1.1 General Introduction

In this fast-growing modernization age, there is an urgent need to develop low-cost, sensitive, selective, field-deployable, handheld, and rapid sensors for qualitative and quantitative detection of analytes related to health and environmental issues. Early-stage monitoring of disease is essential for human health safety. The diagnosis and monitoring of any disease relying on its respective disease biomarker may be an early alarm for quantifying the criticality of health-related issues [Califf, 2018]. Thus, the identification and regular monitoring of the level of biomarkers such as cancer biomarkers, cardiac biomarkers, kidney biomarkers, etc., and biomolecules such as glucose, cholesterol, cysteine, and acid phosphatase in bio-fluids are the most reliable way to the prediction of diseases. Up to now, various research work has been performed on multiple biomarkers, including cancer biomarkers [Malhotra et al., 2016], cardiac biomarkers [Rezaei et al., 2016], kidney biomarkers [Malhotra et al., 2017], Liver biomarkers [Ballestri et al., 2021] and other biomarkers to prior estimate the disease level. The monitoring and diagnosis of disease through these biomarkers are limited due to their expensive cost. So we are focusing on cost-effective and field-deployable sensors for the detection of several biomolecule levels in the body and real samples to diagnose the problem related to human health at the early stage. Field-deployable sensors are in high demand to deliver precise data on health and medical status to optimize the required level of biomolecules in the body.

Further, coronavirus disease 2019 (COVID-19) outbreaks have been reported in many nations recently [Nyaruaba et al., 2021]. Since the virus is very contagious, it will be crucial to identify affected people as soon as possible to stop the viral transmission. This circumstance served as further inspiration for us to create economic and user-friendly field-deployable sensors that are small enough to readily use as a portable kit and robust enough to be deployed in a remote location also. In remote areas, there are a lot of infrastructure

problems, including medical transport and telecom facilities, as well as a lack of skilled labor. Due to this reason, people living in remote areas do not have medical facilities, and they face lots of health problems. Hence, these findings lead us to assume that our workflow should be quick, reliable, adaptive, and, most importantly, field-deployable.

With the introduction of nanotechnology, nanomaterials have exhibited considerable promise in the field of sensors due to their outstanding optical, luminescent, magnetic, catalytic, and electrical properties. Because of these adaptable properties, nanomaterials exhibit the potential to better regulate the analytical performance of the developed sensors. Thus, in this chapter, we revisit the selected contributions in the area of synthesis of metallic and carbon nanomaterials and their applications in catalysis and sensing, which is fascinating from both academic and technological perspectives.

1.2 Sensor

The world is full of sensors, and their applications and sensors can be regarded as ubiquitous devices. A sensor is a device that generates an output signal by transforming chemical and biological information into an analytically meaningful signal. These sensors make our lives easier and have wide-ranging applications in our homes, offices, fire alarms, robotics, automobiles, medical diagnostics, and so on. Sensors are devices that can solve our day-to-day problems, including health issues.

Starting with functions like turning on lights, television, and fans, automatically adjusting the room temperature *via* air conditioning, creating a thumb expression, glucose monitoring sensors, etc., these sensors make our life incredibly simple and comfortable. So sensors play a significant role in bio-sensing, temperature, pH, pressure, humidity, gas, current, ultrasonic, etc. All the sensors mainly consist of two components, i.e., receptors and transducers [Abid et al., 2021]. Receptors can directly interact with analytes and transmit

data by producing detectable signals. A transducer, also known as an energy converter, is a device that transforms a non-electrical signal into an electrical signal. There are three kinds of sensors, i.e., Physical, Chemical, and Biosensors. A physical sensor is a device that measures physical quantity (such as mass, distance, temperature, pressure, etc.). A chemical sensor is a device that measures and identifies the chemical qualities of a chemical constituent, for example colorimetric and chemiluminescence sensors. A biosensor measures chemical substances (analytes) by using a biological component.

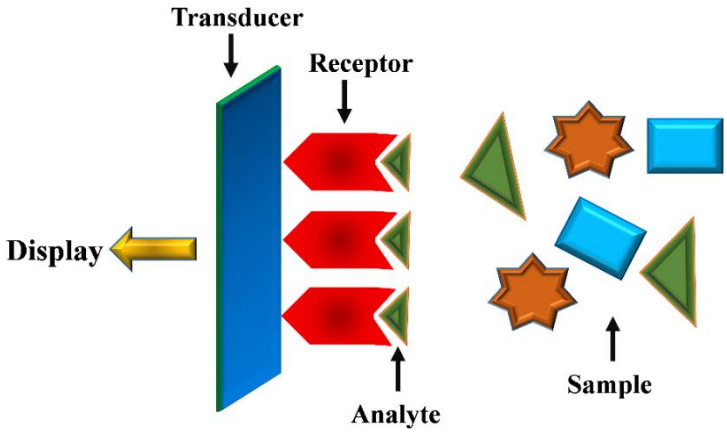

Figure 1.1 An illustration of the various sensor components schematically (where dark blue color = Transducer, Red color = Receptor, Green color = Analyte, Mixture of Brown-Blue-green colors = Sample)

1.2.1 Receptor

The receptor is a component of a sensor that physically interacts with the analyte. The receptor and analyte interact differently depending on the sensor (Figure 1.1). The receptor-sensitive recognition element is a crucial component of the sensor. The type of receptor is the primary distinction between biological and chemical sensors. In the first instance, it is a biomaterial, and in the second instance, it is a chemical compound or a set of chemical compounds that interact with an analyte in a certain way [Kozitsina et al., 2018].

1.2.2 Transducer

A transducer is an electrical tool that transforms one type of energy into another. It is the second component shared by all the sensors. The transducer takes the chemical information of the interaction between the receptor and analyte and transforms it into equivalent electrical information. The process of transforming energy into a signal is known as signalization. Transducers frequently produce electrical or optical signals that are correlated with concentrations of the target analyte. The transducer can be categorized as optical, electrochemical, thermal, electrical, and gravimetric according to its mode of operation.

1.3 Types of Sensors

There are various types of sensors, like chemical, electrical, electrochemical, optical, thermal, pressure, etc. Among these, electrochemical and optical sensors got much more attention for detecting foreign species.

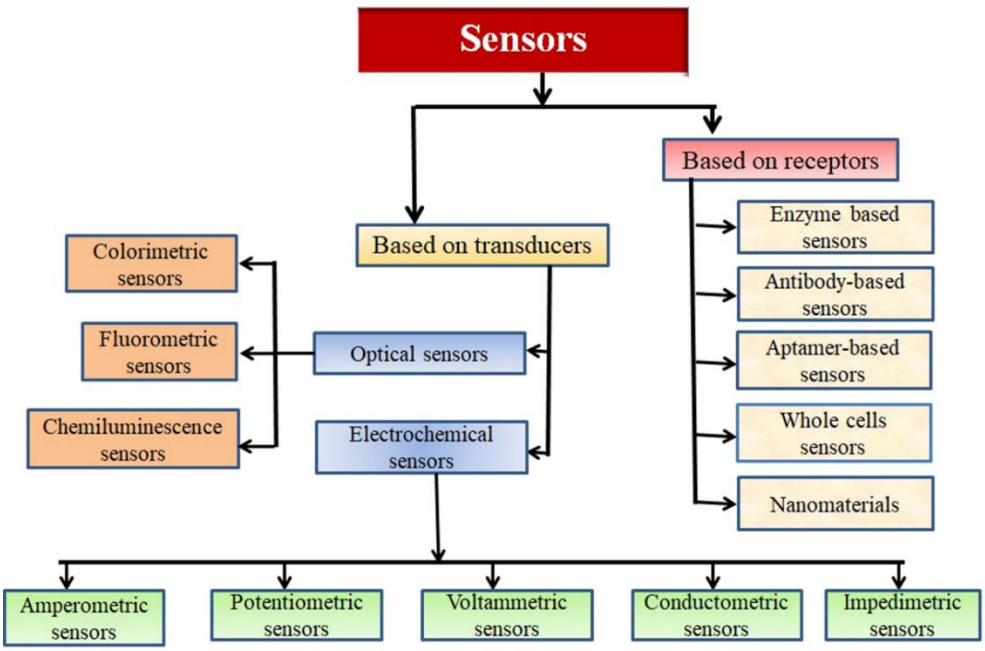

Figure 1.2 Classification of optical and electrochemical sensors based on transducer and receptor

1.3.1 Based on Transducers

On the basis of the transducer, sensors can be broadly divided into electrochemical and optical sensors. Due to their greater sensitivity and selectivity with compact size for portable applications, sensors are currently one of the most active research domains.

1..3.1.1 Electrochemical sensor

Electrochemical sensors are a subset of chemical sensors that are less expensive than sophisticated analytical tools, can be made from various nanomaterials that are electroactive, and can be utilized for real-time monitoring in a variety of media. Electrochemical sensors convert information related to electrochemical reactions (reactions between electrodes and analytes) into suitable qualitative or quantitative signals [Shetti et al., 2019]. In these sensors, an electrode acts as a transducer element in the presence of an analyte. After contacting analytes with an electrode's sensing surface, electrochemical transducers analyze the electrochemical signal [Collings et al., 1997]. The electrochemical sensing method can be used in a wide range of analyte concentrations and is reliable, easy to use, repeatable, extremely sensitive, and selective. The electrical changes could be potentiometric (measured as a difference in voltage between the reference electrodes and the indicator), conductometric (change in the sensing material's tendency to conduct the charge), or amperometric (a current change measured at applied voltage). Most commercially available sensors for clinical diagnostics use the amperometric electrochemical technique. This sensor is able to detect various biomolecules such as glucose, uric acid, cholesterol, etc.

