Project report

on

Biosensors based on Nanomaterials

Submitted in Partial Fulfillment of the Requirement for the Degree of

B. Sc.(Honours) Physics

Submitted by

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B.Sc.(H) Physics (VI th Semester)

Under the Supervision of

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GALGOTIAS UNIVERSITY
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(Established under Galgotias University Uttar Pradesh Act No. 14 of 2011)

CERTIFICATE

This is to Certify that Ms Iram Fatima has carried out her project work entitled

“ Biosensors based on Nanomaterials ” under my supervision.

This work is fit for submission for the award of Bachelor Degree in Physics.

Dr. A. K Jain **Dr. Priya Jadoun**

Dean, SBAS **Supervisor**

DECLARATION

I hereby declare that the dissertation entitled “Biosensors based on Nanomaterials” submitted by me in partial fulfillment for the degree of B.Sc. (H) in Physics to the Division of Physics, School of Basic and Applied Science, Galgotias University, Greater Noida, Uttar Pradesh, India is my original work. It has not been submitted in part or full to this University of any other Universities for the award of diploma or degree.

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Name of student

ABSTRACT

By manipulating matter on a nanometer-scale, or at the level of atoms, molecules, and supramolecular structures, nanotechnology is the production and application of materials, technologies, and systems. Working at these scales to produce larger things with fundamentally different molecular organisation is the heart of nanotechnology. These "nanostructures," which are the tiniest things ever created by humans and display novel physical, chemical, and biological features and phenomena, are constructed from fundamentally new building blocks. The goal of nanotechnology is to discover effective ways to make use of these features and create and use structures.

In fields of study as various as physics, chemistry, materials science, biology, medicine, engineering, and computer simulation, control of matter at the nanoscale already has a significant impact. For instance, it has been demonstrated that nanoparticles may target and kill cancer cells and that carbon nanotubes are 10 times stronger than steel while weighing only a sixth as much. Supersonic transportation could become more affordable with the use of nanoscale technology, and computers could become a million times more efficient. As knowledge of how molecular activity at the nanoscale scale governs natural and living systems grows and as the effects of this knowledge are recognised in science and medicine. Researchers are looking for organised methods for producing goods manufactured by humans at the nanoscale.

Controlling matter at the molecular level entails adjusting the fundamental characteristics, events, and processes precisely at the scale where the fundamental characteristics are established in all natural materials and systems. Therefore, nanotechnology could have an impact on the manufacturing of almost every human-made object, ranging from cars, tyres, and computer circuits to cutting-edge medications and tissue replacements, as well as inspire the creation of objects that have not even been thought of yet. The technologies currently employed in manufacturing, medical, military, energy generation, environmental management, transportation, communication, computation, and education will be substantially altered by nanotechnology during the course of the coming century.

In this thesis, we are going to discuss about Nanosensors and biosensors, different types of biosensing mechanisms and various future possibilities.

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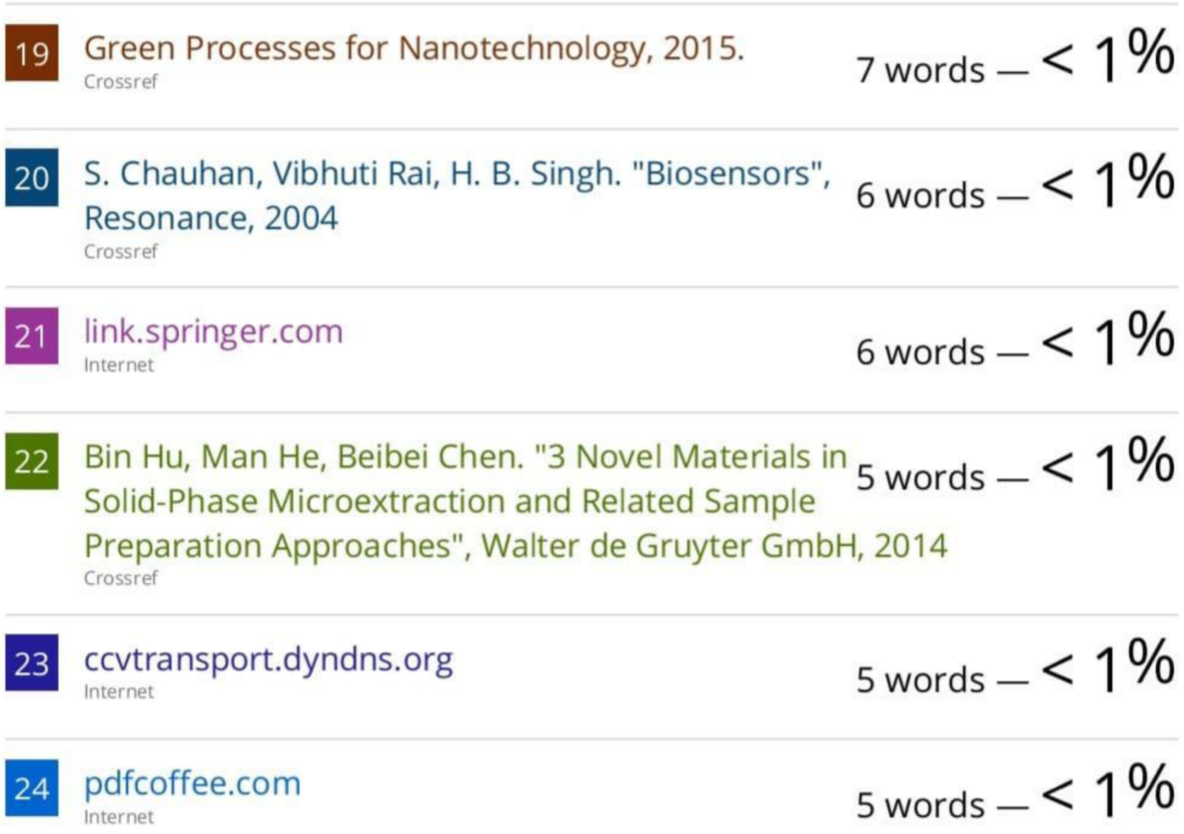

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ABBREVIATIONS

1. CNT - Carbon nanotube
2. NW - Nano wires
3. NR - Nano rodes
4. NP - Nano particles
5. NM - Nano-materials

CHAPTER 1|

INTRODUCTION TO NANO-MATERIALS

1.1| What is Nano-materials?

Nanoscience and nanotechnology have exploded during the past twenty years. Research in this new sector has been substantially sparked, in part, by the National Nanotechnology Initiative (NNI), which was established towards the end of the 20th century. Numerous techniques for the synthesis, characterisation, computer simulation, theoretical modelling, manufacture, and use of nanomaterials with at least one nanoscale dimension have been developed as a result of research activities (1-100 nm). Nanomaterials that are between normal continuous materials (over microns) and molecules in size are in a special state of matter [1-5]. They have fundamentally diverse physical and chemical characteristics, and typically interact with electrons, photons, electromagnetic fields, etc. in a way that is dependent on their size and form.

