

Multifunctional Nanomaterials for Environmental Remediation

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ABSTRACT

To provide healthy and sustainable lifestyles for future generations, humans must nurture our environment. Rapid industrialization, urbanization, and population growth have caused environmental damage in a short time. These activities have endangered humans and their ecosystems. Over the past few decades, excessive consumption of natural resources and unscientific and improper disposal of toxic industrial byproducts like heavy metals (lead, cadmium, zinc, and arsenic), ammonium derivatives, organic wastes, and acid wastes into river streams have been widely reported to pose a threat to human health. Pesticides, fertilizers, and drugs pollute soil and water. Thus, treating these poisonous and dangerous elements/compounds is a huge issue for scientists and researchers worldwide. Due to their versatility and economic feasibility, scientists are interested in using multifunctional nanomaterials to catalyze solid, liquid, and gaseous waste. The design, development, and realization of such catalysts involve combining strategies to enhance and bring forth desirable catalytic properties like electronic interaction of surface with reactant molecules, Lewis acid site concentration, availability of active surface sites for adsorption, metal support interactions, and electronic band gap in a material. Three parts comprise this chapter. The first portion introduces the present situation and difficulties facing humanity, types of pollutants, and nanomaterials used to reduce pollution. This section emphasizes the mechanistic specifics of remediation methods including photocatalysis, photoelectrocatalysis, and adsorption. The following part discusses how heterojunction, Z-scheme, surface tailoring, and interface and defect engineering affect catalytic efficiency.

KEYWORDS: *Nanomaterials, Environmental, Remediation*

I. Introduction

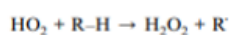
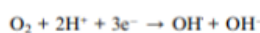
The quick rate of industrialization and the byproducts it has produced have had a negative impact on the environment. These byproducts include the production of hazardous wastes as well as deadly gas fumes and smokes, which have been discharged into the environment. Adsorption, biological oxidation, chemical oxidation, and incineration are some of the conventional methods that have been utilized in the past for the treatment of various kinds of organic and hazardous waste. It has been suggested that a method known as supercritical water oxidation (SCWO) may be used to dispose of a variety of organic wastes that are toxic to the environment. It has been attracting a lot of interest owing to the fact that it is able to dispose of a wide variety of high-risk wastes that are the consequence of the demilitarization of weapons and the processing of complicated industrial chemicals. In the concentration range of 1% to 20% of organic contaminants, the cost of treating waste with SCWO is much lower than the cost of treating waste with active carbon. Concurrently, the lightning-fast development of nanotechnology has sparked a surge of curiosity regarding the ways in which nanomaterials might be used to improve environmental quality. The removal of contaminants from water and air is a significant problem, and the application of nanomaterials is essential to the process of environmental restoration. Because of the extremely high reactivities and massive specific surface areas of nanomaterials, they make for fantastic adsorbents, catalysts, and sensors. Because nanoparticles have a high ratio of surface area to mass, they are able to significantly boost the adsorption capabilities of sorbent materials. Because of their much smaller size, nanomaterials have a surface area that increases exponentially while maintaining the same density as larger materials. In addition, nanoparticles in solution have a high degree of mobility, and due to the diminutive size of nanomaterials, it is possible to rapidly scan an entire volume using just a little quantity of these particles. The nanoparticles have a surface that is extremely reactive (mostly owing to the high density of low-coordinated atoms at the surface, edges, and vortices) because to the nanomaterials' decreased size and large radii of curvature. This is because the nanomaterials have a surface that is exceptionally reactive. The use of these one-of-a-kind features allows for the degradation and scavenging of contaminants in water and air.1 It is possible to remove the species that have been adsorbed onto the nanomaterials by exerting a gentle gravity (centrifugal) force (in the case of magnetic nanoparticles) or magnetic force (in the case of magnetic nanoparticles). The quality of the air and water in natural environments may be significantly impacted by nanomaterials, which can take on a variety of sizes, morphologies, and forms.2 The ability of magnetic nanoadsorbents to be easily retained and separated from treated water is one of the factors

