silica-coated magnetite nanoparticles ($Fe_3O_4@SiO_2$) [48].

As a practical input for the treatment and recovery of metal and carbon-based nanoparticles, we also go into detail on crucial waste identification facts [50]. In a proof-of-concept test of a new technology for applications in water quality and safety, waste-derived MI nanoparticles were created using a range of chemical synthesis techniques [51].

Structure of Magnetite (Fe_3O_4) Nanoparticles

The ferromagnetic, super para-magnetic, half-metallic and ferro-fluid features of the y-Fe_2O_3 and Fe_3O_4 (iron oxide) nanoparticles give them incredible promise. With oxygen ions forming FCCs (Face-centered cubic closed packings), the iron oxide magnetite is a member of the class of super paramagnetic iron oxides. Tetrahedral and octahedral interstitial spaces are occupied by the Fe^+ cations. In **Figure 4**, the electrons in the octahedral sites can jump between the Fe^{2+} and Fe^{3+} ions when their charge is high. The classification of ferrite as a sort of half-metallic substance and of dispersion particles as a ferro-fluid would follow [52].

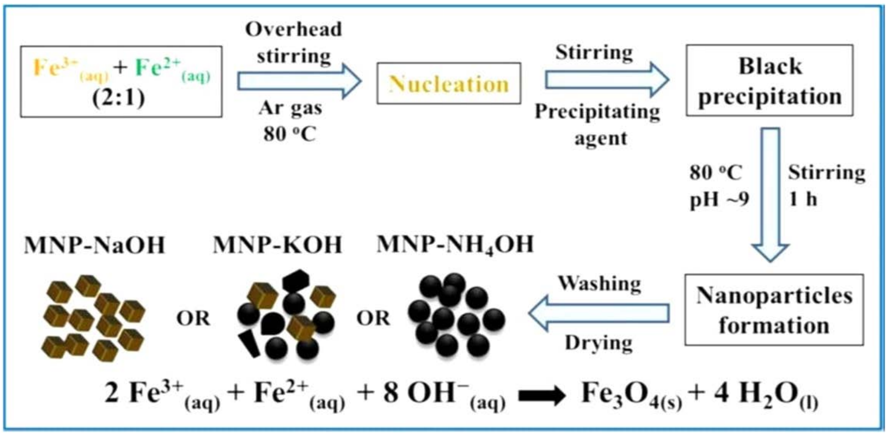

Figure 4. Structure and Properties of magnetite (Fe_3O_4) nanoparticles [52].

3. MI-NPs with Molecularly Imprinted Functionalized Surfaces

In addition to other uses, iron oxide nanoparticles are frequently employed to release medicinal compounds, detect cells, sort biological products, and act as an efficient corrosion inhibitor. Impurities are separated and eliminated from Fe_3O_4-NPs for corrosion inhibition using an external magnetic field. However, it has been discovered that bare Fe_3O_4-NPs are unstable, susceptible to air oxidation, and quickly aggregate in aqueous environments. Due to anisotropic dipolar attraction, Fe_3O_4-NP has a tendency to cluster into massive structures and loses its special magnetic properties as a result. For the majority of these applications, chemical stability, size uniformity, and good distribution in liquid media are necessary. Iron oxide particles need to have their surfaces modified in order to be stabilised so that they can be used in a variety of sectors [53]. To prevent agglomeration and to produce stable colloidal solutions of Fe_3O_4-NPs, it is possible to do this by passivating the surface of the Fe_3O_4-NPs with inorganic or organic chemicals during the preparation process or afterwards. Both organic and inorganic coatings can be applied on MI magnetite nanoparticles.

3.1. Silica

Silicon is the most common material used to create functionalized iron oxide nanoparticles in contemporary nanotechnology. Silicon plays a key role in the development of magnetic nanoparticle coatings, both for fundamental studies and practical applications [54].

3.1.1. Magnetite Nanoparticles (Fe_3O_4-NPs) Coated with Silicon (SiO_2) Have the Following Characteristics

(a) Because of the magnetic dipolar affinity between the nanoparticles, silica-coated magnetic nanoparticles prevent acidic environments from leaching. In liquid mediums, the coating also prevents the magnetic dipolar attraction of nanoparticles.

(b) These composite nanoparticles have good biocompatibility, hydrophilicity, and stability.

(c) Magnetic nanoparticles coated with silica can also be used to form a surface with different

functional groups. The abundance of silanol groups on the silica layer adds to this result.

(d) Because the methods for creating adjustable composite nanoparticle shells are well-established, controlling them is not too difficult.