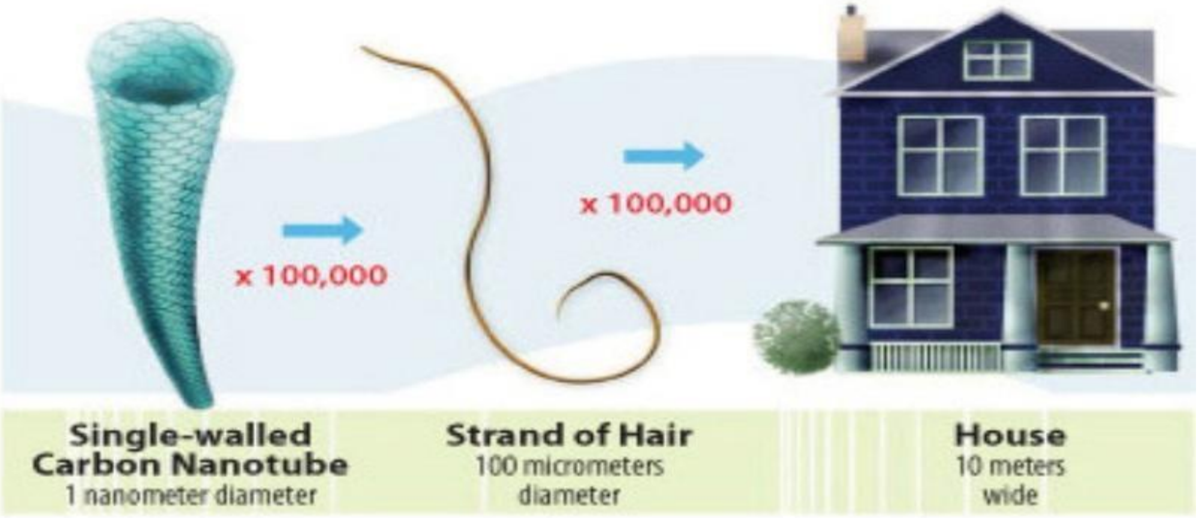

Fig. (1): CNT (Nanomaterials) [9].

Nanomaterials and nanodevices have the potential to be used to examine and control biological systems from the molecular level up to macroscopic tissues since their size is comparable to that of biomolecules. This offers numerous opportunities to pinpoint the underlying molecular causes of diseases, create more targeted treatments, enable health monitoring and early disease diagnosis, and build the foundational knowledge for biocompatible prosthetics and regenerative medicine. Despite numerous obstacles, the fusion of synthetic nanomaterials with living systems has made tremendous strides, opening the door to the quick development of numerous early illness diagnoses as well as the foundation for biocompatible prosthetics and regenerative medicine.[6]

The rapid creation of several nanodevices utilised for biomedical studies at the molecular and subcellular level to tissue engineering has resulted from the integration of artificial nanomaterials with natural biological systems, despite numerous difficulties. Based on a wide range of nanomaterials' distinctive optical, electrical, magnetic, and thermal properties, this book describes recent developments in the applications of these materials in biosensors and other biomedical equipment.[7, 8]

1.2| History of Nano-materials

The formation of nanostructures in the first meteorites marked the beginning of the history of nanomaterials shortly after the big bang. Many more nanostructures, including skeletons and seashells, were later developed by nature. Early humans' usage of fire resulted in the formation of smoke particles with a nanoscale. But the history of nanomaterials in science did not start until much later. Michael Faraday's creation of colloidal gold particles in 1857 is one of the earliest reports in science. For more than 70 years, researchers have also studied nanostructured catalysts. Precipitated and fumed silica nanoparticles were being produced and offered as an alternative to ultrafine carbon black for rubber reinforcements in the USA and Germany by the early 1940s.

Nanosized amorphous silica particles are widely used in a variety of common consumer goods, including non-dairy coffee creamer, tyres, optical fibres, and catalytic supports. Metallic nanopowders for magnetic recording tapes were created in the 1960s and 1970s. Granqvist and Buhrman published the first article on nanocrystals made using the now-common inert-gas evaporation method in 1976. Maya blue paint has just been discovered to be a nanostructured hybrid material. " Studies of genuine samples from Jaina Island show that the material is made of needle-shaped palygorskite (clay) crystals that form a superlattice with a period of 1.4 nm, with intercalates of amorphous silicate substrate containing inclusions of metal (Mg) nanoparticles".[4] The origin of its colour and its resistance to acids and biocorrosion are still unknown. The creation of synthetic samples has demonstrated that the lovely blue hue can only be attained when both these nanoparticles and the superlattice are present.[9]

1.3| Classification of Nano-materials

Nanomaterials are incredibly tiny, with at least one dimension being 100 nm or less. Nanoscale materials come in one or more dimensions, such as surface coatings, strands, or fibres, or three dimensions (eg. particles). They come in spherical, tubular, and irregular shapes, and can be found alone, fused, aggregated, or agglomerated. Typical examples of nanomaterials include fullerenes, quantum dots, dendrimers, and nanotubes. Nanomaterials are used in nanotechnology and exhibit different physical and chemical properties from ordinary substances (i.e., silver nano, carbon nanotube, fullerene, photocatalyst, carbon nano, silica).

The classification of nanostructured materials by Siegel includes zero-, one-, two-, and three-dimensional nanostructures.

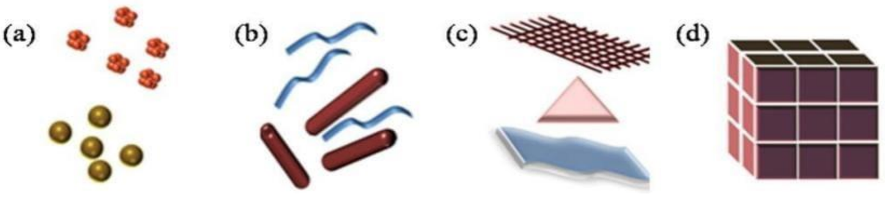

Fig. (2): Classification of Nano-structured materials(a) Zero- Dimensional: Spheres or clusters; (b) One-Dimensional: Nanowires(NW), Nanorode; (c) Two- Dimensional: Nanofilms, Nanoplates; (d) three-Dimensional:Nanomaterials[9].

Nanomaterials are substances with ultra-fine grain sizes (50 nm) or dimensions that are no larger than 50 nm. According to Richard W. Siegel, nanomaterials can be made with different modulation dimensionalities: zero (atomic clusters, filaments, and cluster assemblies), one (multilayers), two (ultrafine-grained overlayers or buried layers), and three (nanophase materials made of equiaxed nanometer-sized grains), as depicted in the above diagram[9].

