

Advancement in Nanomaterial-Based Analytical Methods: Innovations and Applications

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Abstract : Nanomaterials change the analytical chemistry by introduction of new methods which difficult to achieve by convention bulk method. Their extremely small size, large surface area, tunable surface chemistry and unique optical or electronic behaviours help to detect molecules at lowest concentration including the femtomolar range. Over the last two decades, nanomaterials have become central to advanced sensing platforms including Surface Plasmon Resonance (SPR), Surface-Enhanced Raman Spectroscopy (SERS), fluorescence-based assays, and nanoparticle tracking analysis (NTA). These technologies have enabled new levels of sensitivity, faster response times, and enhanced compatibility with complex sample matrices. This review focus on discussing nanomaterial classes, their principle with analytical system and recent innovation applications in pharmaceuticals, diagnostics, environmental science, and food safety.

- **Keywords:** - Nanoparticle Tracking Analysis (NTA), Nanomaterials, Environmental monitoring, Pharmaceutical analysis, Surface-Enhanced Raman Spectroscopy (SERS), Fluorescence-based assays, Biosensing, Surface Plasmon Resonance (SPR),

I. INTRODUCTION

The necessity for an internationally accepted definition of a "nanomaterial" has become more pressing in the wake of the quick advancements in nanotechnologies and nanoscience. There are several meanings available at the moment. However, these are primarily dependent on size parameter(s) and are not applicable to particulate materials that contain primary nanostructures in highly agglomerated or aggregated forms, or that only have a size fraction in the nanoscale. [1] The ISO (International Organization for Standardization) says that, materials are considered nanoparticles if at least one of their three dimensions falls between 1 and 100 nm. Industries like textile colour and panels of window the usage of nanowire in middle eastern metalsmith is around 2600 BC. In 1959 Richard Feynman was the first scientist to work on nanotechnology But Norio Taniguchi didn't employ it for semiconductor processes until 1974. [2]

A number of characteristics, including their origin, form, and source, can be used to classify nanomaterials. They present a biological and environmental concern that must be evaluated and properly managed due to their growing usage in everyday objects, industrial settings, electrical gadgets, etc. For the characterisation and quantification of nanomaterials in different matrices, it is crucial to develop trustworthy analytical techniques. This review provided an overview of current developments in analytical techniques for identifying and characterizing nanoparticles in biological matrices.[3]

The foundation of a new technological revolution is nanomaterials. These material's distinct mechanical, electrical, biological, and thermal qualities set them apart from more traditional materials. Systems with greatly enhanced work and innovative uses in chemistry zoology & botany, physics, computer science and engineering have been produced by combining these special qualities with their outstanding recognition abilities. The majority of nanomaterials' remarkable qualities, aside from their great mechanical strength and low weight, are related to feature of surface like surface area, its roughness, and some other, which allow for better connection with a variety of biological entities.[4]

transducer element in electro chemical sensors, work of nanolabel's in optical sensors stationary phase in liquid and gas chromatography, in capillary electrophoresis as pseudostationary phase or buffer phase and in enrichment as extraction material these are some enhanced uses in development and application in analytical chemistry of nanomaterials.[5]

II. SCOPE AND ROLE

In the many fields like analytical technology the nanomaterials and nanoscience have created a revolutionary trend. Due to unique properties of nanomaterials like high Physicochemical stability, high surface area and chemistry for the functionalization nanomaterials have gained attention of many scholars. And because of characteristics like these nanomaterials have been successfully used as analytical tools in analytical chemistry Moreover, the use of nanomaterials as analytes is also applied just considering the analytical control of the sample variety. The scientific discipline that would be responsible for providing information that is reliable and accurate is analytical chemistry for nanomaterials.