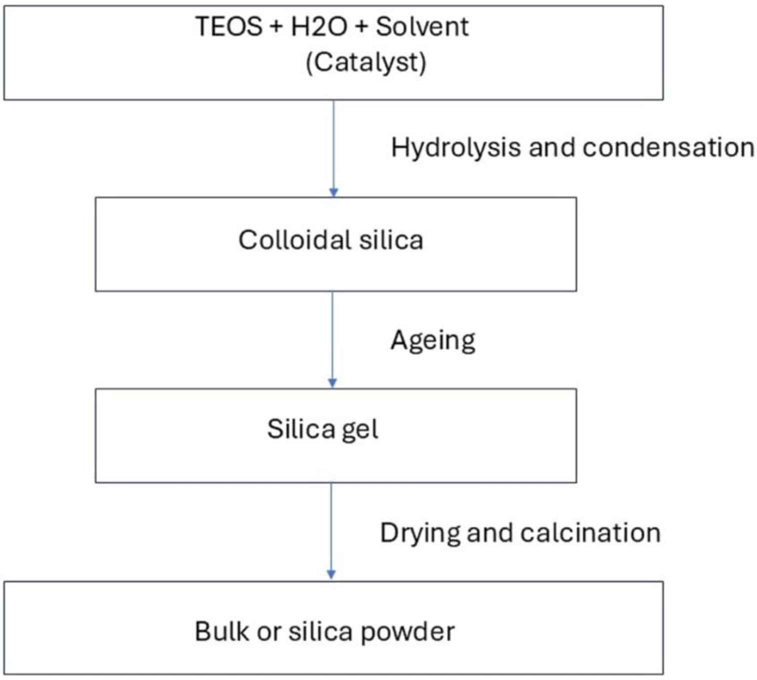

Figure 5. Flow chart of a typical sol-gel process of Silica (SiO_2) [55].

Studies demonstrated that the recovery of harmful material depositions from environmental samples and actual environments may be accomplished using magnetite nanoparticles (Fe_3O_4-NPs) functionalized with various functional groups. Fe_3O_4-NPs have been coated with silica using stober method are shown in **Figure 5** [55].

3.1.2. Synthetic Approach of Silica (SiO_2)

Smaller, more uniform particles can be created using the micro-emulsion method and the quantity of iron oxide and magnetic characteristics can be controlled [56]. The Stober method shows the reaction sequences below.

It is possible to express the general TEOS as a precursor that result in the creation of silica particles in the sol-gel process as follows [57]:

$$\mathrm{Si}\left(\mathrm{OC_2H_5}\right)_4 + \mathrm{H_2O} \xrightarrow{\text{Hydrolysis}} \mathrm{Si}\left(\mathrm{OC_2H_5}\right)_3\mathrm{OH} + \mathrm{C_2H_5OH}$$

$$\equiv \text{Si-O-H} + \text{H-O-Si} \equiv \xrightarrow{\text{Water Condensation}} \equiv \text{Si-O-Si} \equiv + \mathrm{H_2O}$$

$$\equiv \text{Si-OC}_2\text{H}_5 + \text{H-O-Si} \equiv \xrightarrow{\text{Alcohol Condensation}} \equiv \text{Si-O-Si} \equiv + \mathrm{C_2H_5OH}$$

Stober Method—Hydrolysis and Condensation Reactions

3.1.3. Sol-Gel Process

When TEOS molecules are hydrolyzed, silanol groups are created [58]. Silica (SiO_2) is made up entirely of siloxane bridges (Si-O-Si) created by condensation or polymerization of both silanol and ethoxy groups [59]. Silica particles are formed in two stages: nucleation and growth. To explain silica growth, several models have been put forth: the addition of monomers. The aggregation model emphasizes, in contrast, that nucleation happens continuously throughout the reaction and that the resulting particles (primary particles) quickly aggregate to generate dimmer, trimmer, and larger particles (secondaries). Figure 6 illustrates how both models result in a spherical or gel network depending on the reaction circumstances [60].

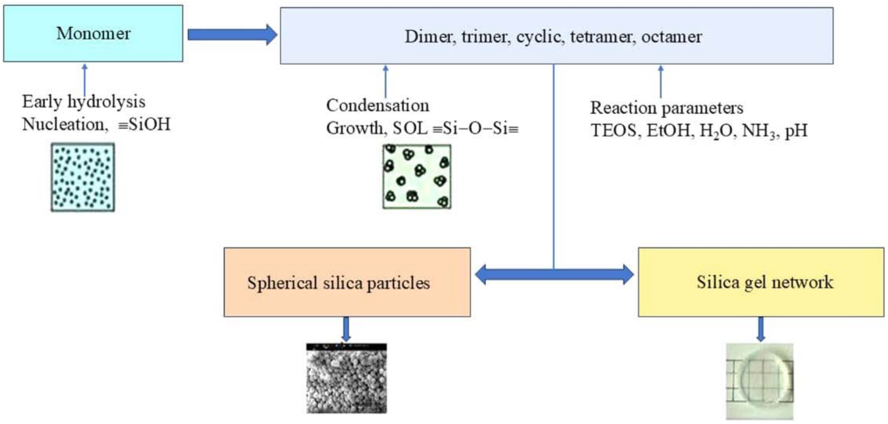

Figure 6. A Schematic representation of silica (SiO_2) formation by sol-gel process [60].