CHAPTER 2|

SYNTHESIS TO NANO-MATERIALS

Three alternative methods can be used to create nanoparticles. They are listed below.
(1) Natural techniques

(2) Physical techniques

(3) Using chemicals

The bioconversion is straightforward and easy, typically requiring just one step. In this specific sense, we can create the nanomaterials using both microorganisms and various plant parts.[11]

2.1| Synthesis of Nano-materials- with the help of microbes

Microbes can be utilised to generate a variety of nanomaterials from an aqueous solution of metal salts. Examples of these microorganisms include bacteria, fungus, and algae.

2.1.1| Utilization of Bacteria

By employing a protein, living things will help create the nanoparticles through the biomineralization process. For instance, magnetotactic bacteria use magnetosomes, which are protein-coated for the manufacture of nanosized magnetic iron oxide crystals, at the bottom of the ocean in anaerobic circumstances to create the magnetic particles as a compass to the direction of their chosen habitat . It is possible to create homogenous particles with a core diameter of 20–45 nm in an in vitro setting. Despite this, magnetosomes have strong magnetic characteristics in medicinal applications, possibly leading to hyperthermia.

2.1.2| Utilization of Fungi

Extracellular silver nanoparticles were created using the fungus Fusarium oxysporum. Due to NADH-enzymatic reductase's activity, these nanoparticles are long-term stable.
In comparison to bacterial cells, more protein is secreted by fungal cells. T. reesei is now widely used in the food, animal feed, pharmaceutical, paper, and textile industries.

2.1.3| Utilization of Algae

Extracellular gold nanoparticles made from Sargassum wightii algae were suggested by Singaravelu et al. 95 percent of the output was reached after 12 hours of incubation . There is a lack of further investigation into the synthesis of nanoparticles using algae.
Some bacteria, fungus, and algae in this process are harmful, thus precautions should be taken to prevent them.

2.1.4| Nano-materials's synthesis with the help of natural templates

The synthesis of nanomaterials inside the organism can be accomplished by leveraging the biological process. The main methods for achieving this are biological templates. By utilising biological building blocks like DNA and proteins, they create distinctive and sophisticated nanostructures. Through these nanoparticles, biosensors, bioNEMS, and bioelectronic systems can be created. The primary building blocks of nanocomposite materials are proteins. For instance, ferritin is the protein that stores internal iron in prokaryotes and eukaryotes. It accumulates as in form of iron oxide and releases it gradually. When there is an iron deficiency or an iron overload in people, it functions as a buffer and controls. It has an iron oxide core that is encapsulated in a protein shell. It is possible to selectively dissolve the iron oxide poferritin without harming the protein around it. Once more, iron oxide or any other desirable nanoparticle can be inserted into the vacant core of apoferritin. Now, an inorganic nanocomposite protein has been created. Fan et al. created the gold nanoparticles using the ferritin found in horse spleen. Wu et al. produced a yttrium phosphate radionuclide nanoparticle inside the apoferritin and coupled it with biotin. The nanoparticles can be assembled using the DNA templates as well. The closed circular DNA molecules known as plasmids are present in many bacterial species. The combination of cadmium perchlorate and plasmid DNA can be spin coated to create 5–10 nm CdS DNA nanoparticle conjugates.[2]

2.1.5| Nano-materials's synthesis with the help of different parts of plants

The nanoparticles have also been created using plants and plant extracts. The phytochemicals found in plants diminish the metal nanoparticles. Phytochemicals such as flavones, organic acids, and quinones naturally function as effective reducing agents for the creation of nanoparticles. The biomass of Pelargonium graveolens (Geranium) and Medicago sativa (alfalfa) plant leaves is used to create gold nanoparticles in a variety of forms. From the leaves of Azadirachta indica (neem), bimetallic Au, Ag, and bimetallic Au core-Ag shell nanoparticles are produced. This plant contains sugars and/or terpenoids that function as reducing agents. Aloevera leaf extract is used in the preparation of gold nanotriangles. Brassica juncea (Indian mustard), Helianthus annuus, and other plants are used to create silver, nickel, cobalt, zinc, and copper nanoparticles (sun-flower).[2]

2.2| Physical process used to create nanoparticles

The two types of physical methods are top-down and bottom-up approaches. The larger materials are mechanically milled into smaller particles in a "top-down" manner. The biggest drawback of this approach is how difficult it is to achieve the proper particle size and form. The deviation of magnetic properties of the samples prepared by milling process is observed when compared to regular particles of the same size. This is because the milling process created defects in the lattice parameters. In the "bottom-up" approach, nanoparticles are condensed in either the liquid or gaseous phase, where the larger materials are created by the chemical fusion of the smaller ions.

2.2.1| Laser Evaporation technique

The promising bottom-up technique for creating magnetic nanopowders is laser evaporation. The raw metal oxides that serve as the foundation for synthesis have been evaporated using a laser. As a result, the sharp temperature differential causes quick condensation and nucleation outside the evaporation zone, which leads to the formation of nanoparticles. The size of the particles and magnetic phase can be altered by adjusting the laser intensity and atmospheric composition in the evaporation chamber.

2.2.2| RF plasma technique

The RF Plasma approach, which necessitates a high temperature, is another physical method. The metal is heated past its evaporation point using high voltage RF coils wrapped around the evacuated system. The system is then filled with helium gas, which causes the coils to reach a high temperature. Metal vapour begins to form on the atoms of He gas. Diffusion causes it to enter the cooler collector rod, where it forms nanoparticles.

2.2.3| Thermal Decomposition

The deterioration brought on by the heat. This process is endothermic. This heat causes the substance to divide into smaller chemical bonds and to break them. Iron oxide nanoparticles were created by thermal breakdown by Hyeon et al. Park et al. created monodispersed nanoparticles with a diameter of 13 nm. Monodispersed nanoparticles are the most practical in biomedicine for the treatment of cancer. According to Kelly et al., metallocenes ancoordination compounds make the ideal precursors for the thermal breakdown process used to create monodispersed nanoparticles. The stabilising and capping agents should be applied to the coordination compounds before performing the thermal breakdown.The size and morphology can be changed by adjusting the concentration of precursors, the solvents, the time of the reaction, or the stabilising and capping agents. In some cases, the stabilising agent also serves as the capping agent. Lithium azide, for instance, can be used to create LiN3 tiny lithium particles. The substance is put into an evacuated quartz tube, which is then heated to 400 C. LiN3 breaks down at a temperature of about 370 C, generating N2 gas. The pressure reduces after all of the N2 gas has been extracted, which takes a few minutes. The metal colloidal particles are created when the lithium atoms that are missing mix. By using this technique, the smallest nanoparticles, less than 5 nm, can be produced.

