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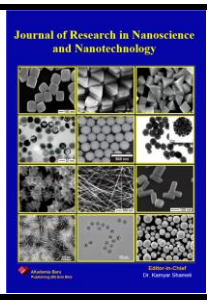

Characterization of Synthesized Copper Nanoparticles from Curcuma Longa: A Preliminary Review

Engku Noradila Zulaika Engku Razali [1], Siti Amira Othman[1,*]

Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, 84600, Pagoh, Johor [1]
* Correspondence: sitiamira@uthm.edu.my;
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ABSTRACT

Due to its eco-friendly and sustainable character, the synthesis of metallic nanoparticles utilising biological resources has attracted much attention recently. To give a general overview of the biological production of copper nanoparticles (CuNPs), Curcuma Longa (Turmeric) is used as a reducing and stabilising agent in this literature study. The paper also emphasises the characterisation methods used to examine the synthesised nanoparticles, including UltraViolet-Visible Spectroscopy (UV-Vis), Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). To comprehend their possible applications and related concerns, it also described how hazardous these copper nanoparticles (CuNPs) are.

Keywords:
Copper, nanoparticles, curcuma longa, toxicity, metal

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1. Introduction

Turmeric, also known as Curcuma Longa, is well known for its therapeutic benefits and active ingredients like Curcumin. The strong reducing and stabilising properties of Curcumin make it a prime option for nanoparticle production. Several research studies have shown the use of Curcuma Longa extracts as a green, easy and affordable method to create copper nanoparticles (CuNPs). Active functional groups in Curcuma Longa operate as reducing agents and help in the stabilisation of nanoparticles, which causes the reduction of copper ions [1].

Turmeric or Curcuma Longa, has drawn a lot of interest as a natural resource for producing metallic nanoparticles. Its primary ingredient, Curcumin, is well suited to produce nanoparticles because of its potent reducing and stabilising abilities. Curcuma Longa can be used to biochemically synthesise copper nanoparticles (CuNPs) as an environmentally benign and sustainable alternative to current processes. Several biomolecules, such as phenols, flavonoids and polysaccharides, are present in Curcuma Longa extract and work as capping and reducing agents during the creation of nanoparticles. Utilising an extract of Curcuma Longa, copper ions in a precursor solution are reduced

throughout the synthesis process. copper nanoparticles (CuNPs) are formed due to the extract active ingredients' interactions with copper ions [3,4].

Copper nanoparticles (CuNPs) produced by biological synthesis are characterised using various methods. A popular method for examining the creation and stability of nanoparticles is UltraViolet-Visible Spectroscopy (UV-Vis). Surface plasmon resonance (SPR) in copper nanoparticles (CuNPs) causes a distinctive absorption peak in the UV-Vis spectrum. The size, shape and concentration of the synthesised copper nanoparticles (CuNPs) may be determined from the location and strength of the absorption peak [31]. The effective synthesis of copper nanoparticles (CuNPs) using Curcuma Longa extract is confirmed by UltraViolet-Visible Spectroscopy (UV-Vis) examination, which also enables quantitative evaluation.

The functional groups and biomolecules responsible for the reduction and stabilisation of copper nanoparticles (CuNPs) are examined using Fourier Transform Infrared Spectroscopy (FTIR). Researchers can determine the chemical groups involved in the synthesis process by comparing the Fourier Transform Infrared Spectroscopy (FTIR) spectra of Curcuma Longa extract and copper nanoparticles (CuNPs). The interactions between the components of the extract and the nanoparticle surface are shown by shifts or changes in the Fourier Transform Infrared Spectroscopy (FTIR) peaks, which shed light on the capping and stabilisation mechanisms.