Nanomaterials are materials in which at least one dimension is in the nanometer range (1-100 nm), and they often exhibit unique physical, chemical, and biological properties compared to their bulk analogs. Such features include large surface areas with respect to volume, which results in increased reactivity and interaction with biological molecules. Nanomaterials have specifically engineered optical, magnetic, and electrical properties, which make them versatile tools for use in many applications. Nanoparticles are flexible tools for applications since they can be designed with specific optical, magnetic, and electrical properties.[6]

Nanomaterial clearly enhances analytical method by improving their sensitivity, speed and their accuracy. Like an example of nanoparticles of gold used in the colorimetry assay because of their plasmonic solid properties, which can be used for biomarker used to detect the small amount of disease. nanomaterials from carbon like graphene can increase speed of conduction which can increase accuracy and faster result. [7]

In the field of analytical nanoscience and nanotechnology (AN&N), nanomaterials mostly used as instrument for analysis. Given their two primary areas of focus, the examination of nanomaterials and their use as useful tools in analytical nanoscience and nanotechnology now they show mostly workable roadmap for enhancement in analytical science. Analytical techniques can be enhanced by the application of nanotechnological technologies. The characteristics of materials at this size differ significantly from those of the same substance at a larger scale. As a result, nanotechnology and nanoscience have gained popularity. In the context of analysis, nanomaterials may be seen as both analytical objects and analytical instruments to enhance the analytical qualities of measurement processes.

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III. TYPE OF NANOMATERIALS

1. Carbon-Based Nanomaterials

The cylindrical molecules known as nanotubes of carbon which are made of rolled-up sheet of graphene, only one layer of carbon atoms. They may consist of many concentrically connected nanotubes or have one or more walls. As drug carriers, these nanotubes of carbon can have high loading capacities because of their large surface area. These nanotubes are also can be used as biological sensors and contrast agents for imaging because of their distinct optical, mechanical, and electrical characteristics.

2. Metal-Based Nanomaterials

Metallic nanoparticle: Nanoparticle can be used in drug delivery e.g. iron oxide and gold due to their special optical and magnetic properties. Gold & iron oxide nanoparticles are examples of metallic nanoparticles. PGE or dextran or other hydrophilic polymer combined with a magnetic core they can form up iron oxide. On other side a single layer of surface moieties can be combined with ligands for active targeting to functionalize the negative reactive groups that surround the core of gold atoms that make up gold nanoparticles. Metal based nanoparticle have been used for and laser-based therapies, contrast agents for imaging, optical biosensors, and drug delivery.

Quantum dots:

Fluorescent semiconductor nanocrystals, known as quantum dots (QDs), having size range of 1 to 100 nm and have showed promising numbers of biological uses like cellular imaging and drug administration. The shell and core structure of quantum dots is mostly made up of the II-VI or III-V groups of elements of the periodic table. Quantum dots have been used for stability, high brightness medical imaging because of their unique optical characteristics, compactness.[9][10]

3. Polymeric Nanomaterials

Due to advantages and properties of polymeric nanomaterials have been mostly used in biomaterials. which include easy design and elaboration, high biocompatibility, a wide range of structural options, and observable bio-imitative properties. PNPs played a significant part in the field of smart drug delivery because of their exceptional efficiency in delivering medicines to the intended location in the human body. Based on the few hundred prior published studies, PNPs have demonstrated their potential to overcome the challenges faced by numerous promising treatments. In the field of nanotechnology, the PNP is currently moving from a sprouting to a flourishing stage and requires much more attention to thorough research in order to develop new effective formulas.[11]

4. Lipid-Based Nanomaterials

In the analytical sciences, lipid-based nanoparticles (LBNPs) are being used more and more for analytical separations, biosensing, bioimaging, and diagnostics. They are perfect candidates for improving analytical methods because of their special qualities, which include biocompatibility, structural adaptability, and the capacity to include both hydrophilic and hydrophobic compounds.[12][13] Since nanostructured lipid carriers (NLCs) and solid lipid nanoparticles are essential to medication delivery, they have expanded the pharmaceutical industry's horizons. Their success is mostly attributable to their intriguing physicochemical properties, which include high bioavailability, the ability to administer drugs via various routes, large-scale manufacturing, the natural capacity to penetrate the blood-brain barrier, and the capacity to transport macromolecules like DNA, proteins, and oligonucleotides. This review's goal is to give a concise overview of the benefits, drawbacks, and manufacturing processes, along with their current and future oriented applications in the drug delivery field.[14]