2.3| Chemical Process Used to create Nano-particles

The chemical method demonstrates a range of bottom-up synthesis techniques for creating nanoparticles. This technique works best with gas or liquid phases. This technique can be used to produce pure, regulated particle sizes. There are numerous ways to prepare nanoparticles for the bottom-up approach. The size, kind of nanomaterial, simplicity of the process, and characteristics of the nanocomposite will be used to choose the best preparation strategy. The many synthesis techniques include “the sol-gel method, co-precipitation, hydrothermal procedure, solvothermal, sonochemical, pyrolysis, vapour deposition, microemulsion, microwave aided, intercalation, ion-exchange, and reflux” [2].

2.3.1| Co-precipitation technique

This is a widely used, straightforward approach for creating a variety of nanoparticles. The aqueous medium is necessary for precipitation in this approach. This method can be used to produce uniform nanoparticles . In a nutshell, the coprecipitation process entails combining two or more salts of water-soluble metal ions, often those that are divalent and trivalent. The soluble salts are primarily present in them as trivalent metal ions. These water-soluble salts go through a process and are reduced to create at least one precipitated water-insoluble salt. Continuous stirring of the solution is required; depending on the reaction circumstances and reducing agent, this stirring may or may not be done in a heated environment.

This approach typically results in particles with less crystalline character. To increase the degree of crystallinity in the particles, heat energy can be applied. By including common reducing agents like ammonia solution, sodium hydroxide, and many others to maintain the proper pH, the entire process is kept running in the alkaline medium. The ratio of salts used, the pH of the solution, the temperature of the reaction medium maintained, and the type of base utilised are some of the variables that affect the size of the nanoparticles.The solvent can be isolated, further purified, and dried using centrifugation or filtration. Doped ferrites can also be created by doping various rare earth elements into the ferrites. The use of very small size nanoparticles is required in biomedical applications. Therefore, the biocompatible nanoparticles can also be created using this method. This method incorporates the following steps for the production of nanoparticles: nucleation, growth, coarsening , agglomeration, and stabilising mechanisms. They mostly involve nucleation and growth.[11]

The process of the tiniest elementary particles of the new thermodynamic phase forming is called nucleation. The level of supersaturation is the primary determinant of the nucleation process. When a solution is in a supersaturation state, it has more dissolved material in it than the solvent can really dissolve. The solute thus has a solubility greater than equilibrium. The larger particles will eat the smaller ones as they expand in order to minimise their surface energy. The term "coarsening" or "Ostwald ripening" refers to this process. Agglomeration may also happen in order to lower the surface energy. The particles may continue to expand past the nanoscale if the coarsening and aggregation are not controlled. It can be useful to use some stabilising or capping chemicals to stop the growth of nanomaterials.

Through the chemisorption of charged species, the capping agents bond to the nanoparticle surface and create electrostatic (van der Waals) repulsion on its surface. Stable nanoparticles will form if the repelling forces are strong, else coagulation will take place . Hydrogen , metal borohydrides , hydrazine hydrate , and hydrazine dichloride are a few examples of reducing agents . The following reduction reaction will occur:

$$M^{n+} + ne^- \rightarrow M^0 \, (M^{n+} \text{ is a metal})$$

Additionally, an oxidation reaction takes place simultaneously and is represented as follows:

$$X^m - ne^- \rightarrow X^{\mathrm{m-n}} (X^m \text{ is reducing agent})$$

The final chemical is collected in the solid form even though the entire reaction takes place in the liquid state. Reactive crystallisation is another name for this process.

2.3.2| Sol-gel technique

The sol-gel technique was initially created for the low temperature processing of glass and ceramic materials. This procedure involves first hydrolyzing the metal alkoxide solution with water or alcohols while it is in the presence of an acid or base, followed by polycondensation. The loss of water molecules from the solution and an increase in viscosity caused the liquid phase to shift into the gel phase as a result of polycondensation. The transition from the gel phase to the powder phase occurs after all of the water molecules have condensed (Fig.4). To bring out the fine crystalline character of the powder, some extra heat is needed.[11]

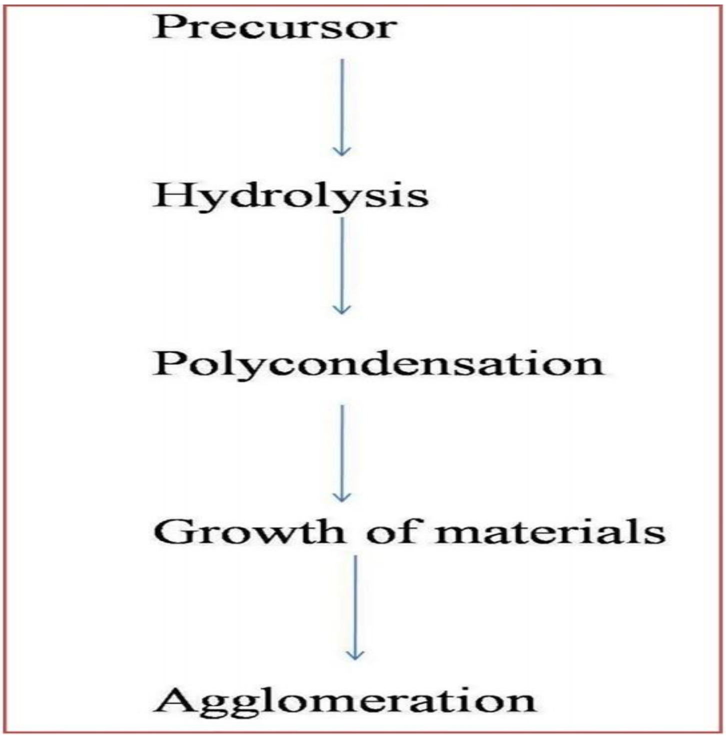

Fig. (4) : Schematic Representation of Sol gel process of synthesis of Nanomaterials. [11]

The creation of oxides, composites, and organic/inorganic hybrid materials benefited from the application of this technique. The sol-gel approach is based on inorganic polymerization processes. This method's biggest benefit is how easy it is to use. However, this method's purity suffers as a result of the creation of composites in it. Therefore, post-treatment is necessary to purify the sample.