3.1.4. Morphological Study of Silica-Coated Magnetite (Fe_3O_4@SiO_2) Nanocomposites

Here in Figure 7, when silica coating is applied to composite NPs, the size of the particles increases and other characteristics, like the magnetic properties, alter as well. Using the Stober method and the sol-gel process, hydroxyl groups on the surface of iron oxide NPs, quantities of ammonia (NH_3) and tetraethoxysilane (TEOS), and water (H_2O), it was simple to create silica coatings in an aqueous environment. Additionally, as predicted, silica coatings of up to 200 nm could be produced by adjusting the ammonia concentration and TEOS to water ratios [61].

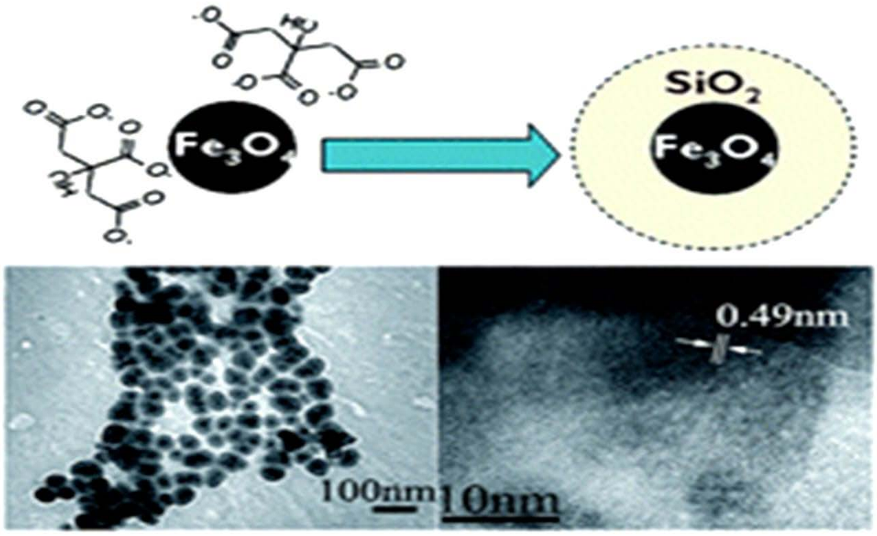

Figure 7. Structural representation of Silica-coated magnetite ($Fe_3O_4@SiO_2$) nanoparticles [61].

3.1.5. Specific Applications of Functionalized Silica-Coated Magnetite Nanoparticles

These studies have as their main objective the functionalization of iron oxide NPs with silica in order to produce adjustable magnetic composites with tunable architectures and good dimension stability. In this scenario, research findings have also been used to improve commercial products. In this case, great progress has been made in terms of silica-coated iron oxide ($Fe_3O_4@SiO_2$) nanoparticles bind with functional groups (RAFT) for target selective. This demonstrates that making silica functionalized iron oxide nanoparticles is a simple process having specific application with illustration in **Figure 8** [62].

3.2. Metal or Non-Metal

In order to shield iron oxide NPs from deterioration, pure single metal or non-metal shells made of gold, silver, platinum, palladium, iron, carbon, etc. can be oxidised. Control of the single-metal or non-metal layer has a significant impact on the uses of iron oxides, particularly in the fields of biomedicine, environmental remediation, and catalysts [63]. Gold is often used as a passivate to inhibit the oxidation of Fe_3O_4-NPs.

The saturation magnetization value of iron oxide NPs will be reduced by the single-metal functionalizations of gold, silver, and carbon; however, depending on the mass magnetic susceptibility value of the materials used, the single-metal functionalizations of cobalt, platinum, copper, and palladium may have the opposite effect [64]. Additionally, the reduction and repeat periods can be adjusted to produce iron oxide NPs with metallic or non-metallic functionalization at the required diameter. Two methods are often used to create the metal functionalized iron oxide NPs. The first method involves directly reducing the single-metal ions that are present on the surface of the iron oxide NPs.