5. Quantum Dots (Qds)

Quantum dots are also known as colloidal semiconductor crystals which are significantly known for emerging use in nanotechnology. Originally, they were supposed to be used for luminescent biological labels, but now with their advancement they are found to be significantly useful for analysis in analytical chemistry where photoluminescent properties of them were used for food quality control pharmaceutical and clinical analysis and monitoring of environment. The automation of QDs base method of analysis can enhance their unique properties by using tools like continuous flow analysis. Their properties including their ability to bind ligand, their versatile chemistry, encapsulation in various material with holding their luminescent properties and generation of reactive species. Although having their many properties we

don't have much options to use them in extreme reaction condition with also implementing renewable chemosensors. The studies put light on their potential in chemical analysis and their use in automated flow based and related methodology [15]

IV. ANALYTICAL TECHNIQUES

This article discusses various techniques such as:

- Surface Plasmon Resonance (SPR) Spectroscopy
- Surface-Enhanced Raman Spectroscopy (SERS)
- Fluorescence-Based Assays
- Nanoparticle Tracking Analysis (NTA) [16]

1. Surface Plasmon Resonance (SPR) Spectroscopy

The process of detection of biological and chemical analyte with molecular weights below 400 Da in severely diluted settings is the primary problem for each one of the optical electrical and mechanical sensors. The most widely utilized optical sensors are surface plasmon resonance sensors because of their exceptional capacity to track molecular binding events in real time. The noticing of small amount of molecules having low molecular weight like antibiotics, hormones, insecticide, explosive material and cancer biomarkers all of them are important for pre diagnosis of disease, food quality maintenance, environmental monitoring, and homeland security protection is not so easy for them. Since nanotechnology has advanced so quickly in recent years, SPR sensors improved by nanomaterials have created and are now useful instruments for detecting chemicals that are difficult to detect in the concentration range of pmol to amol.[17]

The effect of light on free electron in between metal and dielectric medium this is the fundamental idea behind SPR nanomaterial based spectroscopy. The total oscillation of electron is called as surface plasmons, can be produced by light striking a metal surface at a particular angle. By creating an electromagnetic field that penetrates the dielectric medium, these oscillations make it possible to detect variations in refractive index close to the surface.[18]

Recent developments in nanomaterial based surface plasmon resonance (SPR) spectroscopy have played important role in improving its sensitivity, specificity, along versatility over many applications. In this context noticeable developments are:

1.1 Integration of Two-Dimensional (2D) Nanomaterials

To enhance performance, materials like transition metal dichalcogenides (TMDCs), graphene, and black phosphorus have been added to SPR sensors. Effective biomolecule immobilization is made possible by their enormous surface area and superior conductivity, which improves sensitivity and detection capabilities.[19]

1.2 Carbon Nanomaterials in SPR Sensors:

The utilization of carbon-based nanomaterials, including graphene and carbon nanotubes, has been explored to enhance SPR sensor performance. These materials contribute to improved sensitivity and specificity in detecting various analytes these substances help to increase the sensitivity and specificity of the detection of different analytes.[20]

1.3 Nanoporous Gold Metamaterials:

High sensitivity has been shown when using nanoporous gold films in SPR sensors without the requirement for complex fabrication techniques. By encouraging improved light-matter coupling, these films offer exceptional sensitivity, making them appropriate for highly precise analyte detection.[21]

1.4 Localized Surface Plasmon Resonance (LSPR) with Nanoparticles:

Improved LSPR spectroscopy is the result of developments in the synthesis of nanoparticles of different shapes, including nanostars, nanooctahedrons, and nanodecahedrons. The sensitivity and specificity of SPR-based detection techniques are improved by these nanoparticles' distinctive plasmonic characteristics.[22]

2. Surface Enhanced Raman Spectroscopy (SERS):

A potent analytical method called Surface Enhanced Raman Spectroscopy show significant increase in the Raman signal of molecules adsorbed on or close to nanostructured metal surfaces, especially those composed of noble metals like silver and gold. Because of this notable improvement, which frequently reaches several orders of magnitude, SERS is a very sensitive technique for identifying and describing even extremely small concentrations of molecules.[23]