2.3.3| Sono-chemical technique

The most secure and quick way is sonochemical. This technique uses ultrasonic irradiation of a liquid medium to create the cavities (bubbles). “This ultrasound energy diffuses through the medium and increases the massive energy inside the bubble, which has a high temperature of almost 5000 K and 20 MPa pressure”[2]. The bubbles then spontaneously collapse, which causes the matter inside and around it to become chemically excited. The production of metals like CoS2, alloys, oxides, and selenides like CdSe and ZnSe can all benefit from using this technique.[11]

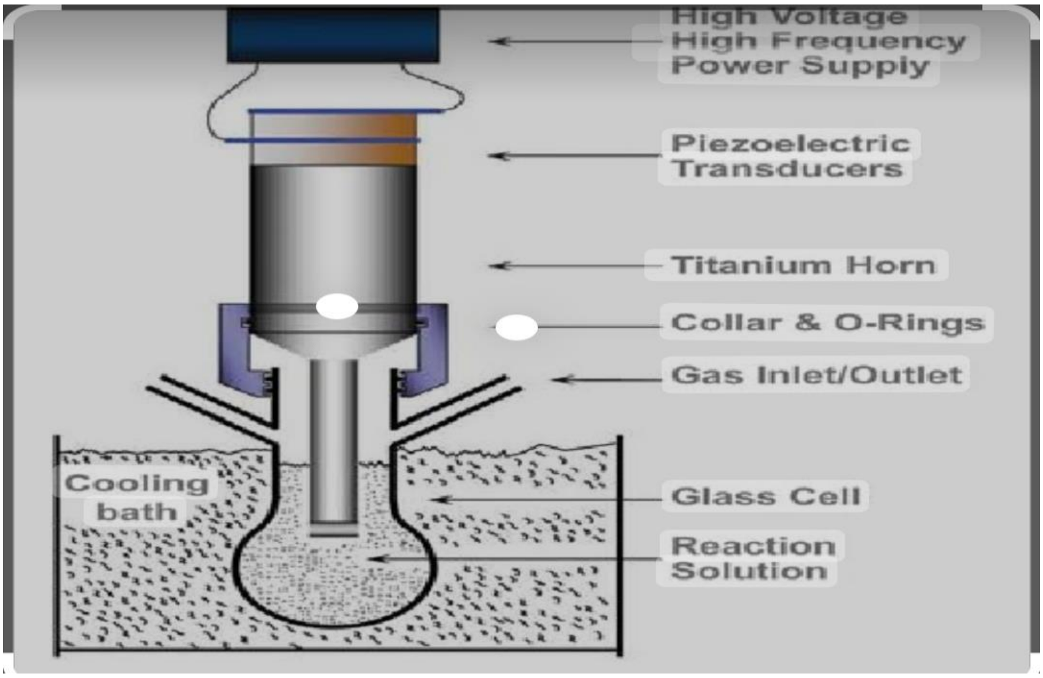

Fig. (5) : Schematic representation of Sono-chemical process of synthesis of Nanomaterials.[10]

CHAPTER 3|

SENSORS

3.1| Introduction

A sensor is a piece of equipment that receives a signal or stimulus and reacts to it by producing an electrical signal. Various types of electrical signals, such as current or voltage, are represented by the output signals. The sensor is a tool that takes in various signals, such as physical, chemical, or biological signals, and transforms them into an electric signal. Based on the applications, input signal, conversion method, material utilised, and sensor properties like price, accuracy, or range, the sensors are divided into many types.

Active and passive sensors are the two primary categories of sensors. A passive sensor does not need an additional energy source, and it responds to external stimuli by producing an electric signal. The sensor transfers input energy to output signal energy in this way. Photographic, thermal, electric field sensing, chemical, infrared, and seismic sensors are a few examples of passive sensors. The response of the active sensors, or excitation signal, requires external energy sources. Sensors make the appropriate adjustments to these input signals to produce the output signals. Due to their inherent ,ability to alter in reaction to an external stimulus and then transform those changes into electric signals, active sensors are often referred to as parametric sensors.Applications for active sensors in meteorology and the study of the Earth's surface and atmosphere are numerous.

Some other kinds of sensors are differentiated by their capabilities for detection, including analogue, digital, and variation mechanisms. The characteristics of sensors for detection “include electric, magnetic, physical, chemical, etc. The variation mechanism includes converting the input signal to the output signal, with examples including photoelectric, thermoelectric, electrochemical”[1], and electromagnetism, etc. A digital sensor is the reverse of an analogue sensor, having discrete characteristics and a digital output by nature. Analog sensors produce an analogue output, or continuous output signals with respect to the quantity being measured.[12]

3.2| Types of Sensors

Numerous sensors are frequently employed in a variety of applications. According to their physical characteristics, such as temperature, resistance, pressure, heat flow, etc., all of these sensors are grouped.

3.2.1| Temperature Sensor

The amount of energy produced by an object or system in the form of heat or cold is measured using a temperature sensor. It provides the output as analogue or digital and enables one to perceive or detect any physical change to that energy. Temperature sensors are utilised in a variety of applications, including medical equipment, cars, and environmental temperature notification. There are many different types of temperature sensors available depending on the application and its specifications.

Contact temperature sensors and non-contact temperature sensors are the two main categories of temperature sensors. In a contact temperature sensor, the object being sensed is physically in contact with the sensor, and conduction is employed to track temperature changes. It can detect gases, liquids, or solids at a variety of temperatures. Convection and radiation qualities are used in a non-contact temperature sensor to gauge temperature changes. Heat and cold are used as forms of radiant energy.

Thermostat, thermister, thermocouple are some examples of temperature sensors.

3.2.2| Position Sensor

The position sensor determines an object's position in relation to a fixed point or position either linearly or in rotation. The separation between two points as they move away from some fixed points can be used to determine position. Rotational sensors can measure angular displacement while linear sensors can measure displacement of position along a straight line. Potentiometers, another name for position sensors, are devices that gauge an object's movement. Since the operating concept of a potentiometer is based on the change in wire resistance with length, it can be either an electrical or resistive type of sensor. The electrical voltage is changed from rotary or linear displacement through this. The length of a wire directly relates to its resistance.

The resistance of a wire also changes as its length does. “With the help of voltage division, changes in resistance can be used to produce an output voltage that is directly proportional to the input displacement using potentiometers, which are commercially available as rotary and linear potentiometers and can be used to measure the angular position and linear position, respectively”[1].

The three terminals on the sensors are referred to as the ends and the wiper and middle, respectively. Resistance is measured between the wiper and either of the end terminals since it is a moving contact. With the use of the potentiometer's sliding component, the displacement of a moving item is measured. When a moving body's position varies, the resistance it experiences between two fixed points likewise alters. The outcome is represented by a differential output voltage that changes linearly with core position. The output signal that is produced has both amplitude and polarity. Polarity determines movement direction, and amplitude is determined as a linear function of displacement.The potentiometer has many benefits, including as simple operation, inexpensive, high output amplitude, and sensors that can measure even significant displacements, but its operating cycles are constrained.

3.2.3| Light Sensors

A light sensor is a passive photoelectric sensor that converts light energy into an output electrical signal. It calculates ambient light, which includes reflected light, outside light, and indoor light. The light dependent resister (LDR) or photoresistor is a key part of a light sensor. It is a resistor that is light-dependent, and the amount of light that strikes it affects how much resistance it exhibits. Since the sensors are comprised of semiconductor materials, they

become low conductive and exhibit less resistance when light is incident on them. Figure illustrates how resistance diminishes as light intensity rises and vice versa. Lux units are used to express how much light falls on an LDR.