1.3.1.2 Optical sensors

Over the past three decades, the study of optical sensors has become a more active topic. Optical sensors detect light in a specific range of the electromagnetic spectrum (ultraviolet,

visible, and infrared) and convert it to an electric signal *via* the photoelectric effect [Tshabalala et al., 2020]. The basic principle of the optical sensor is to produce optical signals as per analyte concentration and provides real-time detection. The optical sensor-based devices are based on internal reflectance and surface plasmon resonance principles. Through planar waveguides or optical fibers, light that enters an optical device is refracted and directed toward a sensor surface. A detector, or photodiode, measures the intensity of the light that is reflected. Fluorescence, absorbance, surface plasmon resonance, and chemiluminescence are among the most frequently recorded optical signals. The optical signals are obtained as a result of the interaction of the receptor with target analytes. In optical sensors, the transducer detects changes in absorption, reflection, transmission, and refraction that result from chemical or physical changes caused by an analyte recognition event in the receptor. According to the underlying concepts, the optical sensor can be categorized as both a label-free and label-based approach. The analyte and receptor directly interact in the case of the label-free colorimetric method. On the other hand, the label-based method is indirect and relies on luminescent, fluorescent, or colorimetric technologies to provide the signal. Due to their higher sensitivity, cost-effectiveness, small size, and ease of use, optical sensors are preferable to traditional analytical approaches [Sant et al., 2003; Luo et al., 2004]. Optical sensors are working in a variety of fields, including biomedical research, pharmaceutical development, environmental monitoring, healthcare, homeland security, and military operations [Luo et al., 2004]. Here we are discussing three types of optical sensors as;

1.3.1.2.1 Colorimetric sensor

In recent years, colorimetric analysis has grown in significance to enhance the operationalization of plasmonic-based sensors. Optical sensors in the colorimetric sensor class alter their color in response to environmental stimuli. Any modification to the physical

or chemical surroundings qualifies as such a stimulus. On the basis of the interaction of molecules, Colorimetric sensors are classified as biosensors and chemical sensors, respectively [Piriya et al., 2017]. As a result of the colorimetric sensing offered by metal nanoparticles and the special features of nanomaterials, numerous plasmonics applications have been developed.

Since colorimetric sensors are simple to make, quick to detect, have great sensitivity and selectivity, and are simple for the human eye to notice, they have a bright future in the detection of metallic cations, anions, organic dyes, medicines, pesticides, and other harmful contaminants. This sensing technique has been widely used in glucose, H_2O_2, metal ions, and biomolecule sensing using a chromogenic substrate (Figure 1.3). The Peroxidase-like activity of the material (F-MoS_2-FePt NCs) gives oxidation of the TMB substrate in the presence of H_2O_2 and produces blue color contrast [Hu et al., 2019].

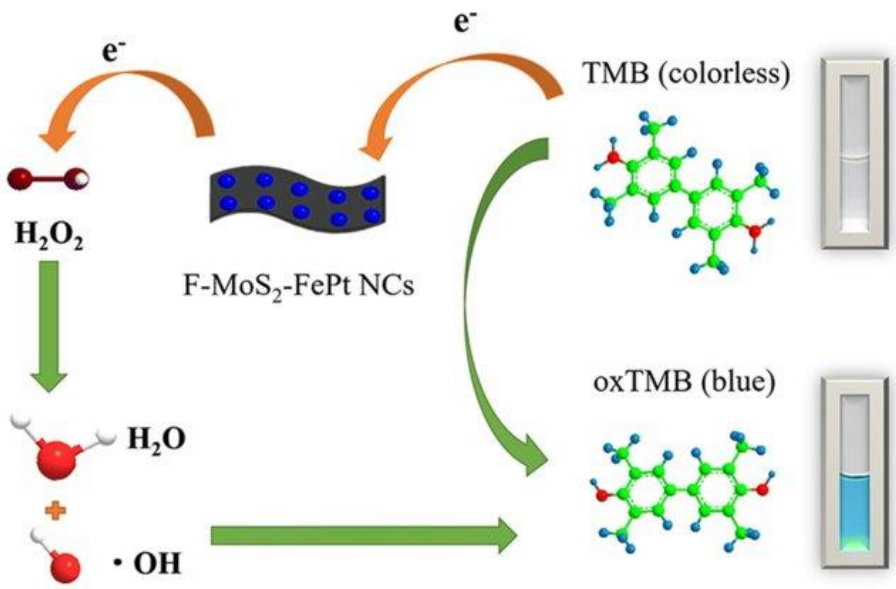

Figure 1.3 Colorimetric sensing (where ·OH = Hydroxyl radical, H_2O = water, H_2O_2 = Hydrogen peroxide, e^- = electron, TMB = Tetramethylbenzidine, oxTMB = Oxidised Tetramethylbenzidine, F-MoS_2-FePt NCs = FePt-loaded few-layer MoS_2 nanosheets nanocomposites) [Hu et al., 2019]

1.3.1.2.2 Chemiluminescence sensor

Chemiluminescence (CL) is a type of luminescence phenomenon in which the emission of light is caused by a chemical reaction (exothermic), which results in an electronically excited intermediate gets decays to the ground state. The chemiluminescence process differs from Fluorescence or Phosphorescence in terms of an excited state that is the result of a chemical reaction rather than that of the absorption of a photon (Figure 1.4).

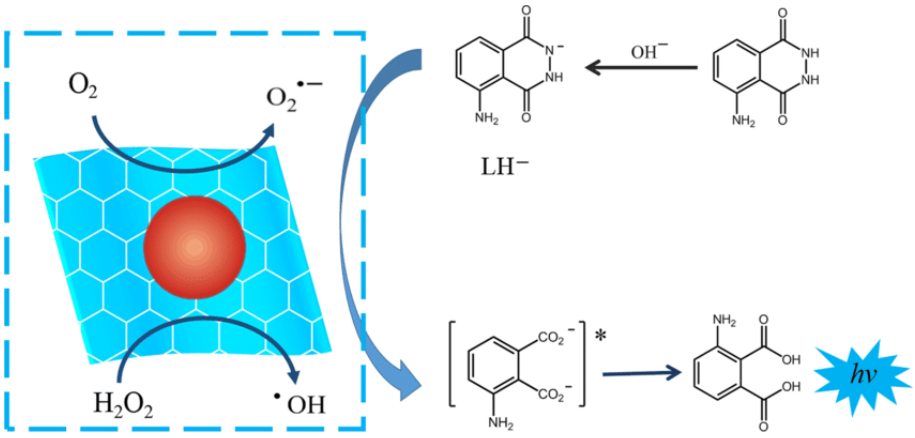

Figure 1.4 Chemiluminescence mechanism for luminol-H_2O_2 system [Shi et al., 2019]

Chemiluminescence in an aqueous system is mainly governed by redox reactions. This is an antipode of a photochemical reaction. CL reaction is of two types, the first one is direct, and the second one is an indirect process. In the direct process, the excited state intermediate acts as a luminophore and emits light. In an indirect process, a species transfers its electron to an acceptor that is a luminophore when it deactivates to the ground energy state. The CL reaction can be categorized according to the type of luminescent material as Luminol (5-amino-2,3-dihydro-1,4-phthalazinedione), Peroxyoxalate, Acridinium ester, $KMnO_4$, etc. The beauty of this luminescence phenomenon is that it has been widely applied to the field of pharmaceutical, forensic science, and research area related to biological assay. It is a putative sensing technique for a variety of biological assays that offers benefits, including

high sensitivity, selectivity, inexpensive apparatus, and simple operation. To further improve the sensitivity and stability of the CL intensity in various sensor fabrication, some substances are introduced, such as enhancers and catalysts (e.g., nanomaterials) that enhance and catalyze the CL reaction. The mechanism for chemiluminescence reaction in the presence of luminol has been demonstrated in Figure 1.4.

Luminol (chemiluminescent substrate), in the presence of a base, produces anionic luminol (dianion) whose acidic proton is abstracted and tautomerizes to form a stable luminol substrate. This stable luminol liberated $N_{2,}$ and the formation of unstable 3-APA (3-aminophthalamine) takes place. This unstable 3-APA on releasing of the photon emitted blue colored light having a wavelength peak at 425 nm.

1.3.1.2.3 Fluorescence sensor

Fluorescence-based sensors have made significant advancements over the past few decades, which have substantially impacted chemical and biological sensing [Shin et al., 2021]. Fluorescence is the phenomenon in which an excited molecule relaxes to a lower energy state via the emission of a photon. Fluorescent sensors are well-known to mostly sense metal ions and biomolecules through fluorescence signal changes. These chemo sensors or probes can change fluorescence intensity or color upon interaction with selective ions. The sensitivity, selectivity, and a number of other properties of the fluorescence sensing system may be improved with the right choice of excitation light. Fluorescence-based sensors have shown excellent potential for gathering crucial requirements for easy, quick, and precise testing in remote locations with limited resources. It involves a fluorescence probe, metal ions, or fluorescent protein. This sensor is utilized in the field of biochemical detection, water quality monitoring, and biomedical sensing to detect

contaminant levels in the environment and detection of biomolecules and ions [Shin et al., 2021].

1.3.2 Based on receptor

Based on the types of receptors employed and the types of interactions taking place, sensors can be divided into various groups. According to the bio-recognition principle, there are two types of biosensors: affinity and catalytic biosensors. When analyte and receptor interact to create a new product in a catalytic biosensor, receptor moieties are modified with enzymes, tissues, microbes, and whole cells, whereas in an affinity biosensor, the receptors are modified with cell receptors, antibodies, and nucleic acids.