It is possible to see and characterise the form, size, and distribution of copper nanoparticles (CuNPs) using Scanning Electron Microscopy (SEM) imaging. It offers high-resolution photographs of the nanoparticle surface and details on their dispersion, aggregation, and form. The presence of well-dispersed and unique copper nanoparticles (CuNPs) is confirmed by Scanning Electron Microscopy (SEM) examination, which also aids in determining the size range of the copper nanoparticles (CuNPs) [2,8].

To investigate the safety of copper nanoparticles (CuNPs) for possible uses, a toxicity study must be conducted. The possible negative impacts of copper nanoparticles (CuNPs) on living things and the environment are examined using a variety of factors. Inflammatory reactions, oxidative stress, cytotoxicity, genotoxicity and environmental risks are a few of these [17,20,21].

The effects of copper nanoparticles (CuNPs) on cell survival and growth are assessed using cytotoxicity tests. Genotoxicity studies evaluate the potential Deoxyribonucleic Acid (DNA) damage that copper nanoparticles (CuNPs) may cause, whereas oxidative stress studies look at the production of reactive oxygen species (ROS) and how it affects biological systems. Understanding the immunological responses brought on by copper nanoparticles (CuNPs) requires an investigation of inflammatory responses. In addition, research on the environmental toxicity of copper nanoparticles (CuNPs) investigates how they affect aquatic life and ecosystems [27,28].

In fact, employing Curcuma Longa extract in the biochemical production of copper nanoparticles (CuNPs) offers a sustainable and ecologically benign method. The synthesised copper nanoparticles (CuNPs) may be thoroughly characterised by UltraViolet-Visible Spectroscopy (UV-Vis), Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM), revealing important details about their physicochemical characteristics. The toxicity research done on copper nanoparticles (CuNPs) also helps to understand possible dangers and ensures the safe deployment of these nanoparticles. Further investigation is required to examine the numerous uses for copper nanoparticles (CuNPs) made using extract of Curcuma Longa as well as to resolve any safety issues. The creation of risk-free and environmentally friendly nanomaterials will be aided by the use of modern characterisation techniques, green synthesis processes, and thorough toxicity analyses [10].

2. Biochemical synthesis

The complicated process by which living things create complex compounds necessary for their life and operation is known as biochemical synthesis. This intriguing process takes place inside the cells of living things, where enzymes and specialised biochemical pathways collaborate to create a vast range of substances, from basic metabolites to complex macromolecules. Research into the fundamentals of biochemical synthesis has been quite active, and it has enormous potential for many other sectors [32].

To maintain cellular homeostasis and sustain life, biochemical synthesis is essential. It includes the synthesis of necessary components such as proteins, nucleic acids, lipids and carbohydrates that are necessary for cellular functions, energy generation and structural integrity. The manufacture of secondary metabolites, such as antibiotics, pigments, and signalling molecules, which aid in adaptability, defence mechanisms and intercellular communication, is also a process that involves biochemical synthesis [4].

Complex pathways made up of enzyme events that happen one after another are necessary for biochemical synthesis. To provide exact control over the production of certain molecules, these pathways are tightly controlled. These synthetic processes are aided and controlled by enzymes, which function as the catalysts of biological reactions. They have exceptional specificity, which enables them to identify and attach to certain substrates, start chemical reactions, and create the necessary products [6].

Applications in metabolic engineering and biotechnology are now possible because of our growing understanding of biochemical synthesis. Through the process of metabolic engineering, desirable substances may be produced more effectively, or new metabolic pathways can be introduced into organisms. According to Stephanopoulos *et al.,* [33], this discipline has played a critical role in the development of biotechnological techniques for the manufacture of medicines, industrial chemicals, and biofuels. Researchers can optimise yields, boost productivity, and develop environmentally friendly production techniques by modifying metabolic networks and enzyme activity.

Synthetic biology is a new science that aims to create innovative biological systems by using engineering principles and ideas. Because it makes it possible to create complicated biological circuits and artificial creatures, biochemical synthesis is essential to synthetic biology [35]. Scientists may design genetic circuits and cellular networks to perform specific tasks, such as manufacturing therapeutic proteins or spotting environmental toxins. According to Gibson *et al.,* [14], this multidisciplinary topic has great potential in several fields, including sustainability of the environment, agriculture, and medicine.