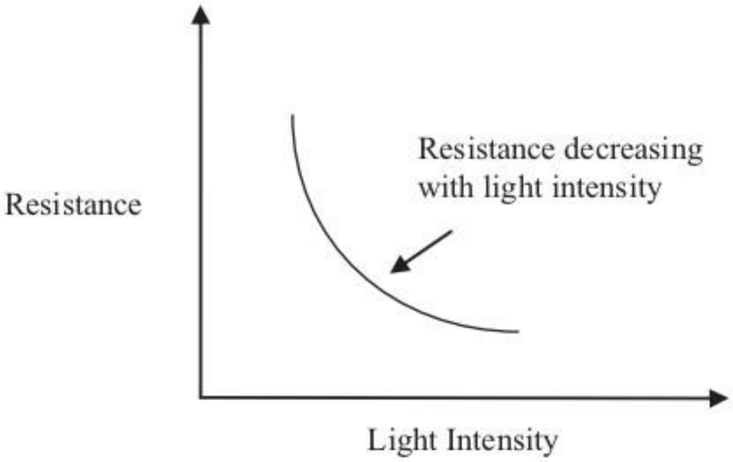

Fig. (6): Resistance is inversely proportional to Light Intensity.[12]

There are numerous types of light sensors, including "charge coupled devices (CCDs), photoresistors, photodiodes, photovoltaic cells, phototubes, photomultiplier tubes, and phototransistors"[1].

3.2.4| Chemical Sensors

Chemical information from a chemical reaction is transmitted by a chemical sensor. Chemical information might include composition, concentration, and chemical activity that results from physical or chemical reactions. It can be used in a variety of industries, including the chemical and home appliance industries. The receptor, a chemical resonance system, and the physical chemical transducer are the two fundamental parts of a chemical sensor. Analytical chemicals are interacted with by the receptor, and an electric signal is then sent by the transducer. The receptor receives a test sample to examine the composition of the transducer's connection. Information from the receptor is gathered by the transducer and sent to the signal amplifier.

The transducer's signal is amplified and sent as output signals as a result. Optical and electrochemical sensors are the two types of chemical sensors used to determine the composition.

1. Optical sensor: The two primary components of an optical sensor are an emitter and a detector. The emitter transmits light to the optical sensor, where it is detected. Light rays strike the analyte and may be refracted or reflected. The detector receives these refracted or reflected rays. Now that these lights have been received by the detector, the chemical substance present is analysed based on their intensity. An optical sensor's operation is fairly straightforward and relies on the medium's absorption coefficient properties and the rays' journey length.

2. Electrochemical sensor: The electrochemical sensor works by interacting with target gas molecules to generate an electric signal proportional to the gas's concentration of the target compound. It consists of electrodes and sensing modules that are spaced apart by a thin electrolyte layer. Electrolytes are contained in the centre of the two plates. The cathode plate is one, and the anode plate is the other.

   Certain ions from the solution absorb an external membrane that has been added to it. Therefore, as the solution's chemical properties change, the electromagnetic field will as well.

As a result, a change in the electromagnetic field guarantees that the gas's chemical composition is present.

3.2.5| Magnetic Sensor

Magnetic sensors generate a proportionate output in response to the presence or interruption of a magnetic field's flux, strength, and direction. It transforms magnetic data into an electrical signal that the electronic circuit can process. A magnetic sensor is employed in a variety of applications, including detecting an object's position, motion, and velocity. The technology used to create a magnetic sensor is diverse. Magnetic sensor use is different for Fluxgate, Hall effect, resistive, inductive, proton processing, etc.Both resistive and inductive magnetic sensors, which utilise coils around their magnetic materials and are able to detect changes in the Earth's magnetic field, maintain the electrical resistance of the magnetic field. A magnetic fluxgate sensor employs this technique by varying the flux parameters. For identifying measurements to be detected, each sort of technology focuses on a particular area. The magnetic field is surrounded by an electric current, which increases the magnet's sensitivity and allows for the detection of variations within the field. A magnetic sensor's output rises in the presence of a strong magnetic field and falls in the absence of one.

3.3| Modern Sensors

In the past ten years, there have been significant advancements in sensor
technology in terms of sensitivity, intelligence, and compactness. Traditional sensors including “photo sensors, optical sensors, capacitive sensors, and nearly all other types of sensors have been supplanted by integrated circuit versions such as MEMS (microelectromechanical system)”[1]. Since the sensors are compactly integrated into all contemporary computer and navigational devices, a typical smartphone typically contains around 22 sensors that serve a variety of functions. The development of sensor technology has led to the creation of smart sensors that are intelligent and wearable. In major applications like “self-driving cars, where hundreds of smart sensors are used for seamless and smooth driving without aid from a driver, this can be observed in smart watches, smart gadgets, or other electronic devices.The same is true for robotics, medical diagnosis, brain-computer interface (BCI), and many other fields”[1] , where artificial intelligence (AI) has given sensors the ability to think and act intelligently for cutting-edge applications in business, healthcare, and sophisticated automation[12].

CHAPTER 4

BIOSENSORS

4.1| What is Biosensors?

An analytical tool called a biosensor transforms a biological response into an electrical signal (Fig. 7). The word "biosensor" is frequently used to refer to sensor devices that measure the concentration of chemicals and other biologically relevant characteristics without directly utilising biological systems. A transducer is used to connect a biological sensing component with a detecting system in a biosensor. Electrochemical sensors for various analytes were the first biosensors that were both scientifically proposed and successfully commercialised. A biosensor is also described as "a chemical sensing device in which a biologically generated recognition is coupled to a transducer, to allow the quantitative development of any complex biochemical parameter" in the definition.

The biosensor's schematic diagram is primarily separated into three components, as illustrated below." (i) “Transducer: It is the detector element (works in a physicochemical way; optical, piezoelectric, electrochemical, etc.) that transforms the signal"[13]produced by the interaction of the analyte with the biological”[3] and is in charge of the user-friendly display of the results. (ii) Sensor: A sensitive biological element (biological material (e.g. tissue, microorganisms, organelles, cell receptors, enzymes, antibodies, nucleic acids The linked electronics make up the third part (iii), which also includes a processor, a display unit, and a signal conditioning circuit (amplifier).