1.3.2.1 Enzyme as receptor

Enzymes are biocatalysts that accelerate reactions. They are composed of proteins and exhibit strong catalytic activity as well as substrate/analyte selectivity [Guilbault, 1976]. The binding and catalytic properties of the enzymes toward the target analyte to be detected are what determine how the enzyme-based sensor functions [Morrison et al., 2007].

1.3.2.2 Antibody as receptor

The protein molecules known as antibodies are employed to create biosensors because they have particular binding properties to certain antigens. They frequently interact physically and covalently to become immobilized on the transducer surface. Amino, carboxyl, or aldehyde group conjugation is a typical covalent connection.

1.3.2.3 Aptamer as receptor

Short single-stranded nucleic acids (15-80 nucleotides) are known as aptamers. In the laboratory, they are synthesized as DNA or RNA sequences, and they attach only to the target molecules. Due to less spatial blockage and higher surface densities, aptamers' ability

to fold into two- and three-dimensional structures results in improved binding sites. The nucleic acid nature of aptamers makes them more stable than antibodies throughout a wide range of storage and temperature conditions [Dhiman et al., 2017]. Additionally, aptamers can be altered to encounter the needs of the sensor.

1.3.2.4 Whole cells as the receptor

Microbes, including fungi, bacteria, algae, viruses, and protozoa, are used to create whole-cell-based sensors because they have the ability to recognize biological material. These cells self-replicate to produce pure recognition molecules, such as antibodies [Gui et al., 2017]. In comparison to plant or animal cells, whole-cell-based sensors are easier for us to use. Simple interactions between the cells and various analytes can result in quantifiable electrochemical signals.

1.3.2.5 Nanomaterial as receptor

With the development of nanoscience and nanotechnology, nanomaterials introduce a new category of receptors that have received significant attention in the field of sensors. Nanomaterials' high surface-to-volume ratio makes it easier to immobilize analytes in a restricted space. The immobilization of the analytes on the surface of nanomaterials can occur through adsorption, covalent interaction, and entrapment methods. The nanomaterials such as graphene, graphene oxide, carbon nanotubes, gold nanoparticles, silver nanoparticles, quantum dots, and polymer nanoparticles have received the most attention in this area [Holzinger et al., 2014]. Therefore, in some conditions, nanomaterial-modified sensors exhibit high sensitivity because they are similar in size to the analytes of interest (such as biomolecules, antibodies, DNA, pathogen, and metal ions), which makes it feasible to conduct studies that were previously impossible. Additionally, the addition of organic sensors to nanomaterials offers great sensitivity and selectivity for the detection of

target molecules. Examples include G-protein-coupled receptors for dopamine, hormones, trimethylamine, and other substances, as well as nano bioelectronic tongues and nostrils for odorants and tastants, respectively [Kwon et al., 2019].

1.4 Nanomaterial

Nanomaterials can be defined as materials possessing one external dimension quantifying the nano-scaled structure (size range 1-100 nm). These are categorized into different types according to their morphology and size, such as zero, one, two, and three-dimensional nanomaterials (Figure 1.5). Nanomaterials with zero dimensions (0-D) have three dimensions that are all very small or nanoscale. Nanoparticles will fall under this category. One-dimensional nanomaterials (1-D) are materials that only have one dimension that is in the nanoscale range and the other two that are outside of it. This class includes nanowires, nanorods, and nanotubes. Two-dimensional nanomaterials (2-D) are those where any two dimensions fall inside the range of the nanoscale, whereas the last dimension does not. These consist of nanocoatings, nanolayers, and nanofilms. Bulk or three-dimensional nanomaterials are nanomaterials that are not nanoscale in any dimension. This indicates that they are >100 nm scale in all three arbitrary dimensions. Nanocomposites, core shells, multiple nanolayers, bundles of nanowires, and bundles of nanotubes are some examples of 3-D nanomaterials.

The nanoparticles vary in size, shape, and structural features. The shape and structure can be spherical, tubular, hollow core, cylindrical, conical, flat, etc., or irregular, and its size can range from 1 nm to 100 nm. The surface differences may exist, and they may be uniform or asymmetrical. Some nanoparticles are either crystalline or amorphous in nature, having single or several crystal solids that are either loosely dispersed or agglomerated together (Figure 1.6).

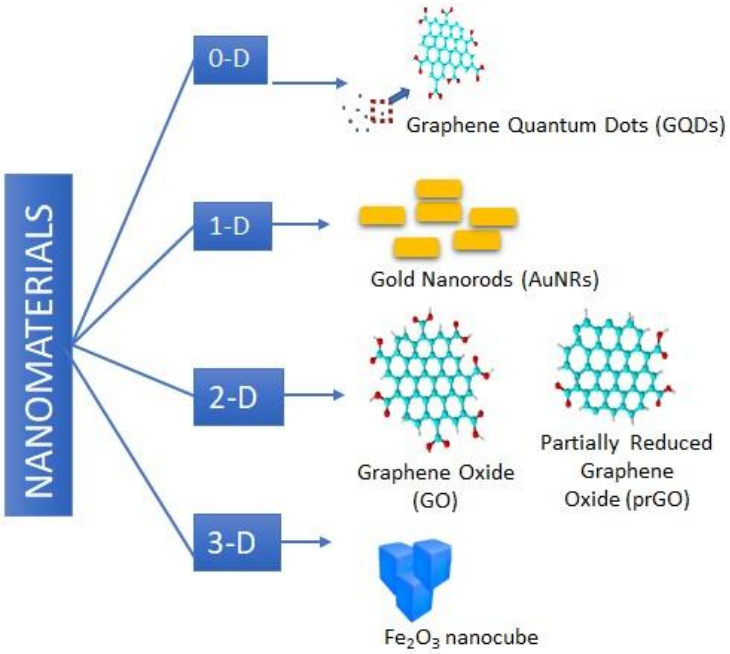

Figure 1.5 Nanomaterial's subdivision on the basis of morphology and size.

These nanomaterials have attracted researchers' attention in various fields because they have a high surface-to-volume ratio, small particle size, and high surface energy. In nanomaterials, size and shape play an important role as optical properties such as absorbance, and refractive index depend on these factors, but in the case of bulk materials, optical properties don't change. The nanomaterials can be broadly classified into two types based on their core source material: (A) metal-based nanomaterials and (B) carbon-based nanomaterials.

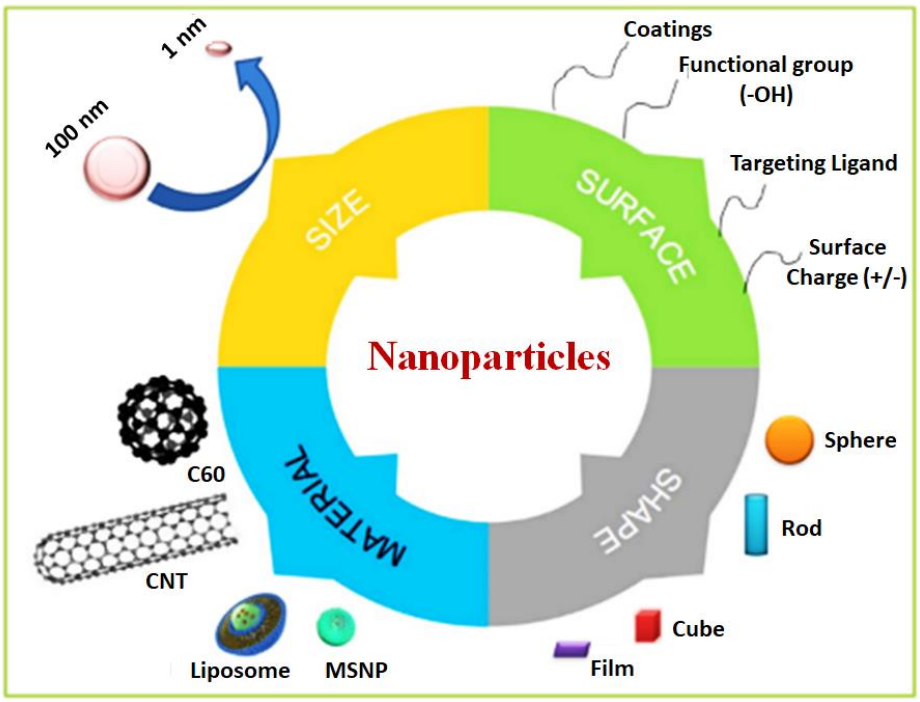

Figure 1.6 The size, shape, material, and surface of the nanoparticles [Chandrakala et al., 2022]

1.4.1 Metal-based nanomaterials

Metal oxide nanoparticles (MONPs) are currently attracting a lot of attention in the research area due to their distinctive properties, such as an increased surface area to volume ratio, high surface energy, and long-lasting surface absorption [Santos et al., 2020]. There are many examples, including Iron oxide nanoparticles, Molybdenum trioxide, cerium oxide, titanium dioxide, zinc oxide nanoparticles, etc. Some experimental methods such as chemical vapor deposition, hydrothermal reaction method, laser ablation, thermal decomposition, sol-gel process, and biological methods can all be used to synthesize these MONPs.