In reality, the manufacturing of various chemicals required for life is underpinned by the fantastic process known as biochemical synthesis. Researchers have made significant advancements in their understanding of and ability to control this process for various applications through discovering biochemical pathways and the modulation of enzyme processes. The ongoing development of synthetic biology, biotechnology and metabolic engineering has the potential to transform whole sectors and address some of society's most pressing problems.

3. Copper nanoparticle

Due to their distinctive characteristics and wide range of uses, copper nanoparticles (CuNPs) have attracted much attention lately. These nanoscale particles differ from bulk copper in interesting physicochemical ways, making them highly beneficial in various industries like electronics, catalysis,

energy and healthcare. This essay examines the creation processes, characteristics and uses of copper nanoparticles, illuminating their tremendous potential. Physical, chemical and biological techniques have all been established to create copper nanoparticles. The size, shape and content of the nanoparticles may be precisely controlled using chemical techniques such as chemical reduction, thermal breakdown and electrochemical deposition [30]. Due to its eco-friendliness and gentle reaction conditions, green synthesis techniques using plant extracts, microbes or biomolecules as reducing and stabilising agents have also become more popular.

Due to the effects of quantum confinement and their high surface-to-volume ratio, copper nanoparticles have unique features. Compared to bulk copper, copper nanoparticles (CuNPs) have improved electrical, thermal, and optical characteristics due to their smaller size. By adjusting their size, shape and surface changes, these nanoparticles' outstanding conductivity, catalytic activity, antibacterial characteristics and localised surface plasmon resonance (LSPR) may be modified [22].

There are several uses for copper nanoparticles. Due to their high electrical conductivity, copper nanoparticles (CuNPs) are widely used in electronics, notably in creating printed circuit boards, interconnects and conductive inks. The development of next-generation electronic devices has a lot riding on their incorporation into flexible electronics, transparent conductive films and sensors. Copper nanoparticles (CuNPs) perform as effective catalysts in catalysis for various processes such as oxidation, hydrogenation and the creation of carbon-carbon bonds. The creation of greener and more sustainable chemical processes is made possible by their special catalytic features, including a large surface area and redox potential. Copper nanoparticles (CuNPs) are employed in energy-related products such as batteries, fuel cells and solar cells. Improved light absorption, charge transfer and energy storage are made possible by their superior electrical conductivity and plasmonic characteristics. Copper nanoparticles (CuNPs) are intriguing candidates for biological applications because they have antibacterial and anticancer characteristics. They can be used as contrast agents for imaging procedures, antibacterial agents and drug delivery systems [8]. Due to its photothermal conversion and angiogenic capabilities, copper nanoparticles (CuNPs) have also demonstrated promise in photothermal treatment and wound healing.

In actuality, copper nanoparticles (CuNPs) have become a versatile nanomaterial with several uses. They are extremely appealing to a variety of sectors due to their distinctive characteristics, synthesis adaptability and eco-friendly synthesis pathways. Further investigation of copper nanoparticles (CuNPs) has the possibility of innovative applications and revolutionary technological developments as nanotechnology research develops.

4. Curcuma Longa (Turmeric)

Turmeric, often referred to as Curcuma Longa, is a perennial herbaceous plant that is a member of the Zingiberaceae family, which also includes Ginger. Native to the Indian subcontinent and Southeast Asia, Turmeric has long been utilised in traditional medicine, religious rituals and as a culinary spice. The different facets of Curcuma Longa are examined in this essay, including its botanical features, chemical makeup, therapeutic benefits and prospective uses.