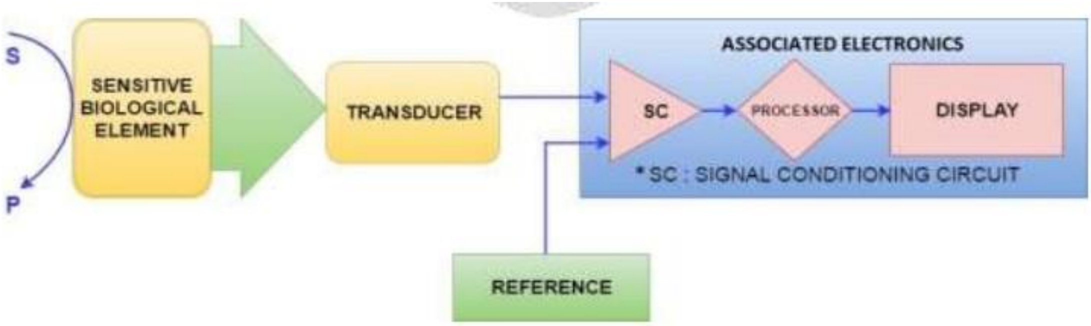

Fig. (7) : Schematic diagram of Biosensors components.[13]

4.1.1| Principle and Working of Biosensor

By using traditional techniques (physical or membrane trapping, non-covalent or covalent binding), the necessary biological material (often a particular enzyme) is immobilised. This organic material is immobilised and in close proximity to the transducer. The analyte binds to the biological substance to create a bound analyte, which then causes the measurable electrical reaction. Sometimes the analyte undergoes conversion into a product that may involve the release of heat, oxygen, electrons, or hydrogen ions. Product-linked changes can be converted by the transducer into electrical signals that can be amplified and measured.

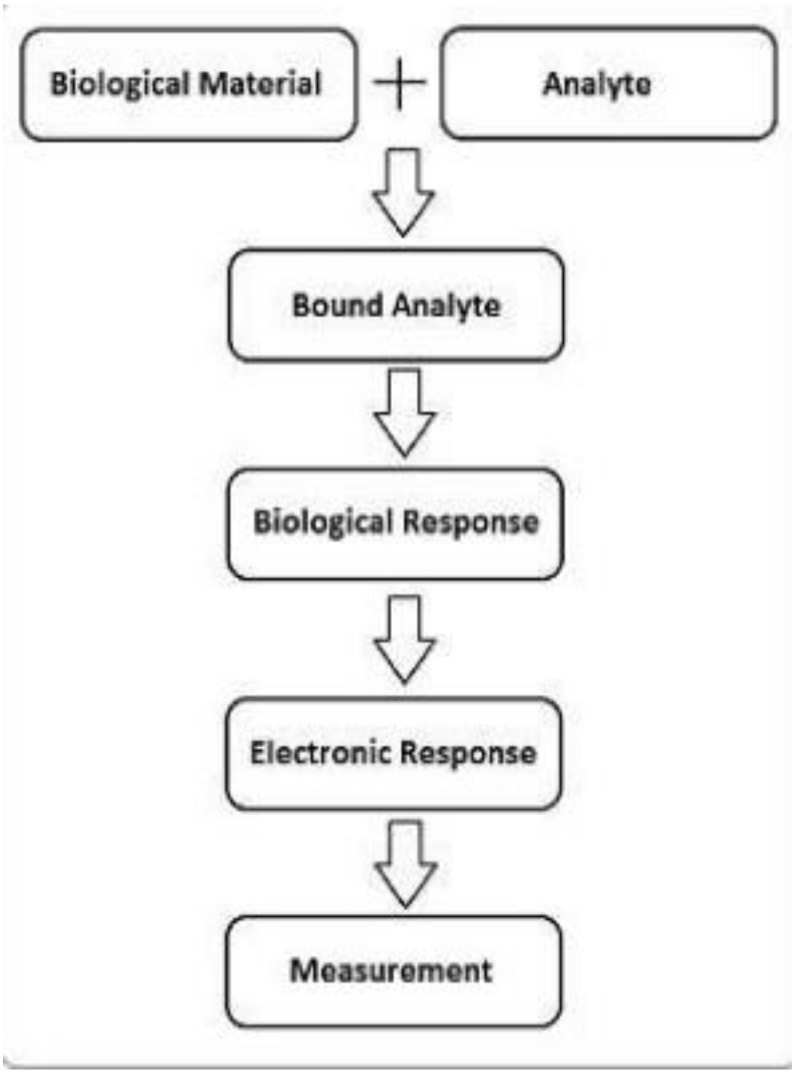

Fig. (8): Flow measurement for a Biosensor

The electrical signal from the transducer is frequently low and superimposed over a relatively high and noisy baseline (i.e., comprising a high frequency signal component of an apparently random nature, caused by electrical interference or created inside the transducer's electronic components). Signal processing typically entails amplifying the resulting signal difference and electronically filtering (smoothing) out the unwanted signal noise. The reference baseline signal is derived from a transducer with a similar design but no biocatalyst membrane. Electrical noise filtration is made much easier by the biosensor's comparatively slow reaction time. The analogue signal generated at this stage could be transmitted directly, but it is more common to convert it to a digital signal before sending it to a microprocessor stage, where the data is processed, translated to the necessary units, and output to a display device or data repository[13] .

4.2| Types of biosensor

4.2.1| Biosensor with Resonance

This kind of biosensor combines an antibody and an acoustic wave transducer (bioelement). The mass of the membrane changes when the analyte molecule (or antigen) binds to it. The transducer's resonance frequency is then altered by the consequent change in mass. Then, this frequency shift is measured.

4.2.2| Optical Biosensors

For this kind of biosensor, the output transduced signal that is measured is light. The biosensor can be created using electro-chemi-luminescence or optical diffraction. Optical transducers are very appealing for use in direct (label-free) bacterial detection. When cells connect to receptors fixed on the transducer surface, tiny changes in the refractive index or thickness occur, which these sensors are able to detect. They link direct changes in the properties of light to variations in concentration, mass, or number of molecules. Surface plasmon resonance (SPR), ellipsometry, the resonant mirror, the interferometer, and monomode dielectric waveguides are only a few of the optical methods that have been reported for the detection of bacterial infections.

4.2.3| Thermal Biosensors

“This particular form of biosensor makes use of one of the basic characteristics of biological reactions, namely the absorption or creation of heat, which alters the temperature of the medium in which the reaction occurs. They are created by fusing temperature sensors and immobilised enzyme molecules”[7]. The heat reaction of the enzyme is measured and calibrated against the analyte concentration when the analyte and enzyme come into contact. This sort of biosensor is frequently used to detect harmful germs and chemicals.

4.2.4| Electro-chemical Biosensors

The primary applications of electrochemical biosensors include the detection of hybridised DNA, DNA-binding agents, glucose content, etc. Based on the electrical parameters they use to measure, electrochemical biosensors can be divided into three categories: conductimetric, amperometric, and potentiometric. Electrochemistry enables the analyst to work with turbid materials and has far cheaper equipment capital costs than optical approaches. However, compared to their optical counterparts, electrochemical approaches have slightly lower selectivity and sensitivity.