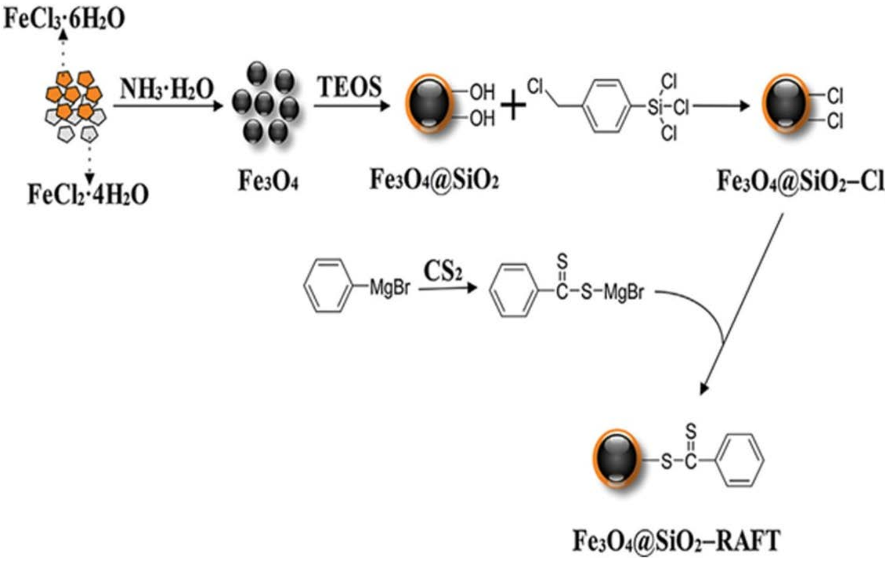

Figure 8. Silica coated magnetite ($Fe_3O_4@SiO_2$) nanoparticles bind with functional groups (RAFT) for target selective [62].

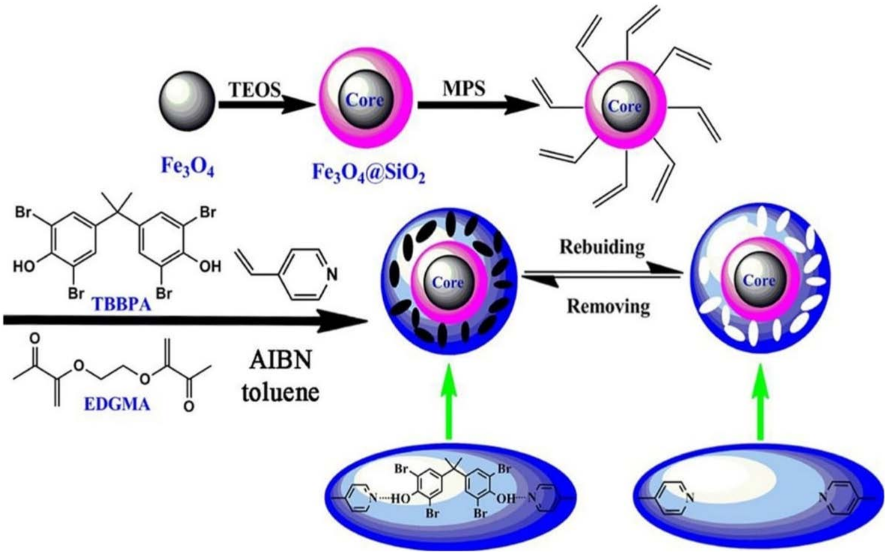

Figure 9. Schematic representation for the synthetic approach of nanostructured core–shell magnetic surface imprinted polymers ($Fe_3O_4@SiO_2@$Toluene) [68].

The surface of a small molecule, polymer, or Silica functionalized iron oxide NPs is reduced to generate metallic functionalized iron oxide NPs in the second procedure [65]. Since the magnetic coating on the surface of magnetite is more stable under heat and chemical conditions more biocompatible than that of other non-metals. For their potential use as energy storage materials, a variety of magnetite nanocomposites covered with carbon have been created and thoroughly investigated [66].

3.3. Metal Oxides and Metal Sulphides

There has been a tonne of research on functionalizing magnetite nanoparticles

(Fe_3O_4-NPs) with metal oxides and metal sulphides as a result of the significance of their distinct physical and chemical properties. Mesoporous Titania microspheres with a thin anatase-structured shell were generated using a straightforward approach of surfactant poly (ethylene oxide) assisted nanoparticle assembly in non-aqueous solutions. In the investigation, it was discovered that the surfaces had hydroxyl groups on them and had a smaller band gap.

Applications involving surface multi-functionalization and photo-catalysis may benefit greatly from these findings. Researchers typically utilise ZnO, MgO, CaO, SnO_2, Al_2O_3, etc. for functionalizing magnetite nanoparticles (Fe_3O_4-NPs) [67]. Magnets are usually constructed using oxides of iron such as CoO, NiO, $CoFe_2O_4$, etc. TiO_2, ZnS, Y_2O_3, and other optical and electrically functional elements are used to functionalize magnetic nanoparticles (Fe_3O_4-NPs). **Figure 9** illustrates coating on SiO_2 that is present with toluene as a functional group [68].