Metal nanoparticles (MNPs) feature a metal center comprised of inorganic metal that is typically encased in an organic, inorganic, or metal oxide-based shell. Due to their peculiar characteristics relative to bulk metal, metal nanoparticles have recently been the subject of

significant research. The distinctive color of metal nanoparticles' is caused by plasmon resonance absorption, which is highly dependent on particle form and interfacial contact [Sandrock et al., 2001]. Due to their vast range of applications in research and engineering, platinum (PtNPs), gold (AuNPs), palladium (PdNPs), and silver nanoparticles (AgNPs) are currently the most often utilized MNPs. According to Saxena et al. (2012), Lu et al. (2008), and Rahban et al. (2010), AgNPs is one of the noble metal nanoparticles due to their broad range of utilizations in antiviral, antibacterial, and anticancer therapies. AuNPs have made major contributions in a number of fields, including catalysis, biosensing, cancer treatment, medicine, electronics, etc. [Farooq et al., 2018; Mobed et al., 2020]. But due to the agglomeration issue, metal nanoparticles are unstable and exist far from the equilibrium state. Apart from these metal nanoparticles, a viable alternative is offered by the new class of 2D materials known as transition metal dichalcogenides (TMDCs), which are semiconductors of the form MX_2 where M is an atom of a transition metal (like Mo or W) and X is an atom of a chalcogen (like S, Se, or Te). MoS_2 is the most studied material in this family due to its robustness. The monolayers of 2D TMDs are kept together by Van der Waals attraction, just like graphite. 2D TMDs are excellent for loading a variety of biomolecules because of their ultrathin structure (0.6-0.7 nm) and high surface-area-to-mass ratio. Bulk TMDs have an indirect gap, but the gap becomes direct in a monolayer state. The unique properties of 2D materials with large surface areas provide some wide-range applications, including innovative nanoelectromechanical systems, flexible electronics, energy storage, chemical sensors, optoelectronics, etc. The metal-doped 2D nanomaterials (for example iron doped MoS_2) have also found excellent applications in several fields due to their incredible catalytic performances and large surface area [Shu et al., 2015].

1.4.2 Carbon nanomaterials

Now, there are several carbon-based nanomaterials have been figured out, such as fullerene, carbon nanotubes (CNTs), graphene, graphite, and graphene oxide. These are showing greater possibilities in the diversification of applications such as biosensing, electronics, optics, and biomedicine. Carbon-based materials currently exhibit a wide range of properties due to the manifestation of various allotropes and nanostructures, as illustrated in Figure 1.7.

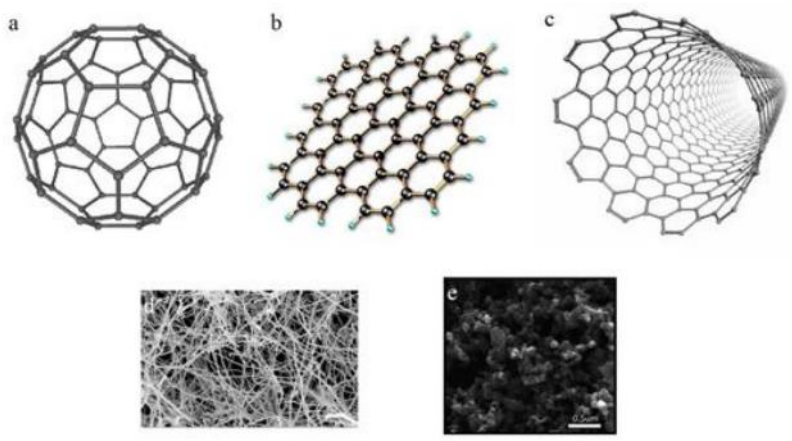

Figure 1.7 Structure of various Carbon nanoparticles (a) fullerenes molecule, (b) graphene sheet, (c) carbon nanotubes, (d) carbon nanofibers, and (e) carbon black nanomaterials. [Ealias et al., 2017]

Fullerenes (C60), a spherical carbon molecule held together by sp^2 hybridization, are composed of carbon atoms (Figure 1.7). The spherical structure of a fullerene is made up of between 28 to 1500 carbon atoms [Ramsden et al., 2011]. Graphene is a 2D material that is regarded as the fundamental building block and bears 1 nm of the thickness of the graphene sheet. Carbon exists in several allotropes, including graphene. Carbon atoms are organized into a hexagonal honeycomb lattice in a two-dimensional planar surface to form graphene [Martín et al., 2014; Zhu et al., 2010]. High surface area, outstanding thermal

conductivity, robust tensile strength, and quick electron transport are only a few of the distinctive physicochemical characteristics of graphene [Chakraborty et al., 2018]. Carbon atoms are coiled into hollow cylinders on a graphene nanofoil to produce Carbon Nano Tubes (CNT). Nanotube lengths range from a few micrometers to several millimeters. Carbon nanotubes (CNTs) are hollow tubes made of rolled-up graphene sheets. There are several varieties of CNTs, such as single-walled (SWCNT), double-walled (DWCNT), and multi-walled (MWCNT), all of which have varied thicknesses and metallic/semiconducting characteristics [Jacobs et al., 2011]. Carbon nanofiber (CNFs) is made from the same graphene nanofoils as CNT, but it is twisted into a cone- or cup-shaped structure rather than a standard cylindrical tube. Many metals can be employed as catalysts to produce CNFs in a reasonable amount of time, whether in powdered or supported form. Other catalyst arrangements, such as gauzes, foils, wires, or supported metal particles, are just as effective for the formation of CNFs as powdered metals. CNFs are promising materials that find application in several disciplines, including photocatalysis, sensors, energy devices, nanocomposites, tissue engineering, filtration, and drug delivery [Mohamed, 2019]. Biochar and biomass can be physically, chemically, physiochemically, and microwave-assisted activated to generate activated carbon. Heat and gas (such as steam, CO_2, N_2, or a mixture) are used in physical activation, while chemicals (such as acids, bases, metal oxides, and alkaline metals) are used in chemical activation, heat and chemical are used in physiochemical activation, and microwave radiation is used in microwave-assisted activation [Heidarinejad et al., 2020]. The activation is dependent on the precursor's characteristics, retention duration, impregnation ratio, method configuration, activation period, and chemical constituents. In order to eliminate volatile, non-carbon species like nitrogen, oxygen, and hydrogen and to increase the fixed carbon content to create biochar, raw materials are thermally decomposed in a furnace with N_2 purge in an inert environment.

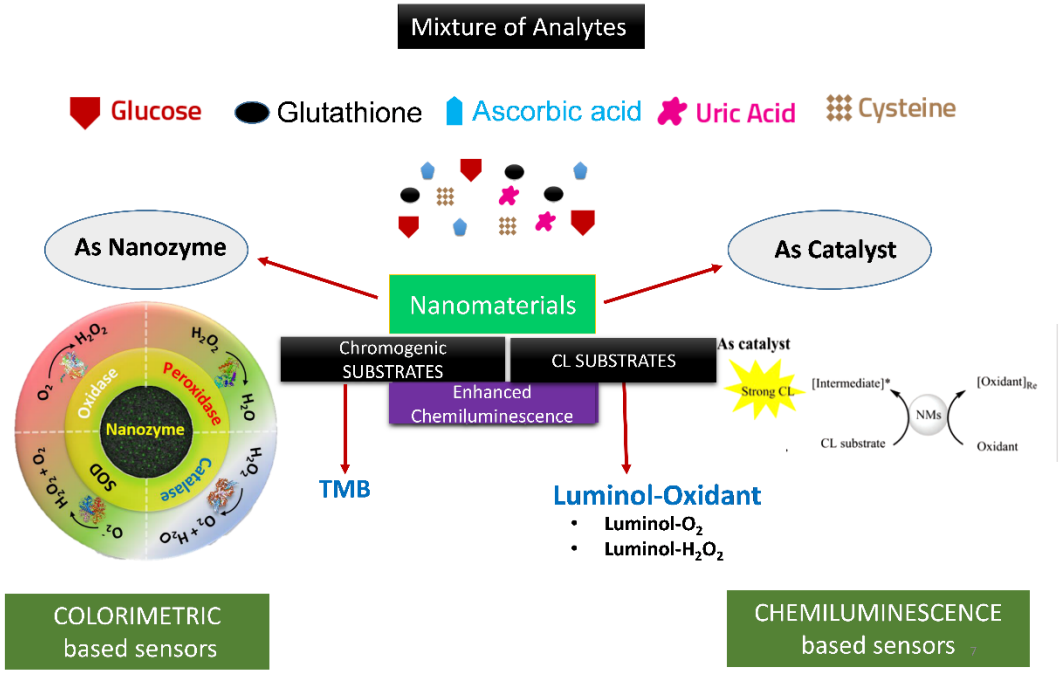

Figure 1.8 Role of nanomaterials for sensing biomolecules through colorimetric and chemiluminescence techniques.

Figure 1.8 illustrate that nanomaterials in colorimetric and chemiluminescence sensing have played an important role in the assay of various analytes. Generally, in colorimetric sensing, it is used as a nanozyme, and in chemiluminescence sensing as a catalyst.

1.5 Nanozyme (Artificial Enzyme) in Colorimetric Sensing

Ronald Breslow coined the term “artificial enzymes” for the first time to describe enzyme mimics [Breslow et al., 1970]. With the aim of replicating the principles of natural enzymes using different materials, these materials introduce a new area of biomimetic chemistry that is inspired by nature. Horseradish peroxidase (HRP) is a naturally occurring enzyme that functions as a biocatalyst and accelerates the rate of biochemical reactions to mediate many biological activities in living organisms. Natural enzymes have numerous uses in the food business, the manufacturing of agrochemicals, sensors, and pharmaceutical processes [Pang et al., 2009; Wulff et al., 2002]. These are often utilized in biocatalysis, biosensing,

and bio electrosynthesis due to their strong biocatalytic activity and specificity. The inherent limitations of natural enzymes include limited operational stability, difficulty in purification, high production costs, and sensitivity to environmental factors [Ellis et al., 2009].

Therefore, it is essential to fabricate artificial enzymes in the field of sensors in order to overcome the aforementioned limitations [Wei et al., 2008]. The figure displays a quick timeline for the recent decades' development and expansion of artificial enzymes (Figure 1.9).