that makes them particularly appealing.³ Nanomaterials also exhibit distinct patterns of reactive surface sites and disordered surface areas throughout their surfaces. Chitosan, silver nanoparticles (nAg), photocatalytic titanium dioxide (TiO₂), and carbon nanotubes (CNT) are only some of the natural and artificial nanomaterials that have been shown to have powerful antibacterial characteristics. In addition, nanotechnology may be utilized for the analysis of pesticides and heavy metals (such as cadmium, copper, lead, mercury, arsenic, and others). In addition to this, nanomaterials exhibit significantly improved redox and photocatalytic capabilities. The fabrication of nanomaterials can be accomplished through the following methods: (1) grinding, milling, and mechanical alloying techniques; (2) physical or chemical vapour deposition or vacuum evaporation; (3) sol-gel chemical synthesis methods; (4) gas-phase synthesis techniques, such as flame pyrolysis, electroexplosion, laser ablation, and plasma synthesis; and (5) microwave techniques or combustion methods or delamination of layered materials (the controlled crystallization from amorphous precursors). The functionalization method is applied to nanoparticles using a coating technique or chemical modification in order to achieve the following goals: (1) to enhance the surface and optical characteristics; (2) to prevent aggregation; and (3) to get rid of the interaction between the nanomaterials and biological substances. For instance, doping with an appropriate dopant can boost the photocatalytic activity of TiO₂ and produce a red-shift in the band gap of TiO₂, which ultimately leads to TiO₂'s capacity to absorb light in the visible range. Nanoparticles (NPs) have a very small particle size, which results in excessive pressure drops when the NPs are applied in a fixed bed or any other flow-through system. Nanoparticles also present certain challenges when it comes to their separation and reuse, and there is even a possibility that they could pose a threat to ecosystems and human health due to the possibility that they could be released into the environment. Because of this, hybrid nanocomposites have been manufactured by impregnating or coating small particles onto solid particles of a greater size. This was done in order to circumvent the restrictions that NPs provide. The resulting polymer-based nanocomposite (PNC) retains the qualities that are intrinsic to the nanoparticles; yet, the polymer support materials offer greater stability, processability, and enhancements as a result of the interaction between the nanoparticles and the matrix. The insertion of nanoparticles (NPs) into polymeric nanocomposites results in an improvement in the materials' mechanical, electrical, and optical characteristics. NP-based membranes may be manufactured by either constructing NPs on porous membranes or combining them with polymeric or inorganic membranes. Both of these methods provide the same result. The production of membranes containing metal oxide nanoparticles might improve not only the quality of the permeate but also the permeability and resistance to fouling of the membranes. The use of nanomaterials in the enhancement of membranes or membrane surfaces results in various changes in the qualities of the membranes themselves. These changes include the porosity of the membrane, the hydrophilicity of its surface properties, its electropositivity or electronegativity, and its surface catalytic properties. The use of nanoporous materials allows for the possibility of size grading, which has the potential to prohibit the passage of a wide variety of pollutants and pathogens across the membrane. Nanofibers have the potential to capture impurities that are much smaller in size and can provide improved filtering as a result of their much reduced porosity. Nanofibers have far larger interior surface areas than traditional filter materials do. In addition to this, nanofibrous materials can feature open pore architectures that are linked with one another and have the potential to allow for high flow rates. This paper provides an overview of the application of nanomaterials in the purification of water and air that has been contaminated with toxic metal ions, greenhouse gases, organic and inorganic solutes, bacteria, and viruses, as well as their performance in environmental remediation, pollutant sensing and detection, cleaner production, and other related areas.

Environmental remediation technologies

Chemical degradation is one of the environmental cleanup approaches that is utilized quite frequently. The following are examples of chemical degradation methods: (1) ozone/UV radiation/H₂O₂ oxidation; (2) photocatalytic degradation; (3) supercritical water oxidation; (4) the Fenton method; (5) sonochemical degradation; (6) the electrochemical method; (7) the electron beam process; (8) solvated electron reduction; (9) enzymatic treatment methods; and (10) permeable reactive barriers of iron and other zerovalent metals. Chemical oxidation processes, such as those based on ozone or UV radiation (O₃/UV/H₂O₂), are applicable to water treatment for the degradation of individual pollutants or the reduction of the organic load (chemical oxygen demand, COD). Additionally, the biodegradability of waste water could be improved by utilizing these techniques. The use of ozone and ultraviolet light alone can serve the objective of disinfection. When it comes to removing foreign substances from water, the O₃/UV/H₂O₂ approaches typically utilize two different paths of oxidation and photolysis. Therefore, ozone, hydrogen peroxide, and/or UV light are all capable of reacting on their own or photolyzing organic materials directly in water. However, if ultraviolet light is combined with the usage of ozone or hydrogen peroxide, the contaminants may be destroyed by an oxidation process involving hydroxyl free radicals that are created locally. With the exception of fluorine, radical hydroxyls possess the highest standard redox potential of any other element. Phenols and some pesticides are two examples of the types of molecules that react quickly with hydroxyl radicals. On the other hand, organochlorine compounds are not as reactive as phenols and other pesticides. Because the pollutants are reacted with hydroxyl radicals in this oxidation process, it is a