3.4. Coating of Organic Compounds on the Surface of the Magnetite (Fe_3O_4) Nanoparticles

To reduce agglomeration and improve their ability to be used in biological and environmental applications, magnetic nanoparticles are frequently passivated with organic compounds during or after the preparation process. The organic coating on the surface of these particles not only prevents the hydrophobic interaction of magnetic nanoparticles that could result in agglomeration, but it also offers a functional site or a reactive site for a variety of impurities in inhibited materials, making the remediation process more precise and targeted.

Recently, a lot of research has been done on nanostructure materials with particular functional characteristics. Contemporary uses can be made of the magnetite NPs covered with organic molecules. These organic compounds functionalized with iron oxide nanoparticles (Fe_3O_4-NPs) revealed biocompatibility and biodegradability in addition to exhibiting the fundamental magnetism properties of magnetic nanoparticles are shown in **Figure 10** [69].

Furthermore, functional reactive group ensembles can be provided by organic molecules. To use them, their groups must be able to connect to bioactive elements such as enzymes, antibodies, proteins, DNA, and so forth [70].

3.5. Different Functional Group Attached on the Surface of the Magnetite Nanoparticles

The synthesis of iron oxide NPs using organic, macro, polymer, and biological components has been investigated by researchers [71]. According to their surface characteristics, magnetic nanoparticles coated with tiny organic molecules can be classified as either oil-soluble, water-soluble, or amphiphilic. The surface of the oil-soluble kind of iron oxide NPs contains compounds that have a poor affinity for the solvent environment, typically fatty acids and alkyl-phenol. Chemical groups that are attracted to the solvent environment may be present in functionalized Fe_3O_4-NPs with water-soluble surfaces. Ammonium salts, polyols, and lycine may be among these compounds. Amphiphilic iron oxides NPs are those that have had their surfaces modified to include both hydrophilic and hydrophobic groups. This could result in concurrent hydrophobic and hydrophilic patches in the main chain of the functionalized nanoparticles which revealed in **Figure 11** [72].

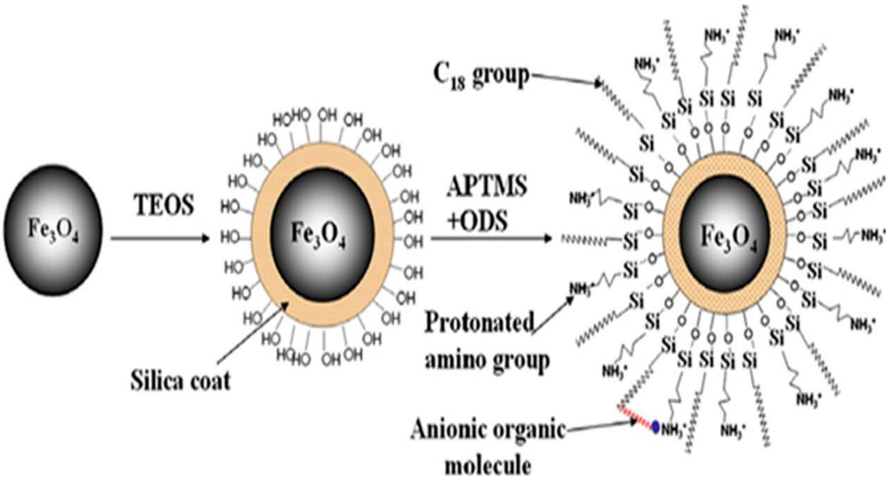

Figure 10. The representative structure of organic compounds functionalized magnetite nanoparticles (Fe_3O_4-NPs) (If iron oxide NPs were always assumed as the core) [69].

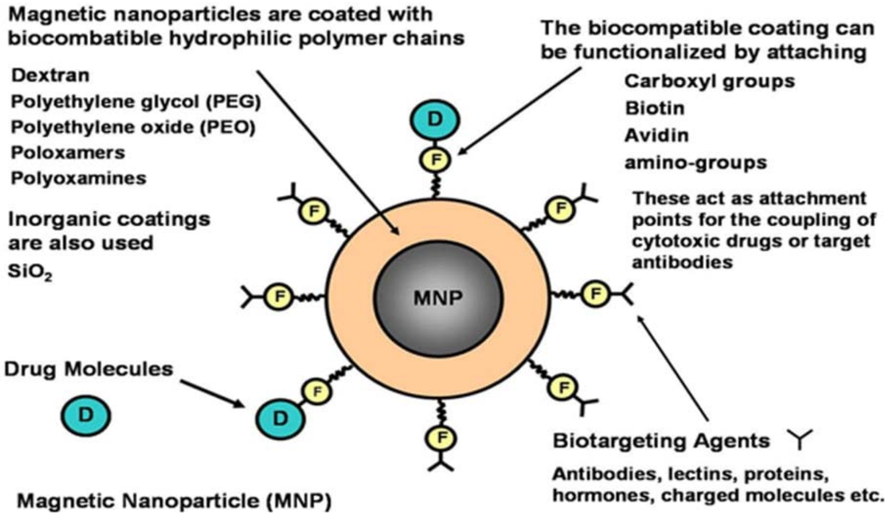

Figure 11. The different organic functional groups attached on surface of magnetite Nanoparticles (Fe_3O_4-NPs) [72].