In terms of Curcuma Longa botanical features, it is distinguished by its long, tapering rhizomes, which are orange-yellow in colour, have a distinctive scent and have a bitter flavour. The plant normally reaches a height of one metre, has trumpet-shaped yellow blooms and also big and oblong leaves. It does well in tropical and subtropical climes, its ideal development conditions include well-drained soil and lots of sunshine [22].

Turmeric has a complex chemical makeup, giving it its therapeutic benefits. Curcuminoids, of which Curcumin is the most prevalent, are the main bioactive components of Turmeric. Turmeric's

bright yellow colour results from the powerful antioxidant, anti-inflammatory and anticancer effects of Curcumin. In addition, essential oils (such as Turmerone and Zingiberene), polysaccharides, proteins, vitamins (vitamin C and vitamin E) and minerals (iron and manganese) are significant components.

Turmeric has anti-inflammatory and antioxidant qualities in medicine. The primary bioactive component of turmeric, Curcumin, has a powerful anti-inflammatory impact by altering several inflammatory molecular pathways. It has strong antioxidant qualities by scavenging free radicals, decreasing the generation of inflammatory cytokines and inhibiting the activity of pro-inflammatory enzymes [1]. Curcumin, a component of Turmeric, has shown anticancer promise by decreasing angiogenesis, which is the creation of new blood vessels to nourish tumours, slowing tumour growth and triggering apoptosis, or programmed cell death. Turmeric also has anti-inflammatory properties. Additionally, it has chemo preventive effects by impeding the development, spread and initiation of cancer cells [17]. Traditional uses of turmeric include aiding in digestion and treating digestive disorders. It improves liver function, encourages the generation of digestive enzymes and has antibacterial action against microorganisms that cause digestive diseases. Additionally, it has neuroprotective benefits since Curcumin contains these qualities and has shown promise in the treatment and prevention of neurological diseases like Alzheimer. It demonstrates antioxidant action in the brain, regulates several cellular pathways involved in neuronal survival and decreases neuroinflammation.

Treatment of inflammatory diseases is one of the medicinal uses for Turmeric and its bioactive components have shown potential. Turmeric's anti-inflammatory properties make it helpful in treating diseases including inflammatory bowel disease, arthritis, and chronic pain [19,20]. Additionally, studies investigating the possibility of Curcumin as an adjuvant therapy for many malignancies including breast, colorectal, lung and prostate cancer, have been prompted by the substance's anticancer capabilities [21,25]. Turmeric is advantageous for skin health because of its antibacterial and anti-inflammatory effects. It is utilised in cosmetic items to lessen acne, ease skin irritations, and enhance skin tone [36].

Turmeric, also known as Curcuma Longa, is a fascinating spice with a long history of traditional use and a growing amount of scientific research demonstrating its therapeutic benefits. Numerous positive benefits are displayed by its active ingredient Curcumin, including anti-inflammatory, antioxidant, anticancer and neuroprotective characteristics. As Turmeric research advances, there is a lot of promise for therapeutic uses in various settings that will benefit human health and well-being.

5. Toxicity study

Studies on chemical toxicity are essential for determining the possible adverse effects of compounds on living things. This research has a significant impact on many different areas, such as consumer product safety, chemicals, medicines and environmental science. The significance of toxicity studies, frequently employed techniques, and their applications in assessing and comprehending the toxicological profiles of chemicals are all covered in this essay.

Studies on drug toxicity are crucial for environmental and human health because they reveal essential details regarding the possible dangers of substance exposure. They support the identification of possible risks, the establishment of safe exposure limits and the direction of regulatory choices and risk management tactics. Toxicology studies are essential for medication development, evaluating the safety of products, evaluating workplace health and evaluating environmental impact.