4.2.5| Bioluminescence sensors

The capacity of some enzymes to release photons as a consequence of their reactions as a result of their reactions has been used to develop bioanalytical sensors recently. Bioluminescence is the term for this phenomena. The creation of luciferase reporter phages sparked interest in the possible uses of bioluminescence for bacterial detection. Numerous studies have used the bacterial luminescence lux gene as a reporter, either in an inducible or constitutive manner. The reporter lux gene is coupled to a promoter that is controlled by the concentration of an interest molecule in the inducible manner. As a result, by measuring the bioluminescence intensity, the compound concentration may be quantitatively examined. A variety of bacteria have been detected using bioluminescence systems

4.2.6| Nuclei Acid-based Biosensors

An analytical tool that incorporates an oligonucleotide and a signal transducer is called a nucleic acid biosensor. The nucleic acid probe serves as a biorecognition molecule by being adsorbed on the transducer and detecting DNA/RNA fragments.

4.2.7| Nano-biosensors

Sensors based on nanotechnology are known as nanosensors. One of the most recent developments in nanotechnology is the creation of nanobiosensors. The use of silver and other noble metal nanoparticles in biolabelling, medication delivery systems, filters, antimicrobial treatments, and sensors is particularly significant.[14]

4.3| Applications of Biosensors

Biosensors provide a number of benefits over existing instruments, including low cost, small size, rapid and easy operation, and improved sensitivity and selectivity. There are several applications for biosensors in clinical analysis and overall healthcare monitoring. The most well-known illustration is the glucose oxidase-based sensor used by diabetics to track blood glucose levels. Potential uses for biosensors include environmental pollution reduction, industrial processing and monitoring, as well as the food and agricultural industries. The development of appropriate biosensors would significantly affect the following areas:

4.3.1| Clinical and Diagnostic Applications:

The most significant use of biosensors is in the area of medical diagnostics, among a wide range of other applications. Nowadays, clinical biochemistry laboratories measure glucose and lactic acid using electrochemical methods. The capability of direct measurement on undiluted blood samples is one of this method's important characteristics. Another significant “area of clinical medicine and healthcare that will be touched by commercial biosensors is consumer self-testing, particularly self-monitoring of blood components”[3]. Unlike today's disposable sticks, which only allow for one measurement, modern reusable sensors provide calibration and quality monitoring. By substituting the currently used, frequently lengthy, and labor-intensive exams, such testing will increase the effectiveness of patient care. It will enable quick clinical decision-making by bringing clinical medicine closer to the bedside.

4.3.2| Industrial Applications:

Large-scale bacterial and eukaryotic cell culture are used to manufacture various new products in addition to materials used in regular industrial fermentation. The monitoring of these complex and expensive processes is crucial for reducing production costs; fermentation product formation can be measured using specialised biosensors.

4.3.3| Environmental monitoring:

Whole cell biosensors may offer significant advantages in the field of environmental water monitoring for preventing pollutants from entering groundwater systems and ultimately drinking water. Anionic contaminants like phosphates and nitrates are now important targets for pollution biosensors. The development of biosensors is crucial for military and defence applications such the identification of biological and chemical species utilised in weapons.

4.3.4| Agricultural Industry:

Pesticide traces of organophosphates and carbamates have been found using enzyme biosensors based on the suppression of cholinesterases. It has been investigated how to quantify ammonia and methane using selective and sensitive microbial sensors. “Biological oxygen demand (BOD) analyzers based on microorganisms like the bacteria Rhodococcus erythropolis immobilised in collagen or polyacrylamide”[3] are the only commercially available biosensors for wastewater quality management, though.

4.3.5| Food Industry:

Commercially accessible biosensors can test acids, alcohols, and carbs. Most often, these tools are utilised in quality control labs, or at their best, they are online connected to the processing line via a flow injection analysis system. The requirements for sterility, regular calibration, analyte dilution, etc. limit their ability to be implemented in-line. “Measurement of amino acids, amines, amides, heterocyclic compounds, carbohydrates, carboxylic acids, gases, cofactors, inorganic ions, alcohols, and phenols”[3] are among the potential uses of enzyme-based biosensors to food quality monitoring. Wine, beer, yoghurt, and soft drink companies are just a few industries that can use biosensors. By identifying harmful organisms in fresh meat, poultry, or fish, immunosensors offer significant potential to ensure food safety[13].

CHAPTER 5|

SUMMARY AND CONCLUSION

We have discussed in this review about nanomaterials, types of process of synthesis of nanomaterials, sensors and their types. A sensor is a piece of equipment that takes in signals and transforms them into electrical signals. These sensors are divided into groups according to their uses, price, precision, and range. Additionally, there are other categories into which sensors can be divided, including thermal, electrical, magnetic, optical, mechanical, and chemical sensors. Modern applications use cognitive and smart sensors, which demonstrate how far sensor technology has evolved.

We have also covered the different kinds and workings of biosensors based on receptors, transducers, and nanomaterials in this review article. In the disciplines of engineering and technology, medicine and biomedicine, toxicology and ecotoxicology, food safety monitoring, medication delivery, and disease progression, biosensors have a wide range of applications. The use of NMs in biosensors has caused the field of biosensing technology to advance quickly in the last ten years.

This is due to the use of new biorecognition components and transducers, advancements in the design, manufacture, and miniaturisation of nanostructured devices at the micron scale, and new methods for the synthesis of NMs, all of which bring together the fields of engineering, technology, and life and physical sciences. The use of nanoparticles has increased the sensing technology's adaptability, durability, and dynamic nature. By utilising several nanomaterials (such as NPs, NRs, NWs, CNTs), each of which has unique properties inside biosensors, the transduction mechanism has been greatly improved (including increased sensitivity, faster detection, shorter reaction time, and reproducibility). Although the usage of nanostructured materials in biosensor applications has significantly improved, there are still a few restrictions that prevent these applications from progressing to the next level.

CHAPTER 6|

FUTURE SCOPE

The majority of research is concentrated on enhancing immobilisation techniques of the biological element to boost sensitivity, selectivity, and stability because in many situations the transduction technology is fully established. Even though it is crucial, the latter has likely received less attention in part because disposable devices are frequently made in a way that makes them most effective in quality assurance laboratories but prevents online implementation for process control.

Sensor and flow system miniaturisation is a dynamic research topic. These technologies may not be immediately useful in the food and agriculture industries because their development is primarily motivated by the need for in vivo applications for medical diagnosis. There is a clear disconnect between research and application in biosensors after over 40 years. A very delayed technology transmission has been caused by the absence of biosensor validation, standardisation, and certification. In the future, this process ought to proceed more quickly thanks to quicker computers and automated technologies.[15]Such as Biosensors are cost effective, highly sensitive, sensors are inherently unsuitable for point of use diagnostics due to their slow response time etc.

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