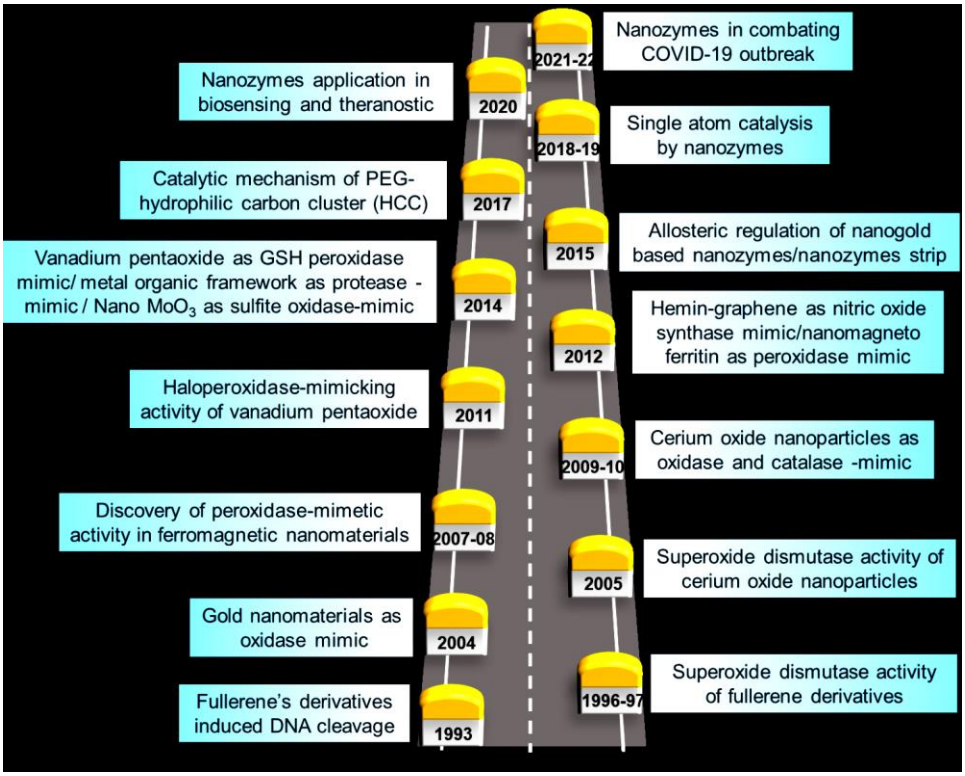

Figure 1.9 A brief timeline for sequential development of nanozyme [Singh et al., 2022]

With the technological advancement of nanoscience and nanotechnology, the development of novel functional nanomaterials and metal-organic frameworks with inherent catalytic capabilities and Enzyme mimicking behaviour has recently gained significant attention. Artificial enzymes are now widely used in colorimetric sensor applications as a highly

stable, sensitive, and affordable substitute for natural enzymes after much research over the past 20 years.

Nanozymes are nanomaterials or nanocomposites that act as a natural enzyme-like activity. Nanocomposites are formed of two or more components with distinctly dissimilar physical and chemical characteristics. When the two separate nanoscale materials are combined, new materials are created that have properties that are distinct from those of the original materials. Nanocomposites also play a revolutionary role in the creation of sensing platforms. Due to their greatly improved conductivity and effective catalytic activity, noble metal nanoparticle-adorned inorganic two-dimensional nanomaterials have received a lot of interest recently in the development of extremely sensitive and selective sensors. These nanocomposites have stronger electrochemical, optical, and catalytic capabilities than nanomaterials alone, making them a promising candidate for use in the sensor industry. Graphene, reduced graphene oxide, tungsten disulfide, and molybdenum disulfide was used to decorate transition metal dichalcogenides (TMDCs) and carbon-based 2D nanomaterials, which led to improvements in sensitivity, catalytic activity, and surface-enhanced Raman scattering (SERS) [Cao et al., 2017; Lin et al., 2014].

Further, tremendous progress has been made in the nanozymes field due to their superiority paralleled to natural enzymes, as nanozymes are cost-effective and have high operational stability. A variety of nanozymes have been developed that exhibit better catalytic activity, low cost, and high stability in comparison to natural enzymes (which include their high cost, poor stability, and difficulties in storage). The unanticipated finding of magnetic Fe_3O_4 nanoparticles exhibiting enzyme-like (peroxidase) activity in 2007 led to the development of nanozymes as the subsequent generation of enzyme mimics [Gao et al., 2007].

Over the past five years, considerable development has been made in mimicking novel enzymatic activity in high-performance nanomaterials, modulating nanozyme activity, illuminating catalytic mechanisms, and expanding possible applications. These developments have benefited from rapid advances in nanotechnology, biotechnology, catalytic science, and computer. Hence, artificial enzymes have been used in biosensing, biocatalysis, nanomedicine, tumour treatment, and environmental clean-up and have been found to demonstrate natural enzyme activity.

Currently, noble metal materials such as Pt NPs, Au NPs, and metal oxides such as Fe_3O_4 NPs, V_2O_5 NPs, MnO_2 nanosheets, and Co_3O_4 nanoflowers have been the main focus of research on nanozymes [Liu et al., 2020]. The rapid progress in nanotechnology has explored the various applications of novel nanozymes. Noble metals have played a significant role in the creation of sensing platforms, but their high cost and risk of aggregation prevent them from being stored or used in real-life applications. Studies have demonstrated that there are a lot of materials that could serve as nanozyme with similar functions and structures, such as cyclodextrin, polymers, dendrimers, porphyrins, and metalexes.

We can use the colorimetric technique for sensing biomolecules and heavy metals due to its simple and non-sophisticated instrumentation. The above figure 1.8 depicts how different biomolecules can be detected by using nanomaterials. For this, we have taken a mixture of analytes (Glucose, Glutathione, Ascorbic acid, Uric acid, and Cysteine) and nanomaterial. In colorimetric sensing, nanomaterials are considered nanozyme, and a chromogenic substrate is used to produce color during a reaction. The Michaelis-Menten kinetics used by the nanozyme is comparable to that of natural enzymes. It has been discovered that the pH, temperature, and substrate concentration all have a significant

impact on Nanozyme activity. The reaction extent as a function of time typically dictates the reaction rate [Stasyuk et al., 2020].

For colorimetric sensing, there is an important role of the chromogenic substrate (Tetramethylbenzidine (TMB), (ABTS)) that produce color on reaction. TMB (3,3',5,5'-Tetramethylbenzidiene) and ABTS (2,2' Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) are universal chromogenic substrates that work in acidic conditions. TMB is ubiquitous in comparison to other chromogenic substrates because it is used as a staining agent in immunohistochemistry and a visualizing reagent in enzyme-linked immunosorbent assay (ELISA). TMB is oxidized by nanomaterials-based nanozymes in the presence of the electron acceptors O_2 or H_2O_2 to produce the oxidized blue result (Figure 1.3). When H_2O_2 serves as the electron acceptor, the nanozymes are known as peroxidase, and when oxygen serves as the electron acceptor, they are known as an oxidase [Priya et al., 2021]. So, TMB in the presence of nanozyme and dissolved oxygen show oxidase-like activity. Further, TMB will be converted into cationic radical (oxidized TMB). The charge transfer phenomenon occurs between oxidized and unoxidized TMB resulting in a blue-colored product and showing an absorbance peak at 652 nm. Here, un-oxidized TMB acts like electron donors, and oxidized TMB behaves like electron acceptor moiety in these charge transfer (CT) phenomena. On addition of stop solution (H_2SO_4) in this CT complex produced a yellow-colored product having an absorbance peak at 450 nm (Figure 1.10).

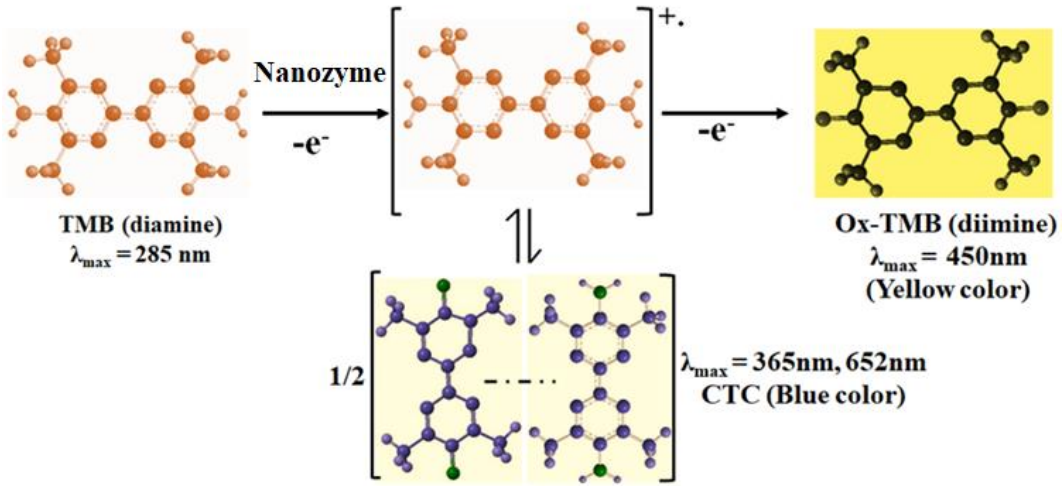

Figure 1.10 Mechanism of colorimetric sensing based on TMB as a chromogenic substrate [Verma et al., 2022]

2D nanocomposites and carbon nanomaterials are also showing nanozyme activity. Nanozyme can sense biomolecules, pesticides, heavy metals, and antibiotics and can treat organic pollutants, antimicrobials, chemical warfare agents, and textile dyes. Nanozyme is mainly subdivided into four types: Peroxidase, Oxidase, Catalase, and Superoxide dismutase.