damaging method of cleaning up water and air pollution. This is one of the characteristics of this oxidation process.^{16,17} Photons and a catalyst are both required for the process referred to as "photocatalytic degradation." Electrons that belong to an isolated atom occupy different levels of energy. Each of these energy levels is subdivided into a greater number of energy levels within a crystal than there are atoms in the crystal. The end effect of this is that the ensuing energy levels are extremely near to one another, and they may be thought of as creating a continuous band of energy levels. The highest energy band of a metal (or conductor) is only half-filled, thus the electrons in that band require just a little amount of energy to be lifted into the vacant portion of the band. This is the source of the metal's high electrical conductivity at ambient temperature. In contrast, valence electrons entirely fill a band in insulators and semiconductors; this band is thus referred to as the valence band. On the other hand, the band with the next greatest energy, which is referred to as the conduction band, is empty, at least at 0 Kelvin. Two HO₂ radicals can unite in liquid water to produce H₂O₂ and O₂ by way of a disproportionation reaction if their concentrations are high enough to allow them to react substantially with one another. In its turn, H₂O₂ has the ability to "scavenge" one electron from either the conduction band or the superoxide and, as a result, has the potential to be reduced to a hydroxyl radical (·OH) and a hydroxide ion (OH⁻). It is hypothesized that these reactions take place on the surface of the TiO₂ since it is known that they occur in phases of homogenous aquatic environments. To put it another way, the very oxidizing OH might, in theory, be created by the three-electron reduction of O₂:

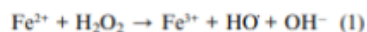


where R-H is an organic species that possesses a H atom that is easily lost; however, this reaction would also compete with H-atom removal from R-H by the OH radical. The oxidation of an adsorbed water molecule or an OH ion by a valence band hole (h⁺), also known as an electron transfer from these entities to the photoexcited semiconductor, is a far more direct method for producing the OH radical. The radicals that are produced at the surface of a photoexcited semiconductor by the combination of oxygen, water, and electron-rich organic molecules are the foundation of the surface chemistry that takes place. In addition, conduction band electrons have the ability to directly decrease cations in aqueous solution, given that the redox potentials of these cations are sufficient (that is, they lie below the energy of the conduction band). At least in principal, the photocatalytic reaction takes place in the adsorption phase, and the entire process may be officially broken down into five stages:

1. The movement of the reactants from the fluid phase to the surface;
2. The adsorption of at least one of the reactants;
3. The reaction in the phase where the reactants have been adsorbed;
4. The desorption of the product(s); and
5. The removal of the product(s) from the region where the reactants and products have interacted.

The photocatalytic reaction rates are susceptible to being influenced by temperature due to the fact that the adsorption and desorption rates are temperature-dependent processes. There have been reports of increased rates for the gasphase removal of some pollutants and, most importantly, for their mineralization rate, when the temperature was raised above the temperature that was considered to be ambient. The supercritical water oxidation (SCWO) process includes combining an aqueous waste stream with oxygen in a heated pressurized reactor that is working at temperatures and pressures that are higher than the critical point of water (374 degrees Celsius, 22.1 megapascals, or 218 atmospheres). Under these conditions, the solubility features of water are reversed (that is, enhanced organic solubility and decreased inorganic solubility), and the viscosity of the medium is decreased to a value that is comparable to gas-like values, which enhances the properties of the medium's ability to transfer mass. Because of its one-of-a-kind qualities, hot pressurized water makes it possible for oxygen and organic compounds to come into contact within a single phase, hence facilitating the fast oxidation of the organic compounds. SCWO may be utilized to produce full oxidation of numerous organic compounds with destruction rate efficiencies of 99.99% or greater by heating the mixture to 400–650 degrees Celsius and applying 3750 pounds per square inch of pressure. Because of the features of supercritical water, it is possible to synthesize small nanoparticles of metal oxides by a process known as hydrothermal synthesis. This process takes place in supercritical water at temperatures and pressures that are higher than critical. Not only does the supercritical hydrothermal synthesis of metal oxide nanoparticles use just water as a solvent, but the nanomaterials that are produced as a consequence contribute to a more sustainable society as well. This makes the process an environmentally friendly one. During the step of selective catalytic oxidation (SCWO) of organic acids in waste water containing benzoic acid, p-tolualdehyde, and p-toluic acid, as well as in organic compounds, such as cobalt and manganese acetate, cobalt manganese oxide nanoparticles, synthesized in situ in the reactor, act as an oxidation catalyst to enhance the oxidation rate of organic compounds. As a consequence of this, either the temperature of the reaction or the amount of time it takes to complete it might be lowered. It was discovered that the TOC of the waste water was 37,480 ppm, and after the reaction, it was fallen to only 200 ppm. The phrase

"Fenton reagent" refers to aqueous mixes of iron(II) and hydrogen peroxide that are produced using the Fenton technique. According to the results of this approach, the most important step is the net reaction that follows:



where Fe²⁺ and Fe³⁺, respectively, represent the hydrated species Fe(H₂O)₆²⁺ and Fe(H₂O)₆³⁺. Even though there are a great number of additional reactions that can take place in Fenton systems, reaction (1) is often known as the Fenton reaction. The creation of OH is the key benefit that the Fenton reagent provides in the process of the degradation of contaminants. The hydroxyl radical is an extremely powerful and nonselective oxidant that is able to break down a wide variety of contaminants. The amplification of heterogeneous reactions can also be connected to mechanical effects created in the fluid system by sonication. Sonochemical reactions are related to novel chemical species that are formed during acoustical cavitation. These consequences include a rise in the surface area available between the reactants, a quickening in the pace at which catalyst surfaces are regenerated, and a quickening in the rates at which dissolution and mixing take place. Because of the unusual nature of sonochemical reactions, alternate paths can be created, which can result in a quicker or more ecologically friendly breakdown of pollutants. Within the cavitation bubbles, sonochemistry creates a one-of-a-kind, high-temperature gaseous environment. In this environment, the thermolysis of CCl₄ molecules may occur at a rapid pace, resulting in the production of $\cdot\text{Cl}$ and $\cdot\text{CCl}_3$ radicals as major intermediate products. These radicals then combine with OH radicals or oxygen to produce stable HCl, HOCl, Cl₂, and CO₂ as the end products of breakdown. An aqueous solution of HAuCl₄·3H₂O that included polyvinylpyrrolidone, 1-propanol, and TiO₂ (Degussa P-25) was sonicated at a frequency of 20 kHz in the presence of a nitrogen environment to produce Au–TiO₂ nanoparticles. Sonophotocatalysis was utilized to break down the waste water solution, which involved irradiating it with light and then using ultrasound to do the actual work.^{26–28} The various electrochemical treatments are depicted in the form of a schematic diagram in figure 1. represents direct electrolysis through the process of anodic oxidation, in which the pollutant undergoes a reaction at the electrode surface with adsorbed OH, which is formed by water oxidation at a high O₂ overpotential anode. symbolizes indirect electrolysis, which is the process in which the pollutant interacts in the solution with an irreversibly electrogenerated reagent (B⁺), which is created from the oxidation of inactive B at the anode. The cathodic reduction and anodic oxidation processes are examples of the usual direct electrolytic techniques. The indirect techniques involve the employment of redox mediators as reagents that are electrogenerated in a way that is reversible, as well as oxidants as reagents that are electrogenerated in a way that is irreversible at either the anode (such as O₃, ClO, Cl, and ClO₂) or the cathode (such as H₂O₂) of the reaction. The electroreduction of halogenated organics can make them more readily biodegradable, despite the fact that they are often hazardous. In the process of electrochemically removing organic contaminants from waste waters by the use of anodic oxidation, this is another aim that is commonly pursued. Even while contemporary technologies have made significant cuts to the operational costs of cathodic reduction and anodic oxidation, both of these approaches are still much too expensive to be in a position where they can compete with biological therapy.

The Need for a Sustainable Environment

The Brundtland Commission, formerly known as the World Commission on the Environment and Development, brought together all nations to work toward sustainable development as a unified front. In the report that the commission put together in 1987, it was stated that "sustainable development is a development, that needs of the present without compromising the ability of future generations to meet their own needs" (Wood 1993). This definition of sustainable development is being used today. In this millennium, there is a rising fear that life on earth is in jeopardy as a result of the degradation of nature that has been brought about by human involvement. There is a dilemma for both present and future generations as a result of the hole in the ozone layer, the possibility of global warming, the loss of biodiversity, and the hazards posed by radioactive and toxic wastes. At the Earth Summit that took place in Rio de Janeiro in 1992, a declaration on the environment and development was issued. Within this declaration, it was stated that "to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it" (United Nations 1992). At the 2012 Rio Earth Summit, four main issues were addressed: (1) systematic scrutiny of the production of toxic and radioactive chemicals, (2) need for development of renewable energy resources as a replacement for fossil fuels, (3) health problems caused by air pollution due to vehicle emissions, and (4) scarcity of noncontaminated water and growing need for drinking water (Tollefson and Gilbert 2012; Cardinale et al. 2012; Haines et al. 2012). According to Rosener and Ortiz-Ospina's (2017) projections, the world's population is predicted to rise from its current level of 7.4 billion to 9.2 billion by the year 2040, despite the fact that the growth rate of the human population is declining. This will put a tremendous amount of strain on the already limited supplies of food, energy, and medicine, as well as the dwindling forests and other natural resources. The quality of either surface water or groundwater is dependent not only on natural factors but also on those that are induced by humans. At each point where surface water may percolate down into groundwater, the latter might get