In the same way that sulfuric lycine does, the nanoparticles also have water and oil soluble. Magnetic nanoparticles have been modified with a range of long chain fatty acids, phosphate, and phosphonate. Researchers proposed that alkyl phosphate and phosphonate coated magnetite nanoparticles (Fe_3O_4-NPs) help them achieve thermodynamically stable dispersion [73].

3.6. Polymers

Due to the advantages that polymer coating offers strengthened repulsion forces in order to poise the magnetic and Vander Waals forces of attraction. So, proposed Polymer-functionalized magnetite nanoparticles (Fe_3O_4-NPs) have recently gained a lot of attention. Because of these benefits, polymer-coated magnetite nanoparticles (Fe_3O_4-NPs) have proven in a variety of applications. Due to their distinctive physical or chemical properties, Researchers have thoroughly investigated magnetite nanoparticles (Fe_3O_4-NPs) functionalized with polymers. Natural and artificial polymers can be grafted onto magnetite nanoparticles (Fe_3O_4-NPs). The magnetite nanoparticles (Fe_3O_4-NPs) have a natural polymer, CS, grafted onto their surface clearly shown in **Figure 12** [74].

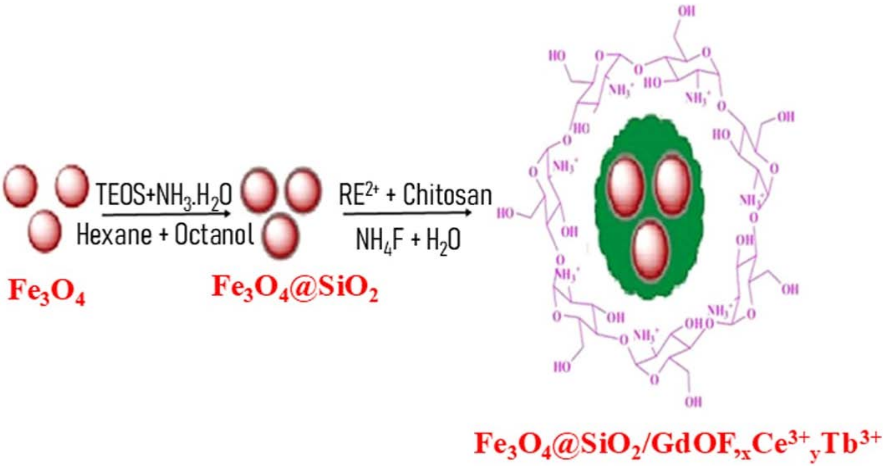

Figure 12. Functionalisation of the magnetite nanoparticles (Fe_3O_4-NPs) with chitosan polymer [74].

Researchers revealed that it is feasible to produce nanoparticles with certain qualities by carefully deciding on the passivating and activating polymers and/or reaction conditions [75]. Both synthetic and natural polymers can be coated with Fe_3O_4-NPs. Polymers are grafted to comprise the absence of tiny organic molecules and surfactants to produce surface functionalized magnetite nanoparticles (Fe_3O_4-NPs).

Now, there are two main ways to synthesize polymer-functionalised magnetite nanoparticles (Fe_3O_4-NPs). Producing monodisperse nanoparticles with precise forms and controlled compositions is one way to increase the spectrum of utilizing for functionalized-nanoparticles with polymer. Although there has been substantial progress, creating functionalized magnetite nanoparticles (Fe_3O_4-NPs) with enough chemical stability and high biocompatibility is still a difficult task. The creation of well-controlled functionalized nanoparticles can be made easier to a certain extent by selecting the right organic material [76].

3.7. Biological Molecules

By chemically attaching to the surfaces of magnetite nanoparticles (Fe_3O_4-NPs) via certain functional end groups biopolymers [77]; such protein polypeptide, antibody, biotin, and avidin can also bind to them directly or indirectly [78]. This makes them specific target [79]. Molecular imaging, drug delivery, and therapeutic nanoparticles are shown in a schematic manner [80]. For specialised diagnoses and treatments, it is possible to create nanoparticles that have been designed and optionally functionalized [81]. Their biocompatibility will be improved by functionalizing molecularly imprinted (MI) core-shell nanoparticles ($Fe_3O_4@SiO_2$-NPs) with biological molecules [82]. Magnetic nanoparticles (Fe_3O_4-NPs) are helpful in the separation of proteins, DNA, cells, biological products, and other materials [83] [84]. The construction of a multifunctional/multimodal MNP combining shell coating and surface changes is shown in **Figure 13** [85] [86].