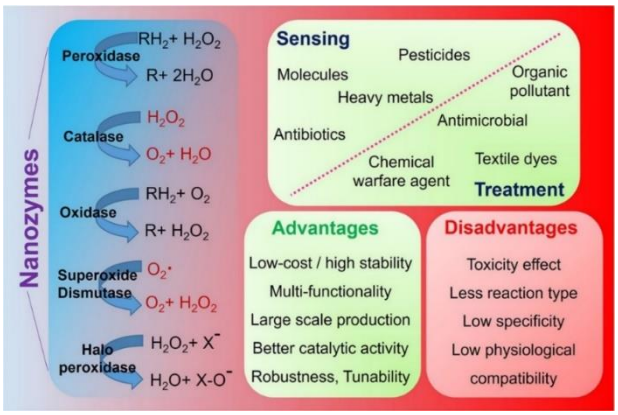

Figure 1.11 Types of Nanozymes [Singh et al., 2022]

1.5.1 Peroxidase

Peroxidase is an enzyme that is present in a wide range of species, including bacteria, plants, and people. It breaks down hydrogen peroxide (H_2O_2). H_2O_2 is one of the poisons generated when oxygen is used for breathing. The first peroxidase nanozyme was used as Fe_3O_4. This material can generate $OH^{\bullet}$ as an intermediate, showing the similarity to peroxidase. The inherent peroxidase-mimicking ability of Magnetic Nanoparticles (MNPs) was first discovered by the Yan group in 2007. These MNPs use H_2O_2 to convert three colorless peroxidase substrates, TMB, o-phenylenediamine, and diazoaminobenzene, into the resultant colored product. The catalytic mechanism for nanozyme has been demonstrated by kinetic studies, in addition, to measure the Michaelis-Menten constants that show greater affinity for TMB than horseradish peroxidase (HRP), but a lower affinity for H_2O_2 [Vinita et al., 2018]. Wei and Wang then used Fe_3O_4-MNP-based peroxidase mimetics to detect glucose and H_2O_2 [Wei et al., 2008]. As a result of pioneering work, iron oxide-based peroxidase mimics, including Fe_3O_4 (magnetite), Fe_2O_3 (hematite), and doped ferrites, have been extensively studied and analyzed. A number of precious metal nanoparticles, including Au, Ag, Pt, Pd, and their polymetallic NPs, are identified as peroxidase enzyme mimics and have been broadly utilized in sensors, antibiotics, and therapeutic procedures. For example, Pd-Ir NPs with excellent peroxidase-like activity were prepared by Xia, Nie, and colleagues [Xia et al., 2015]. The catalytic activity was about 28 times greater than HRPs. Using Pd-Ir nanozymes, they further developed an enzyme-linked immunosorbent test (ELISA) to find disease biomarkers [Xia et al., 2015]. Further, carbon has been another popular nanomaterial used as a peroxidase mimetic. In 2010, peroxidase-like activity was shown by both graphene oxide and SWCNT. These results prompted investigation of other carbon-based peroxidase mimetics, including Fe/N-doped carbon, carbon dots, carbon nitride, and others. Compared to large graphene oxides,

graphene quantum dots (GQDs) exhibit enhanced peroxidase-like activity. Wound disinfection was accomplished with GQDs because $OH^{\bullet}$ was produced during the catalytic reaction that mimicked peroxidase [Nirala et al., 2015].

1.5.2 Oxidase mimics

Natural oxidases are enzymes that use molecular oxygen (or other oxidants) to catalyze the substrates and generate oxidation products and $H_2O/H_2O_2/O_2^{\bullet}$. In the past, some works have been reported on nanomaterials to mimic oxidases. [Hayat et al., 2015]. The recent development of oxidase mimetics, in particular, the investigation of additional different oxidase substrates (i.e., TMB and ABTS) beyond the model substrates, is mentioned here. Metallic nanoparticles were commonly used for catalytic processes, but the finding of carbon-supported gold with glucose oxidase (GOx) mimetic activity is surprising. For the AuNP-based oxidase mimetics, additional kinetics data pointed to an Eley-Rideal mechanism. In order to produce negative gold species, hydrated glucose anions were first adsorbed onto the gold surface. A dioxogold intermediate would then be produced when the negative gold species nucleophilically attacked dissolved oxygen, H_2O_2, and gluconic acids were eventually generated. The rate-limiting stage involves glucose oxidation with the aid of oxygen from the liquid segment, which may involve two electron transfers from glucose to oxygen [Beltrame et al., 2006].

Carbon materials also have excellent candidacy to mimic the oxidase properties, for example, Fe/N-doped porous carbon-800 hybrid [Ding et al., 2021], 2D carbon fabricated via water hyacinth [Verma et al., 2022], etc.

1.5.3 Catalase mimics

In order to convert H_2O_2 into water and oxygen, the catalase enzyme could do so effectively. Catalase enzymes can protect living cells from oxidative damage. So it is

important to synthesize the catalase nanozyme, and catalase-like activities were seen in a variety of nanomaterials, including metals, metal oxides, and Prussian Blue (PB) [Nicolini et al., 2015] [Kim et al., 2017].

1.5.4 Superoxide dismutase mimics (SOD)

Superoxide dismutase mimics (SOD) is an enzyme that consecutively catalyzes the dismutation of the superoxide radical into ordinary molecular oxygen (O_2) and hydrogen peroxide (H_2O_2). It regulates the levels of reactive oxygen species (ROS), as we know that the misregulation of ROS can deface biological arrangements through oxidation. So the monitoring of ROS is necessary and can be done by SOD; for example, one of the ROS, the superoxide anion $O_2^{\bullet-}$, is naturally scavenged by SOD through the disproportionation of O_2 to H_2O_2 and $O_2^{\bullet-}$. Various nanomaterials have been employed to imitate SOD to get rid of the limitations of natural SOD due to their expensiveness. Some examples are carbon, cerium, melanin-based, etc. [Haberle et al., 2010].

1.6 Enhanced Chemiluminescence Sensing

In simple words, enhanced chemiluminescence sensing is a technique that is used to enhance CL signal intensity and stability. To achieve these features, some specific compounds are introduced to the CL system called chemiluminescence enhancers or activators. These enhancers facilitate the generation of reactive oxygen species (ROS) that are essential to produce CL signals in chemiluminescence-based sensing. For example, in the luminol-O_2 CL system, $^{\bullet}OH$, $O_2^{\bullet-}$, $^1O_2$ are ROS that is generated in situ depending upon the nature of the luminol-oxidant (L-H_2O_2, L-O_2) system and metal enhancer (Fe^{3+}, Co^{2+}, Cu^{2+}, Au^{3+}, etc.) as well as catalysts. Recently, some nanomaterials, such as metal NPs [Lei et al., 2011], metal nanoclusters (NCs) [Sheng et al., 2017], QDs [Zong et al., 2018], metal-organic frameworks (MOFs) [Zhu et al., 2015], layered nanomaterials, etc. have been

utilized as participants to enhance the CL signal intensity and stability. Mechanistically, these nanomaterials in the CL system act as catalysts (called Nanozymes), an emitter, energy donors, and reductants, as shown in figure 1.12.

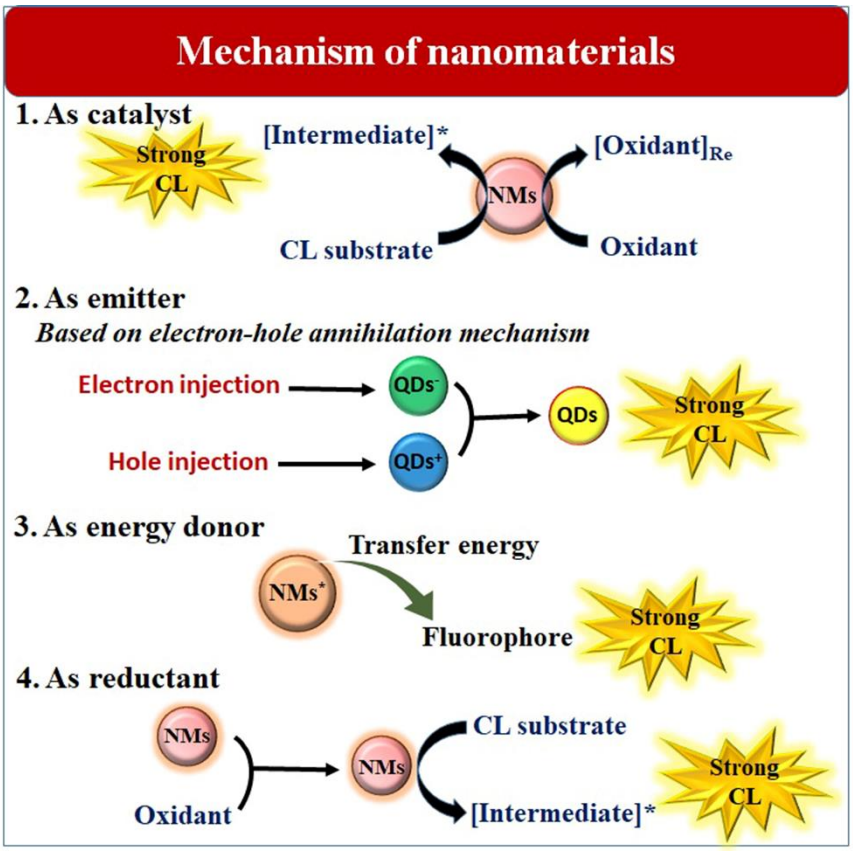

Figure 1.12 Behaviour of nanomaterials in the CL system (where CL= Chemiluminescence)

The CL enhancement was confirmed for the first time in the presence of an anthracene derivative to study ascorbic acid and hemoglobin-dependent brain chemiluminescence [Romodin, 2022]. The enhancement of chemiluminescence by using nanomaterials has been studied by various research groups; for example, Li et al. have developed CL enhancement of Luminol-H_2O_2 system [Li et al., 2011] in assaying of human α-thrombin using CeO_2 nanoparticles. Wei et al. have found CL enhancement by ZnO nanoparticles [Li et al., 2009], Chen et al. reported that CuO nanoparticles could be used to detect cholesterol and glucose [Hong et al.,2013; Chen et al., 2012]. In other cases, researchers have done

noticeable works around catalyzed CL systems by using noble metal nanoparticles, such as Au, Pt, and Ag nanoparticles, that improve the inherent sensitivity performance and selectivity of traditional CL systems [Xu et al., 2007].