contaminated with organic compounds and microorganisms. The presence of newly discovered contaminants in water bodies was previously thought to be the consequence of either point pollution (mostly from urban and industrial areas) or diffuse pollution (from agricultural areas). Pollution from nonpoint sources typically affects wide regions and may have a more significant negative effect on the quality of groundwater than pollution from point sources. The World Health Organization (WHO) is responsible for directing worldwide efforts to prevent the spread of waterborne diseases. In addition, the WHO provides governments with advice on the formulation of health-based policies and legislation (WHO 2018). The spread of illnesses such as cholera, diarrhea, dysentery, hepatitis A, typhoid, and polio can be attributed to the use of contaminated water and the lack of proper sanitation. According to projections made by the WHO, by 2025, places with inadequate supplies of fresh water would be home to 50 percent of the world's population. 38% of health care facilities in low- and middle-income countries do not have access to improved water sources, 19% of these facilities do not have access to better sanitation, and 35% of these facilities do not have access to water and soap for hand washing. It is not unreasonable to anticipate that drinking water will include at least trace quantities of a variety of pollutants. Even if there are some pollutants that might be detrimental if taken at specific amounts in drinking water, the presence of contaminants alone does not always suggest that the water offers a danger to one's health (EPA 2016). Physical, chemical, radiological, or biological pollutants are the most common types of contaminants found in drinking water (World Health Organization 2004; Faust and Aly 2018). The definition of contaminants provided in the United States Safe Drinking Water Act (SDWA) (EPA 2016) utilizes these main categories of contaminants. In most cases, the first sign that water has become contaminated is the presence of contaminants that are physical in nature. Examples of physical pollutants include particles of sediment and organic matter that have been suspended in the water of lakes, rivers, and streams as a result of soil erosion. Chemical pollutants may be things like elements or compounds, and they can be either naturally occurring or manufactured by humans. Nitrogen, bleach, salts, pesticides, metals, poisons generated by bacteria, and human or animal medications are all examples of chemical pollutants. Other types of chemical contaminants include radioactive materials. Organic and inorganic compounds are the two types of pollutants that may be found in chemicals. The presence of organic pollutants in the environment is far more common than the presence of inorganic contaminants. According to Lamastra et al. (2016), Table 1.2 has a listing of the primary organic water pollutants. Organic pollutants can be further categorized into halogenated contaminants, nonhalogenated contaminants, and pharmaceutical contaminants (Pan and Zhang 2013; Jobst et al. 2013; Li et al. 2014; Adeleye et al. 2016) (Pan and Zhang 2013; Jobst et al. 2013; Li et al. 2014; Adeleye et al. 2016). Interactions between the water that comes from the source and the soils that surround it have a significant impact on the chemicals that make up the inorganic component of groundwater. A chemical reaction will take place at the interface between the soil and the water as the source water passes through the soil. This reaction will modify the makeup of both phases. The quality of groundwater can also be harmed by inorganic substances that are found in naturally occurring environments such as soils, sediments, rocks, and dissolved mineral debris. Metal cations and some anions are included in this category of inorganic contaminants. Pb, Cr, Cu, Zn, Co, Mn, Ni, Hg, and Cd are some of the metal cations that have been discovered to pollute water and soils. Radioactive isotopes of Pu, Cs, and Sr, among others, pose potential threats as pollutants. In certain circumstances, some anionic species such as phosphates, arsenate, borate, and nitrates are also considered to be pollutants (Manahan 2017).

Carbon-Based Nanostructures

Many other kinds of metallic and carbon-based nanomaterials have appeared in recent years as interest in nanotechnology has grown. As possible advanced water purification agents, graphene (G), graphene oxide (GO), single-walled carbon nanotubes (SWNTs), and multiwalled carbon nanotubes (MWNTs) have been explored (Smith and Rodrigues 2015; Perreault et al. 2015; Al-Othman et al. 2012). Carbon-based nanomaterials and their respective nanocomposites offer many possibilities for novel applications in water treatment (Fig. 1.3) (Smith and Rodrigues 2015). These properties include a large surface area, the ease of chemical or physical modification, the tuning of properties for particular applications, and excellent capacity for microbial disinfection and removal of both organic and inorganic contaminants. These

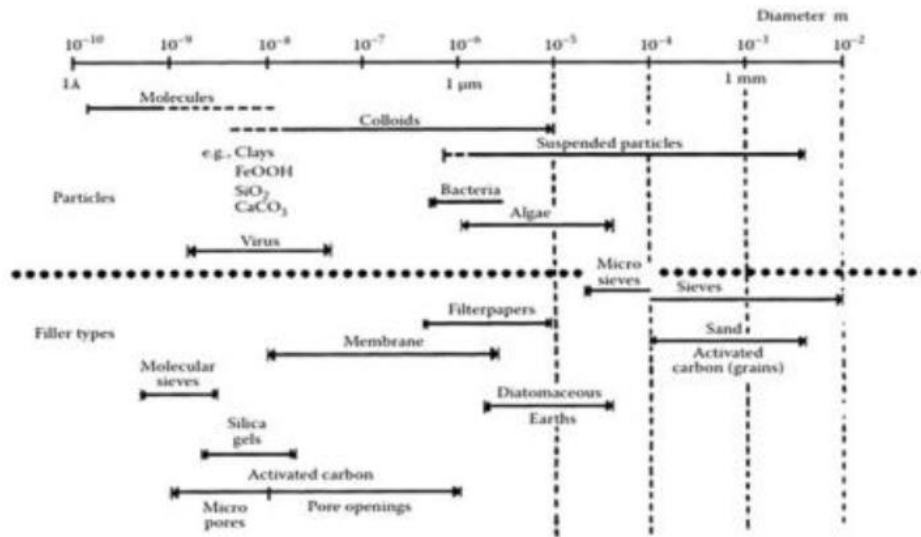


Fig. 1. The full spectrum of particle sizes that can be found in natural waterways as well as in groundwater. There is also an indication of the more traditional physical method of separating the particles. (With the author's permission, this is an adaptation from Stumm (1977). The American Chemical Society granted copyright in 1977.