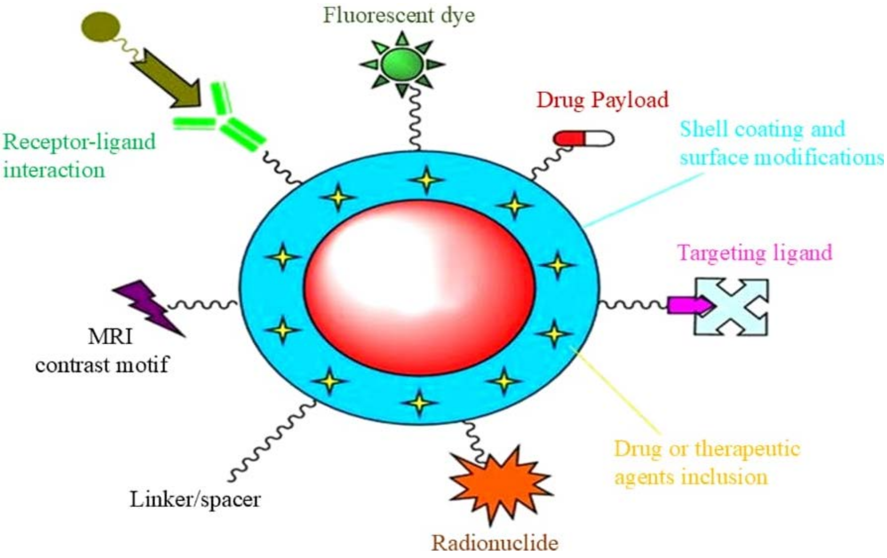

Figure 13. The scheme illustrates two commonly used strategies to fabricate multifunctional magnetic nanoparticles and their potential applications [85].

4. Different Ways of Entry and Translocation of NPs in the Human Body

The propensity of particles to be retained or otherwise carried to various organs or tissues throughout the body, as well as their capacity to enter the body through particular pathways, are influenced by both their physical and chemical characteristics. Ingestion through the digestive tract, permeation through the skin, and inhalation through the respiratory tract are the three primary ways that NPs enter into the body as shown in **Figure 14** [87]. There are other methods as well.

4.1. Inhalation

One of the most frequent ways for people to become exposed is thought to be by inhalation. The size of the particles appears to first determine how much dust and air-borne particles enter, deposit, or finally travel to other places. The finer grains can enter the bronchial tree, where they can be kept and continue to cause harm or depart from there to go to other sites. Typically, the larger particles are deposited in the nose, mouth, and larynx. Epidemiological research on miners and refinery employees exposed to metal particles has shown a connection between exposure and the occurrence of respiratory tract cancer (lung and nose cancer) [88]. The tendency for nickel miners to develop nasal cavity malignancies after exposure to nickel-containing dusts was first noted in 1933 [9] [89]. A particular particle appears to be responsible for the pattern of negative effects on the retention sites. For instance, chrysolite asbestos fibres deposition concentrates on the bifurcations of airways and causes "spots" of fibrosis after acute exposure; they manifest as emphysema in "coal workers" and as fibrotic nodules in chronic beryllium illness via lymphatic pathway along airways [90].

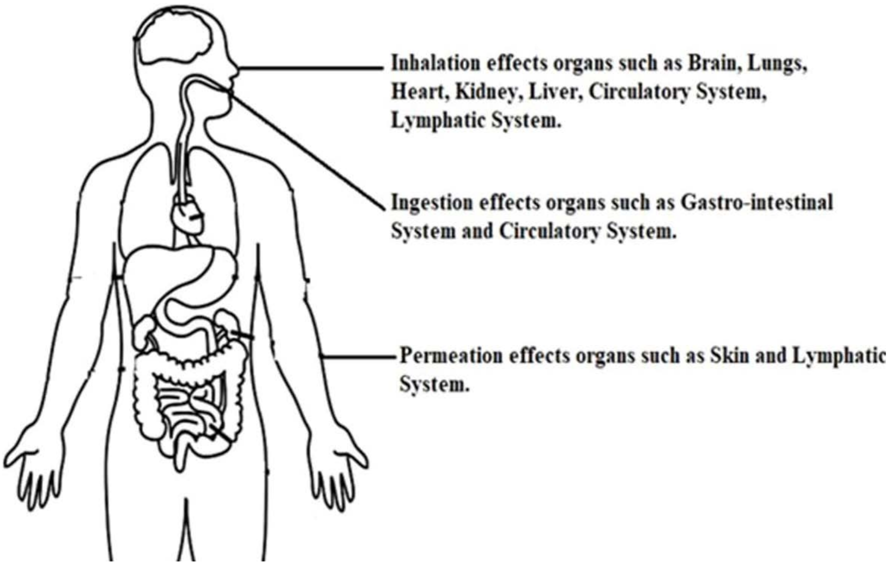

Figure 14. The ways of translocation of NPs in Human body [87].