Now, in the conventional CL system, there is a change in the color intensity of light, so we can easily visualize the image just by using simple image-j software that is readily available to everyone. So it is easy to determine the level of biomolecule quantitatively through this technique. This technique is not limited to specific biomolecules, and it finds several applications in cancer biomarkers, proteins, heavy metals detection, etc.

There are various chemiluminescence reagents used in the sensing field, are luminol, lucigenin, peroxyoxalate, and ultraweak CL system. Among these, luminol (5-amino-2,3-dihydro-1,4-phthalazinedione) is the most common chemiluminescent reagent in various CL-based sensing methods [Zhao et al., 2018; Zhang et al., 2018]. It is a chemiluminescent compound that glows blue when reacted with a suitable oxidant [Mostafa et al., 2020]. In the active form, luminol will give some sort of energy in the form of eCL.

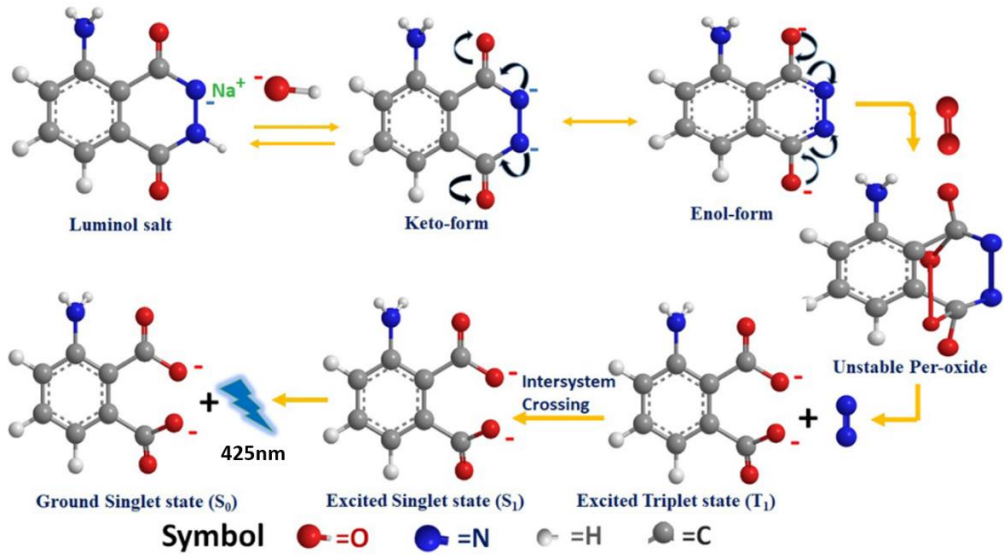

Figure 1.13 A mechanism for the oxidation of luminol in the eCL system [Borrego-Sanchez et al., 2020]

Figure 1.13 elucidate the mechanism involved; the generated superoxide radical's anion ($O_2^{\bullet-}$) attacks the anti-bonding orbital (π^*) of the carbonyl group of luminol dianion (L^{2-}) to produce the high energy key intermediate hydroxy hydroperoxide (LOO-, Chemiluminophore) and N_2 molecules in a concerted mechanism. The resulting active species 3-APA* (3-aminophthalate anion) has energy corresponding to triplet state (T_1) and undergoes two radiations less processes, one is intersystem crossing (ISC), and the other is a spin inversion (SI) and comes to the first excited singlet state (S_1) and then spontaneously deactivates to the electronically ground singlet state (S_0), 3-APA with the illumination of the blue radiation corresponding to wavelength 425nm. The electronic transitions can be demonstrated through the Jablonsky diagram.

The Jablonski diagram is primarily an energy diagram illustrating the electronic states and transitions between the molecules. The Jablonski diagram given below (figure 1.14) shows a pictorial representation of the electronic transition from an electronically excited triplet state (3-APA*, T_1) to an excited singlet state (S_1) via an intersystem crossing and finally to the ground singlet state (S_0).

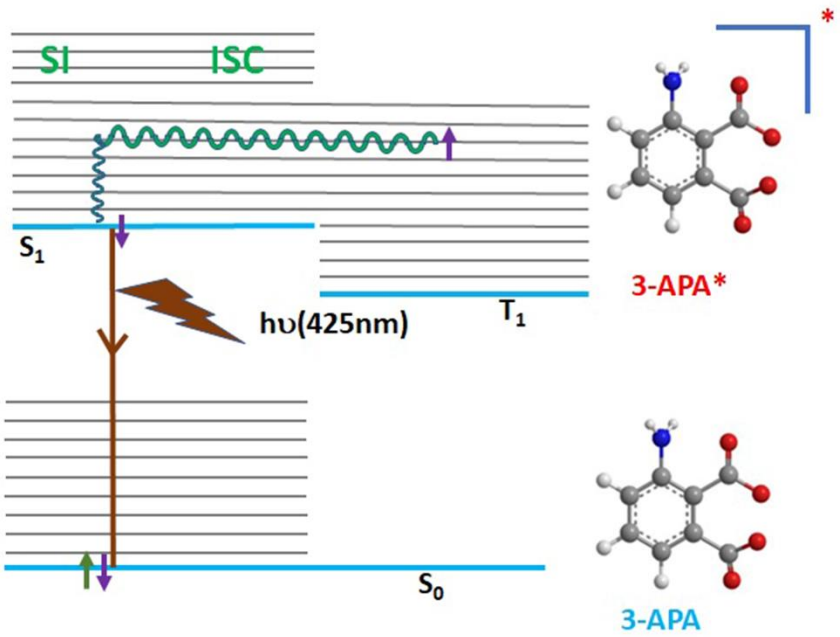

Figure 1.14 Jablonski diagram (where SI = Spin inversion, ISC = Intersystem crossing, S_0 = Ground singlet state, S_1 = Excited singlet state, T_1 = Excited triplet state)

1.6.1 Luminol-Oxidant CL systems

Generally, under alkaline conditions, luminol is oxidized by various oxidants to form an electronically excited-state 3-aminophthalate anion (3-APA*). It emits blue radiation at 425nm when it deactivates to the electronic ground state. Hence depending on the oxidants involved in the CL system, there are various luminol-oxidant CL reactions that are used in the sensing field, for example, luminol–H_2O_2, luminol–$KMnO_4$, luminol–KIO_4, luminol–$K_3Fe(CN)_3$, luminol–O_2 CL reactions [Wang et al., 2020]. In the case of H_2O_2 as an oxidant, the CL system is a luminol H_2O_2 system; the ROS are $O_2^{\bullet-}$, $^1O_2$, and $^{\bullet}OH$, depending upon various kinds of nanomaterials used in the CL system. The generalized reaction involved in this system is illustrated here.

$H_2O_2 + OH^- \longrightarrow HO_2^- + H_2O$

$LH + OH^- \longrightarrow L^- + H_2O$

$H_2O_2 + NMs \longrightarrow 2^{\bullet}OH$

$^{\bullet}OH + HO_2^- \longrightarrow O_2^{\bullet-}$

$^{\bullet}OH + L^- \longrightarrow L^{\bullet-}$

$O_2^{\bullet-} + L^{\bullet-} \longrightarrow 3\text{-}APA^* + N_2 \longrightarrow 3\text{-}APA + h\nu$

Where LH, L^-, $L^{\bullet-}$ corresponds to luminol, luminol anion, and luminol radical. And 3-APA^* and 3-APA are electronically excited-state 3-aminophthalate anion and ground-state 3-aminophthalate anion, respectively.

The luminol H_2O_2 system, used to assay peroxidase, still demonstrates a crucial role in contemporary chemical analysis. For example, the luminol-H_2O_2-CL reaction has enhanced the CL signal by AuNPs of different sizes, according to a study by Zhang's group in 2005 [Zhang et al., 2005]. As more hydroperoxide radicals are adsorbed by aggregated gold nanoparticles, the CL reaction is catalyzed. As a result, reaction rates accelerate, and more aminophthalate ions are produced, which enhances chemiluminescence.

In the case of the luminol-O_2 system, O_2 acts as an oxidant, and the ROS are $O_2^{\bullet-}$, $^1O_2$, and $^{\bullet}OH$. The formation of oxygen-related free radicals is catalyzed by nanomaterials. The general equation for this system is given below.