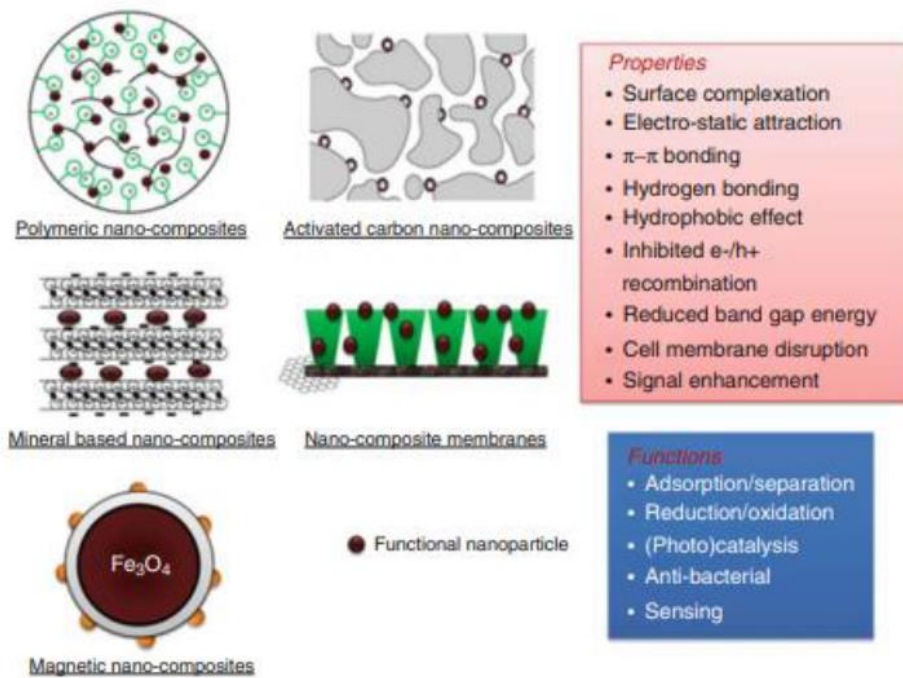


Fig. 2 Unique environmental nanocomposites and the characteristics of the materials themselves (Zhang et al. 2016)

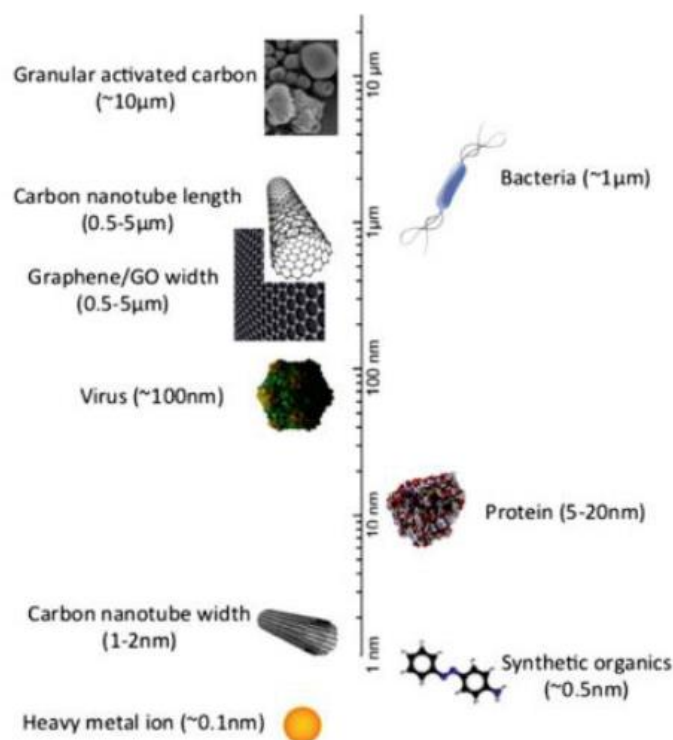


Fig. 3 Size comparisons of the most important groups of carbon nanomaterials and the most prevalent water pollutants (Smith and Rodrigues 2015)