4.2. Permeation

The majority of research on the absorption, delivery, and distribution of NPs in and through the skin indicates that the associated toxicity appears to be minimal; typically, it is reported that the skin acts as a protective barrier and NPs through the skin can only reach the upper layers of the epidermis before permeating the area close to the hair follicles [91]. However, the skin is permeable to nanomaterials and provides holes on its surface through its hair follicles and glands, which can act as channels of entrance, particularly ideal for ultra-fine materials.

In fact, it has been shown that a number of NPs can penetrate the skin and the lymphatic system to enter the systemic vascular system [92]. Millions of individuals use a variety of personal care and cosmetic items every day that include nanoparticles, including shampoo, toothpaste, deodorant, soap, sunscreen, moisturiser, foundation, face powder, perfume, and eye shadow, to mention a few. According to reports, 33 million Americans use sunscreen products every day and many more do so sporadically, and a rising number of individuals are exposed to the sun every day [93].

These strange NPs, which are frequently combined with TiO_2, have the capacity to offer an effective, long-lasting UV barrier that is not unpleasant [94]. ZnO particles with a size less than 100 nm are employed to achieve better dispersion quality and a higher UV protection level [95]. Inhaling sunscreen spray can be a significant exposure method even if, unlike skin applications, spray preparations are typically unable to transcend the stratum cornea layers and may instead find a means to translocate to the essential organs.

ZnO-NPs can offer a significant risk when inhaled, and BEAS-2B cells treated to 20 nm-sized ZnO-NPs showed elevated expression of genes related to oxidative stress and apoptosis. Numerous researches on the toxicity of ZnO-NPs have focused on the harm done to cells, such as oxidative harm, cytotoxicity, and genotoxicity [96]. In these situations, a lot of focus has been placed on the ZnO materials' solubility since they have the potential to release free Zn^{2+} ions inside of cells, which may interact with various binding sites in proteins and enzymes and significantly alter their functions [97]. Additionally, it has been observed that human epidermal cells exposed to 0.8 g/ml of ZnO-NPs with a diameter of 30 nm suffered DNA damage.

4.3. Ingestion

Compared to other routes of entrance into the body, studies on the toxicity of NPs after consumption are less common [98]. Through the nose, through water, food, or medications containing NPs, NPs can enter the body directly into the digestive tract. The primary area of concern and anxiety with regard to ingestion is specifically related to engineered NPs, which are substances created with the intention of being added to various goods like foods or medications in order to accomplish particular functions [99]. As food additives and across several food processing industries, NPs are being employed more and more. Due to this, it is important to pay close attention to the chance that they could cause numerous injuries by travelling via the digestive tract to other target organs and the blood circulation system. Despite the fact that several studies claimed that ingested NPs are quickly removed from the intestinal system because of the ongoing regeneration of the epithelium, many others provide unmistakable proof that specific NPs are translocated to target organs [100].

In reality, it has been discovered that nanoparticles can enter the bloodstream and then travel throughout the body following absorption via the gastro intestinal route [101]. Certain NPs have really been discovered in a variety of organs after oral administration, including the liver, lymph nodes, bone marrow, lungs, kidneys, brain, and both the small and large intestines [102]. The size and morphological characteristics of NPs affect how well they are absorbed from the gastrointestinal tract, as they do for other tracts as well [103]. Positively charged particles are trapped in the negatively charged mucus layer, whereas smaller, more morphologically diverse NPs are better absorbed [104]. The liver, spleen, and lymph have been observed to absorb titanium particles of sizes between 150 and 500 nm that are more pronouncedly than those typically found in sunscreen creams [105].

5. Conclusion

Different options for employing waste materials as inputs for the creation of NPs have been illustrated in this research paper. Even though recycling waste creates new innovative ideas for engineered nanomaterials to maintain eco-friendly, particularly regarding energy use and exposure routes toxicity levels in various organisms, which emphasized the significance of performing life cycle assessments and risk analysis. As a result, there is less chance that unintended repercussions may eventually become apparent. However, life cycle assessments necessitate having access to a sufficiently substantial body of data on emissions and environmental concentrations of engineered NPs. Therefore, empirical data on release coefficients throughout all stages of the life cycle (including production, usage, and disposal) is limited, because the majority of data available in the literature have been obtained through modeling and simulation of the release of NPs from containing products during consumer manipulation. These guidelines are meant to help designers of chemical routes produce more sustainable results. However, these eco-friendly methods for creating NPs are safe and prospective but that does not mean their unrestricted use or release into the environment won't have negative impacts.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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