The interaction between light and the nanostructured metal surface is the fundamental idea underlying SERS. Surface plasmons are collective electron oscillations triggered by light interaction with these nanostructures. The local electric field intensity dramatically increases as a result of these plasmons' creation of localized electromagnetic "hotspots" at the surface. The Raman scattering intensity of molecules located inside these hotspots is significantly increased, which greatly enhances the detectability of their vibrational fingerprints.[24]

Because they offer the required platform for these surface plasmon effects to occur, nanomaterials are essential to SERS. Numerous nanostructures, such as nanoparticles, nanowires, and nanofilms, have been investigated as SERS substrates; each has special characteristics that affect how much the signal is enhanced.[25]

Surface-Enhanced Raman Spectroscopy's (SERS) capabilities have been greatly expanded by nanomaterial-based developments, allowing for more sensitive and selective detection in a variety of applications. innovative nanostructure

development, integration with other analytical methods, and the investigation of innovative materials to enhance SERS performance are examples of recent advancements.

2.1 Development of Novel Nanostructures

Novel nanostructures have been created by researchers to enhance SERS signals. To detect analytes such as Rhodamine 6G, for example, gold-tungsten disulfide (Au-WS₂) nanohybrids have shown significant enhancement factors ($\sim 1.8 \times 10^9$). The promise of these nanohybrids in real-world biosensing applications is demonstrated by their effective use in the sensitive detection of *E. coli* bacteria at concentrations as low as 10⁴ CFU/mL.[26]

Similarly, multi-leg nanotubes of titanium dioxide (TiO₂) have been suggested as inexpensive, noble metal-free SERS substrates. These structures' distinct morphologies improve their light harvesting capabilities and enable them to detect chemicals like Methylene Blue at nanomolar concentrations with notable SERS sensitivity.[27]

Integration with Other Analytical Techniques Multimodal approaches that offer thorough molecular information have been developed as a result of the integration of SERS with other analytical techniques. SERS integration with spectroelectrochemistry, for instance, enables real-time molecular-level electrochemical reaction monitoring, providing information on reaction kinetics and processes. [28]

3. Fluorescence-Based Assays

Advanced analytical instruments known as nanomaterial-based fluorescence assays make use of nanomaterial to improve the functionality, sensitivity, and specificity of fluorescence detection methods. The basis of fluorescence assays is the light that a fluorophore, or fluorescent molecule, emits when excited by a certain light wavelength. Quantum dots, carbon dots, gold nanoparticles, and metal-organic frameworks are examples of nanomaterials that provide special optical and electrical characteristics that enhance assay performance.[29]

The nanomaterial having unique fluorescence properties like quantum dots can have the benefits to increase the quantum yield, variable excitation and superior stability in solution. Also, due to more amount of electron on surface they can be alters to have more functional group on surface. Like an example of the gold and carbon-based nanomaterials can have thiol group and carboxylic groups on their surface respectively. Which can result to additional bioconjugation of biomolecular or receptor on the surface of the nanomaterials.[30]

This work on the basic principle of

1. **Excitation:** A light source that is typically a laser or LED which excites the nanomaterial and causing it to absorb energy.
2. **Fluorescence Emission:** The excited nanomaterial releases the absorbed energy in the form of light at a specific longer wavelength, known as fluorescence.
3. **Signal Detection:** The emitted fluorescence is detected by a sensitive detector like a photomultiplier tube or a charge-coupled device (CCD) camera.
4. **Signal Analysis:** The intensity or wavelength of the emitted fluorescence is analysed for the determination of the presence and concentration of the analyte.[31]

Recent advancements

2D Nanomaterials: -

Graphene Quantum Dots (GQDs): Graphene quantum dots have tunable emission wavelengths, superior photoluminescence qualities, and biocompatibility, which makes them suitable for biosensing and bioimaging.[32]

Transition Metal Dichalcogenides (TMDs): Because of their distinct optical and electrical characteristics, materials like MoS₂ and WS₂ can be used in fluorescence based tests that are both very sensitive and selective. [33]