materials are rarely used in their pure forms; however, graphene has been incorporated into a variety of composite materials because of its extremely large specific surface area and ease of broad functionalization, which offers abundant "anchoring" sites for various functional nanoparticles, including magnetic Fe₃O₄, photoreactive TiO₂, antimicrobial Ag and Au, and multifunctional nanocomposites such as graphene–TiO₂–magnetite and graphene–Au–magnetite (Ji Both functionalized and nonfunctionalized varieties of carbon-based nanomaterials are commercially available. Examples of these include graphene and carbon nanotubes (CNTs). For example, graphene or CNTs may be functionalized with OH and COOH groups by using chemical oxidation procedures to form graphene oxide and functionalized CNTs. In contrast to their unmodified counterparts, these materials are extremely dispersible in water (Vardharajula et al. 2012). According to Hebbar et al. (2017), there are two primary goals that may be accomplished by the functionalization of carbon-based nanomaterials. In the first place, it makes carbon nanotubes and graphene more hydrophilic, which in turn makes it easier for them to disperse in liquid media. A more even dispersion raises the accessible surface area of each nanoparticle, hence increasing the nanoparticles' vulnerability to attack by microbes and chemicals. Second, in order to boost the sorption capacity, the surfaces of nanomaterials can be altered so as to optimize the electrostatic interactions between the sorbent and the sorbate. This modification is dependent on the surface charge qualities of the contaminant that is being targeted. It was discovered that the primary driving force for the adsorption of positively charged substances (i.e., heavy metals) by negatively charged functionalized carbon nanotubes or graphene oxide is electrostatic contact. In addition to this, aggregated forms of carbon nanomaterials have a greater number of mesopores than many traditional carbon-based adsorbents, such as granular activated carbon (GAC), which has a greater number of pores on a microscale. According to Smith and Rodrigues (2015), mesopores make it much simpler to access both large and tiny portions of contaminating chemicals on the surface of the adsorbent. GAC filters are often utilized in traditional water treatment facilities for the purpose of removing heavy metals by adsorption. However, due of its poor removal efficacy at low concentrations of heavy metals and its sluggish adsorption rates, this approach frequently falls short of meeting the standards set out by regulatory authorities. Recent research has demonstrated that carbon nanotubes (CNTs) and graphene oxide, in particular, are capable of extracting substantial quantities of heavy metals from aqueous solutions. In the majority of experiments utilizing nanotubes, single-wall carbon nanotubes (SWNTs) have been able to successfully remove Pb²⁺, Zn²⁺, Cd²⁺, and Cu²⁺ from aqueous solutions (Sadegh et al. 2016; Suárez-Iglesias et al. 2017). [Sadegh et al. 2016; Suárez-Iglesias et al. The findings of research that looked at the affinity order of heavy metal ions for CNTs have been inconsistent. In addition, the results of these experiments have shown that the adsorption capacity of CNTs is extremely sensitive to the pH of the solution that they are used in. All of these investigations have come to the same conclusion, which is that the adsorption

capabilities of these nanomaterials are much greater than those of any other traditional adsorbents when subjected to the same experimental circumstances. Graphene's inherent antibacterial capabilities have led to its use in antimicrobial coatings and antifouling membranes, which is another one of the material's appealing qualities. According to Jiang et al. 2016, the proposed methods of bacterial inactivation and damage to cell membranes include extraction of phospholipids from cell membranes, physical disruption, and oxidative stress.