$O_2 + NMs \longrightarrow O_2^{\bullet-}$

$O_2^{\bullet-} + O_2^{\bullet-} + 2\ H_2O \longrightarrow {}^1O_2 + H_2O_2 + 2\ OH^-$

$H_2O_2 \longrightarrow {}^{\bullet}OH + O_2^{\bullet-}$ or $H_2O_2 + NMs \longrightarrow {}^{\bullet}OH$

$O_2^{\bullet-} + {}^1O_2 + {}^{\bullet}OH + L \longrightarrow 3\text{-}APA^* + N_2 \longrightarrow 3\text{-}APA + h\nu$

There are some examples of nanomaterials as a catalyst in the luminol-O_2 CL system are MOFs (CoOOH NFs, Co-MOFs) and nanocomposites (Cu/Co nanorods, Prussian blue), which can enhance the CL intensity [Wang et al., 2020].

For demonstrating the experimental part, a black box, black ELISA plate, and smartphone cameras are used to develop the portable system. This method is simple, cost-effective, and rapid. We capture the image inside the black box by focusing smart camera phone. The images we got were analyzed through Image-J-software to get data and draw the corresponding calibration plot.

The colorimetric and chemiluminescence technique, unlike the electrochemical method, does not require sophisticated instrumentation and a skilled hand, thatswhy it is applicable in both urban and remote locations and can be deployable in the field as a portable device sensor.

1.7 Motivation and Objective of the thesis

Sensors can make the world a better place by sustaining medical diagnosis, improving people's health, and safety, and monitoring the environment more effectively. Nanomaterials-based optical sensors help in improving and monitoring diseases and various analytes related to biological functions in the human body. Nanotechnology in the sensing field has played a significant role in fabricating advanced sensors due to its wide surface area, which facilitates functionalization and greater biocompatibility, sensitivity, and also selectivity. Nowadays, because of the distinguished properties of nanomaterials, devices can now be miniaturized in size to develop portable sensors for sensing biomolecules. Many diseases, including diabetes, cancer, and heart disease, can become serious and life-threatening if they are not detected early. For its detection, generally, we need serum from the blood, which is a painful process. So non-invasive techniques may be a breakthrough in the sensing field. Therefore, there is a precarious need for readily deployable, affordable, and reliable sensors that may be utilized to recognize them. Motivated by these, we have introduced colorimetric and chemiluminescence sensors to

quantify the level of biomolecules. A higher level of biomolecules may cause several side effects. Hence monitoring disease is important to maintain our health and the efficacy of our immune system.

Recent research has demonstrated the potential of transition metal and carbon-based nanomaterials, such as graphitic carbon nitride, activated carbon from carbon waste, MoS_2 nanosheet, GNPs, and their composites, for the construction of effective sensors [Kiani et al., 2022]. These materials are used as biomimetic materials due to their novelty of low-cost, non-sophisticated instruments, ease, and simple method. Further, Surface modification in these nanomaterials leads to enhance stability and catalytic activity. On introducing these modified nanomaterials in our optical sensing probe enhances the stability of the signal for up to a longer time. Recently, various sensors are reported on glucose [Vinita et al., 2018], ascorbic acid [Shu et al., 2020], and glutathione [Xianyu et al., 2015] important biomolecules to predict various diseases and their constituents in critical situations. However, they are lacking in instability and reliability of sensors, detection limit, and ease of the device. Hence, we propose cost-effective and stable biomimetic nanomaterials to develop paper-based kits and non-invasive sensors for field deployable purposes in remote areas.

The goal of this research is to synthesize nanomaterials and use them for the sensing application using the colorimetric and chemiluminescence approaches, which are based on a thorough literature review and the background information provided above. As a result, considering these facts and futuristic applications of nanomaterials in bio-mimic and sensors, the major objective of the thesis is:

- Amplified peroxidase mimetic activity by doping iron with transition metal dichalcogenides for the colorimetric detection of glutathione in human serum.

- Synthesis of a new oxidase material by using bio-waste hierarchically porous 2D carbon for the colorimetric detection of ascorbic acid.
- Platinum decorated graphitic carbon nitride with enhanced oxidase activity for the colorimetric detection of ascorbic acid based on the paper strip.
- Non-invasive glucose testing in urine samples based on smartphone cameras using enhanced chemiluminescence imaging.

1.8 Benefits of the proposed materials for sensing applications

To improve the catalytic properties and stability, various functional nanomaterials, such as molybdenum disulfide (MoS_2), graphitic carbon nitride (g-C_3N_4), gold nanoparticles (GNPs) and their composites, have been synthesized with metal nanoparticles. However, these pristine nanomaterials are not showing good catalytic behavior. For many applications, surface modification is essential because, at the nanoscale level, bare nanoparticles have high surface energies that cause limited colloidal stability and, ultimately, aggregation. Nanomaterials can become aggregated and lose some or all of their catalytic activity as a result. Utilizing different coating materials, such as tiny organic molecules, polymers, and inorganic materials, it is possible to ensure the stability of nanomaterials [Singh et al., 2023].

The synthesized materials (Fe-MoS_2, 2D-carbon, Pt-g-C_3N_4, GNPs-PDT nanomaterials) exhibit good catalytic activity and enzyme mimic, making them appropriate for the colorimetric detection of several biomolecules (glucose, glutathione, ascorbic acid). We can develop a portable test kit to identify the presence of specific biomolecules in bodily fluids, including blood serum, urine, and tears, due to the stability of these nanomaterials in extreme situations like high or low pH and temperature. Also, with the introduction of nanotechnology, sensing is entering a new age for developing improved sensors that can

detect low-level concentrations of analytes utilizing a portable sensor device, which was previously difficult to do. Since nanoparticles have a large surface area, improved catalytic properties, are simple to functionalize, and have a high degree of selectivity and specificity, they play a crucial role in the development of nanotechnology in the field of sensors.

In this thesis, we are focusing on the concentration of biomolecules (Glutathione, Ascorbic acid, L-cysteine, and Glucose) and their determination in the body, whose discrepancies may cause several health-related problems. Hence, monitoring its level in the body and the real sample is necessary for the proper functioning of the biological processes. For example, antioxidants protect our body from free radicals, which play an important role in cancer, heart disease, and other diseases. Glucose provides energy to our body and is the main source of fuel for our body. Hence the level of antioxidants (like glutathione and ascorbic acid) and blood sugar is very important for human health safety against various diseases like cancer, cardiovascular, diabetes, etc. Due to the shortcomings in diagnostic methods, significant research is being done to develop improved methods to test glucose and antioxidants [Cash et al., 2010]. Hence, Colorimetric and Chemiluminescence based sensors have much potential for screening a large number of samples. This thesis is mainly devoted to these techniques to ensure health conditions based on antioxidants and glucose biomolecules. Table 1.1 depicts the diverse properties shown by different nanomaterials and their composites. We can clearly see that after the surface modification, nanomaterials become more stable, more conducting, and more sensitive, which leads to high catalytic performances.

Table 1.1 Typical properties of nanomaterials used in sensing and catalysis pathway

	MoS_2	Fe-MoS_2	2D-carbon	g-C_3N_4	Pt-g-C_3N_4	GNP	GNP-PDT
High Surface Area	✓	✓	✓	✓	✓		✓
Nano size	✓	✓	✓	✓	✓	✓	✓
Highly Catalytic		✓	✓		✓	✓	✓
Conducting	✓	✓	✓		✓		✓
Stability	✓	✓	✓	✓	✓		✓
Biocompatible	✓	✓	✓	✓	✓	✓	✓
Sensitive		✓	✓		✓		✓
Highly Functionalized		✓	✓		✓		✓
		Colorimetric Sensing				Chemiluminescence Sensing	

Further, on the basis of the above literature survey, we are demonstrating a flow chart (Figure 1.15) for our strategic research work. In this flow chart, first of all, we have synthesized our desired nanocomposite and characterized it through several characterization techniques, and investigated the mimetic and catalytic activity. Further, it is utilized for the sensing applications of several biomolecules.

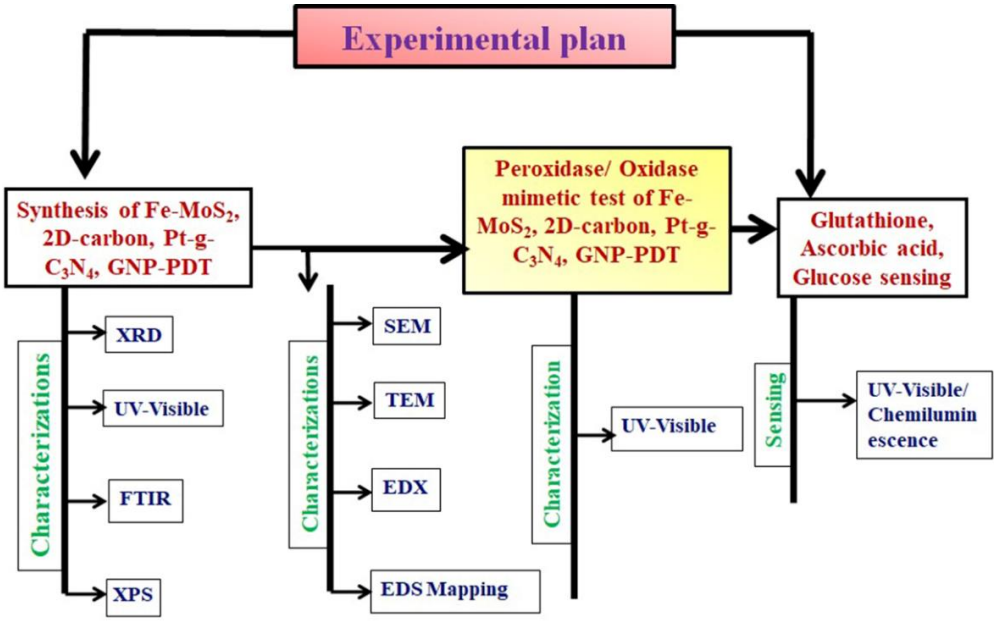

Figure 1.15 Flow chart of research strategy