Metal-Organic Frameworks (MOFs): Fluorescent dyes or nanoparticles can be encapsulated in these porous materials for controlled release and improved stability.[34]

Upconversion Nanoparticles (UCNPs): By converting near-infrared light into visible light, these nanoparticles reduce autofluorescence and allow for deeper tissue penetration during in vivo imaging.[35] Enhanced Assay Design and Engineering Ratiometric Sensing: Ratiometric sensing reduces the impact of environmental variables and increases measurement accuracy by employing a reference fluorophore or a dual-emission nanomaterial. [36]

Multiplex assays: Multiplex assays, can be used to analyse more than one analyte and that is possible due to the enhancement in their nanomaterial fabrication and surface functionalization. [37]

3D Printing microfluidic devices and soe of test material can be designed by using the techniques involved in 3D printing which can help to improvement in assay portability and usability.[38]

4. Nanoparticle Tracking Analysis (NTA)

The analytical method having versatile nature that is nanomaterial tracking analysis now days mostly being used for characterization on nanoparticle specially nanoparticle in colloidal system this method helps determine particle size distribution, concentration and dynamic by determining of Brownian motion of individual particle. In this method laser light which collide in the particle light scattering occurs which is then measure by high sensitivity detector and calculation performed as Stock-Eistein equation for particle size determination.

It provides the more detailed data in a single particle level and due reasons like that plays an important role in research and application in pharmaceuticals and material science.[39]

NTA mostly work on the principle of Brownian motion of particle that is random motion of particle suspended in liquid.

- a) **Illumination:** Dispersed particle glows when laser light collides with them.
- b) **Scattering:** Nanoparticle scatters the light when it interacts with particle.
- c) **Imaging:** Movement of each nanoparticle determined by the high-speed camera working as detector.
- d) **Tracking:** A computer system analyses the video of Brownian motion of particle.
- e) **Size Calculation:** The computer performs the calculation by Stokes–Einstein equation which determines the relationship between particle size and diffusion coefficient.
- f) **Concentration Determination:** Along with the particle size the method also able to calculate the concentration of nanoparticle in a sample. The software can count number of particle lighted [39]

Use of NTA is increased with new recent development along increase in capabilities and application. Here are some advancements in NTA

1. Enhanced Sensitivity and Resolution:

- **Improved Optics and Detectors:** Smaller and more difficult nanoparticle detection is possible due to the advancement in detector like high-speed cameras and software algorithms
- **Interferometric NTA (iNTA):** iNTA tech uses interference scattering tech in microscopy which improve ratio between noise and signal. Which leads to more accurate size and concentration determination

2. Expanded Capabilities:

- **Multi-spectral NTA (MANTA):** This tech combines the NTA with spectra which then provide the information about the optical characteristics of the nanoparticle this help to differentiate between particle according to their optical characteristics
- **Electrical NTA (eNTA):** The stability and interaction of nanoparticle is based on the surface charge hence determination of electrical properties along with zeta potential important to determine which is determined by eNTA [40]

V. APPLICATION OF NANOMATERIAL

Based analytical techniques Advantages like special physical chemical and optical characteristics of nanomaterial the sensitivity accuracy and efficacy of detection method is increased by nanomaterial based analytical technique. This changes a number of route map including medicine and environmental research a detailed explanation is given below:

1. Pharmaceutical Analysis

To increase the precision of analytical method in pharmaceutical science requires nanotechnologies:

- **Quality Control:** Nanomaterial gives an precises number of contaminant and quantity of drug by improving chromatographic technique
- **Counterfeit Drug Detection:** By identifying minute changes in composition, sensitive nanosensors may distinguish real medications from fakes.
- **Stability Testing:** In stability studies, nanoparticles enhance the identification of degradation products.[41]

2. Medical Diagnostics

nanomaterials are having functional versatility and have good biocompatibility and that's why it is important tool for diagnosis:

- **Early Disease Detection:** biomarkers which can detects disease like cancer of cardiovascular disease have's quantum tots and gold nanoparticle in them
- **Biosensors:** Rapid and accurate diagnoses are made possible by nanosensors, which identify particular proteins, nucleic acids, or metabolites in physiological fluids.
- **Imaging Applications:** nanomaterials provide more visibility at cellular level hence it is used in MRI like imaging method [42]

3. Environmental Monitoring

nanomaterial has catalytic properties and large surface area that's why they are ideal for detection of pollutants in environment

- Heavy Metals: water impurities like lead mercury can be detected by the sensor with nanomaterial
- Air Pollutants: Nanosensors can trace toxic gases like carbon monoxide
- Real-Time Monitoring: Devices based on portable nanomaterials offer real-time data on pollution levels, facilitating prompt action and regulatory compliance.[43]

4. Food Safety and Quality Control techniques

Those equipped with nanotechnology give assurances of food safety and quality

- Pathogen Detection: Nanosensors with great sensitivity can detect the bacteria present in food
- Toxin Analysis: The use of nanomaterial-based techniques improves the detection of toxins, including aflatoxins, in food products.
- Freshness Indicators: Food items' freshness or deterioration can be indicated by colour changes in nano-based smart packaging.[44]

5. Forensic Analysis

nanotechnology gives advantage to easy analysing in the forensic science with high precision

- Trace Detection: Traces of chemicals can be easily identified with the technique based on nanomaterials
- Fingerprint Enhancement: Latent fingerprints are easier to see thanks to nanoparticles.
- Substance Identification: Criminal investigations can benefit from the rapid identification of unknown chemicals by sophisticated nanosensors.[45]

6. Chemical Sensing

sensitivity and selectivity of analytical tool is increased by nanomaterial

- Gas Sensors: Tools equipped with nanotubes and graphene used to detection of traces of gases like ammonia, hydrogen and methane
- Ion Detection: Traces of gases including hydrogen, ammonia, and methane are detected using sensors that use graphene and carbon nanotubes.
- Real-Time Monitoring: Real-time data on environmental changes and response kinetics is provided by nano-based sensors.[46]

7. Biological Research

By making it possible to examine systems at the molecular level, nanotechnology creates new opportunities for biological research:

- Imaging and Labelling: In living cells, biomolecules or cellular components can be tracked and labelled using magnetic nanoparticles and quantum dots.
- Single-Molecule Detection: Researchers can examine the behaviour of individual molecules, like enzymes or DNA strands, using tools based on nanotechnology.
- Drug-Biomolecule Interactions: Drug discovery depends on understanding how medications interact with target biomolecules, which is provided by nano-analytical techniques.[47]

CHALLENGES AND LIMITATION

Analytical methods based on nanomaterials have many benefits, but they also have drawbacks and restrictions. These may have an impact on their creation, application, and broad acceptance across a range of industries. An outline of the main difficulties and restrictions is provided below:

1. Fabrication and Reproducibility

Challenge: It is challenging to synthesize nanomaterials consistently with consistent size, shape, and characteristics. [48]

2. Stability Issues

Challenge: The performance of nanomaterials in analytical procedures is impacted by their propensity for agglomeration, deterioration, or loss of functionality over time.[49]

3. Cost and Scalability

Challenge: The large-scale synthesis of nanomaterials for analytical applications is hampered by high production costs and intricate fabrication procedures.[50]

4. Toxicity and Environmental Concerns

Challenge: Certain nanomaterials' potential toxicity limits their application in analytical procedures by posing hazards to the environment and human health.[51]

5. Lack of Standardization

Challenge: Analytical results are inconsistent because there are no common guidelines for the description and use of nanomaterials.[52]

6. Limited Understanding of Mechanisms

Challenge: The optimization and use of nanomaterials in analytical techniques may be hampered by a lack of knowledge about nanoscale processes.[53]

FUTURE ASPECTS

Analytical chemistry has been transformed by nanomaterials, which provide previously unheard-of levels of sensitivity, selectivity, and adaptability. A number of fascinating future developments are envisaged as study advances:

1. Enhanced Sensitivity and Selectivity:

- *Single-molecule detection:* It is anticipated that developments in sensors based on nanomaterials will make it possible to detect single molecules, transforming domains such as environmental monitoring and early illness diagnosis.
- *Multiplexed detection:* As multifunctional nanomaterials are developed, many analytes can be detected simultaneously, resulting in more thorough and effective analysis.
- *Enhanced selectivity:* By adjusting the surface chemistry and characteristics of nanomaterials, one can minimize interference from other components in complex samples and increase the materials' selectivity towards certain targets.