Nanomaterials in Chemosensors and Biosensors

The utilization of carbon nanotubes (CNTs) and graphene, as well as related species, has garnered the most interest to this point for the purpose of employing them in sensing applications. In sensing applications, pure graphene is not the only form that has been employed; many surface-treated forms, such as photoluminescent graphene oxide and reduced graphene oxide (RGO), have also been utilized (Chen et al. 2012; Baptista et al. 2015; Peik-See et al. 2014). Graphene is a two-dimensional material made up of carbon atoms. For any potential application involving sensing, the purity of the carbon nanostructures that were produced is a vital factor to take into account. The presence of impurities and a polydisperse sample are two significant difficulties that need to be addressed (Baptista et al. 2015). Impurities can interfere with the detection of analytes, and a polydisperse sample can affect both the optical characteristics and the capacity to build ordered assemblies. Both of these issues are caused by the presence of a polydisperse sample. Carbon nanostructures, in general, have a low degree of solubility in aqueous solutions, where they are prone to aggregation due to the hydrophobic interactions that exist between them. On the other hand, this problem may be solved by surface functionalization, which can be accomplished using either covalent or noncovalent techniques. The introduction of receptor sites for sensing can also be accomplished by surface modification. The diverse intrinsic properties of carbon nanomaterials give rise to a variety of sensing mechanisms, the most common of which are as follows: (1) electrical, where binding of the analyte changes the dielectric environment; (2) electrochemical, due to a redox process at the CNT surface; and (3) optical, such as fluorescence quenching, where there is a loss of emission due to the interaction between the carbon nanomaterials and the analyte (Holzinger et al. According to Yang et al. (2010), detecting tiny molecules, which can include pharmaceuticals, metal ions, gaseous analytes, and biomolecules, is of utmost significance in the fields of public health, environmental protection, food production, and safety. According to Baptista et al. (2015), detecting the presence of metal ions such Fe²⁺, Zn²⁺, Ca²⁺, Na⁺, K⁺, and Mg²⁺ is of utmost significance in the field of medicine. Glucose, neurotransmitters like dopamine, gene sequences for the detection of disease, and the components of illicit drugs are some examples of other analytes that are very important to the human body. The detection of these pollutants in tiny concentrations, particularly mercury, is of crucial importance (Baptista et al. 2015). Sensors are also required for environmental monitoring of metal ion pollutants and poisons. Not only can functional nanomaterials produce a synergic effect involving catalytic activity, conductivity, and biocompatibility to accelerate signal transduction, but they can also amplify biorecognition events with specifically designed signal tags, leading to highly sensitive biosensing. This is in addition to the materials that are used for electrodes. (Jiang et al. 2012) State-of-the-art functional electrode materials and multiple electrochemical techniques have been developed as a direct result of the extensive research that has gone into developing these materials. In addition to that, a broad variety of different approaches are being utilized to increase the efficiency of sensing for a number of different electrochemical applications (Zhang and Li 2012; Jiang et al. 2012). Utilizing nanoparticles (NPs) as carriers or tracers, catalysts, and electronic conductors can result in signal amplification. This can be accomplished by creating a synergistic effect between the catalytic activity, conductivity, and biocompatibility of the NPs. Electrochemical sensors and biosensors have evolved thanks to recent breakthroughs in nanotechnology and material science, as well as in the custom manufacturing of biorecognition components. These advancements have enabled the sensors to become more useful and trustworthy. Materials and biomaterials with rich nanostructures not only enhance electrical characteristics and increase the effective electrode surface for transmitting electrochemical signals, but they also provide detectable signals for the indirect detection of targets. This is because the nanostructures boost the conductivity of the electrode surface. Consequently, the procedures that were developed have a high sensitivity and a high level of specificity. The diagram labeled "Fig. 1.7" provides an illustration of electrochemical sensors as well as biosensors that are based on nanomaterials and nanostructures.

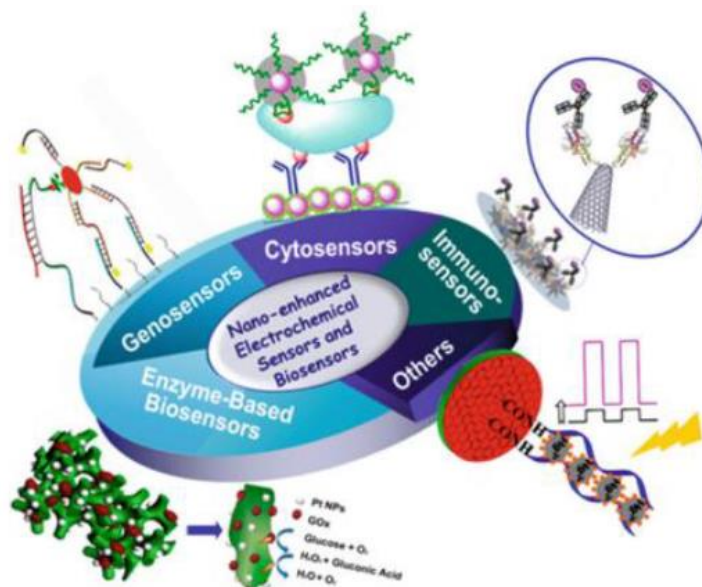


Fig. 4 Electrochemical sensors and biosensors based on nanomaterials and nanostructures, which exhibit electrochemical sensors for enzyme-based biosensors, genosensors, immunosensors, and cytosensors as well as other types of biosensors. GOx glucose oxidase, Pt NPs platinum nanoparticles. (This section was adapted with permission from Zhu et al. (2014). American Chemical Society owns the copyright for this publication (2014).

II. Conclusion

In environmental remediation, the use of nanomaterials for the detection and removal of pathogens results in a better level of sensitivity, a cheaper cost, quicker turn-around times, smaller sample sizes, in-line and real-time detection, a higher throughput, and portability. In addition, these benefits may be achieved without sacrificing throughput or mobility. In addition, metal and metal oxide nanoparticles may be utilized to remove organic pollutants and metals by the reduction or oxidation of the nanomaterial itself. The degree of removal can be increased through the functionalization of the nanomaterial with chemical groups that can capture specifically target contaminants in water and air media. This technology is both efficient and promising, and it may be used to the engineering of improvements to both water and air quality. Applications of nanomembranes include the purification of contaminated water, the generation of drinkable water, the reclamation of contaminated water, the removal of metals, dyes, and NOM, and the removal of pesticides from polluted water. When compared with bulk particles, nanomaterials have a better antibacterial efficacy and more efficiency for water purification and even for sensing applications. This makes them an excellent candidate for the scaling up of this technology for usage on a larger scale. Nanomaterials have the property of having a very high surface area, which means that only very little quantities are necessary to satisfy the demands of the environment, and they can also be extremely inexpensive.

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