2. Miniaturization and Point-of-Care Diagnostics:

- *Lab on a chip device:* By deploying nanomaterials in the microfluidic devices, portable, affordable, and quick diagnostic instruments for point-of-care applications can be developed.
- *Wearable sensors:* Continuous environmental and health parameter monitoring will be made possible by the integration of nanomaterial-based sensors into wearable technology.
- *Smartphone-based diagnostics:* When nanomaterials and smartphone technology are combined, accessible and reasonably priced diagnostic platforms will be made available in distant and resource-constrained environments.

3. Advanced Imaging and Spectroscopy:

- *Super-resolution microscopy:* By acting as probes in super-resolution microscopy techniques, nanomaterials allow for the unprecedentedly detailed imaging of biological structures and processes.
- *Enhanced Raman spectroscopy:* By employing nanomaterials, Surface-enhanced Raman spectroscopy (SERS) would be able to detect molecules with high sensitivity and selectivity, also have applications towards environmental monitoring, medical diagnostics.
- *Novel imaging modalities:* The creation of novel nanomaterial-based imaging techniques, like magnetic resonance imaging and photoacoustic tomography, will offer important new insights into biological systems.

4. Environmental Monitoring and Remediation:

- *Selective removal of contaminants:* Effective and economical remediation techniques are made possible by the selective removal of contaminants from environmental samples using functionalized nanomaterials.
- *Bioremediation:* By increasing the activity of microorganisms participating in bioremediation processes, nanomaterials might hasten the breakdown of contaminants.

5. Artificial Intelligence and Machine Learning:

- *Predictive modelling:* It is possible to optimize the performance of nanomaterials in analytical applications and forecast their behaviour by training machine learning models.
- *Automated analysis:* By automating the analytical process, artificial intelligence can increase throughput and decrease the need for manual intervention.[54][55][56]

CONCLUSION

Nanomaterials are revolution in instrument due to they have high surface area , increased reactivity, and adaptability for many uses. Use of nanomaterial in analytical technique have change the industry including drug delivery, diagnosis and other. To get them to their full potential some issues like toxicity, uniformity and stability should be solved nanomaterial shows creative solutions to the problems as their improved sensitivity, real time monitoring, and sustainable practice along it leads to more investigation in theoretical and practical world.

Analytical chemistry have improvised by use of nanomaterial with the technique like surface plasmon resonance (spr), surface enhanced raman spectroscopy (sers), fluorescence based assay, and nanoparticle tracking technique(NTA) with these technique the use of characteristics like better resolution their high sensitivity, and enhanced selectivity the can offer wide range of uses such as material characterisation, environmental monitoring, and biomolecular detection. As the ongoing advancement the capabilities and application are increasing witch pushes the limit of research and practical world application.

Analytical method based analytical technique have shown many application in numbers of fields and have shown significant increase in level of sensitivity, adaptability and selectivity. Nanomaterial are important part of pharmaceutical analysis as they improve precision and accuracy of research and manufacturing processes by quality control, stability testing, and counterfeit drugs. as in the future analytical technique are going to be advanced with the combination of nanotechnologies with latest most advanced technology like downsizing point of care diagnostic sophisticated imaging and artificial intelligence.

Multiplexed assays, smart wearables, and single-molecule detection will make it possible to do real-time, customized diagnostics in a variety of contexts. Artificial intelligence will enable effective data analysis and automated procedures, while nanomaterials will continue to propel improvements in environmental monitoring by providing improved pollution identification and treatment.

All things considered, the combination of nanomaterials and state-of-the-art technologies promises to advance analytical chemistry and tackle difficult problems in environmental research, healthcare, and other fields.

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