Acute toxicity studies, which evaluate the immediate adverse effects of a chemical after a single exposure or within a short period, are a common approach in toxicity research. The research establishes the median lethal dosage (LD50) or median lethal concentration (LC50) and aids in the classification of drugs according to their degrees of toxicity. Oral, cutaneous or inhalation exposure methods are often used in acute toxicology studies [27]. Additionally, sub chronic and chronic toxicity studies are used to assess the consequences of repeated or prolonged exposure to chemicals. These studies look at possible synergistic effects, including neurotoxicity, reproductive toxicity, organ toxicity and carcinogenicity. They evaluate dose-response relationships and require extended exposure times [28]. Additionally, studies on genotoxicity determine if a drug has the potential to harm or alter Deoxyribonucleic Acid (DNA). These investigations use in vitro and in vivo assays to assess a substance's genotoxic potential, assisting in the identification of possible carcinogenicity and genetic damage concerns [23]. In addition, ecotoxicity studies analyse how harmful compounds are to ecosystems and unintended creatures. These studies evaluate the effects on plants, invertebrates, and vertebrates, as well as aquatic and terrestrial creatures, in order to shed light on potential environmental hazards and effects [27].

Drug development is one area where toxicity studies are used. A crucial step in the development of new drugs is conducting toxicity studies. They evaluate the safety of pharmacological substances, spot potential side effects and help create safe dosing schedules. These studies promote regulatory approval and aid in assessing medication candidates [23]. Toxicology studies are also utilised in chemical risk assessments to identify possible risks associated with consumer goods, insecticides, and industrial chemicals. For regulatory organisations to determine exposure limits, provide safety standards and ensure the protection of human health and the environment, these studies provide essential data [12]. Toxicology studies are essential to assessing the environmental effects of pollutants and toxins in environmental impact assessments. They shed light on the possible harm that might be done to ecosystems, species and ecological processes. Studies on toxicity support environmental monitoring, pollution prevention, and the creation of mitigation plans [34]. Toxicology studies in occupational health and safety help identify possible risks associated with agents and chemicals used at work. These investigations support the establishment of exposure limits, the identification of suitable safeguards and the protection of employees' health across a range of sectors [26].

Toxicity studies are crucial for determining the possible dangers connected to chemical exposure. Important information is provided regarding the negative consequences on human health, environmental safety, and workplace well-being. Toxicology studies support medication development, chemical risk assessment, environmental impact assessment and occupational health and safety by using various research techniques. The improvement of human and environmental safety and the direction of regulatory choices are facilitated by ongoing research and improvements in toxicity testing technologies.

6. Instruments

Previous studies, used a magnetic stirrer, glass beaker (boil), UltraViolet-Visible Spectroscopy (UV-Vis), Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Perkin Elmer Spectrophotometer, staining mat and carbon-coated copper grid.

6.1 UltraViolet-Visible Spectroscopy (UV-Vis)

The solid analytical method known as UltraViolet-Visible Spectroscopy (UV-Vis) is utilised extensively in many disciplines, including Chemistry, Biology, Physics and Materials Science. It includes measuring the amount of ultraviolet (UV) and visible light absorbed or transmitted by a sample to learn essential details about its chemical composition, concentration and electronic characteristics. This essay examines the fundamentals, uses and most recent developments of UltraViolet-Visible Spectroscopy (UV-Vis), emphasising the importance of this technique for scientific investigation and evaluation.

The fundamentals of Ultraviolet-Visible Spectroscopy (UV-Vis) is including the basis of spectroscopy as the interaction of light and matter. Some wavelengths of an ultraviolet or visible light beam are absorbed by molecules in the sample, lowering the intensity of the light passed through the sample. The energy needed to promote electrons from the ground state to higher energy levels or electronic transitions inside the molecules is represented by the absorbed wavelengths. According to Skoog *et al.,* [32], the observed absorption spectrum contains details regarding the electrical structure, conjugation, and chemical environment of the sample [29].

UltraViolet-Visible Spectroscopy (UV-Vis) uses a spectrophotometer, which is made up of a light source, a monochromator, a sample container, and a detector. A wide range of ultraviolet and visible light from the light source illuminates the material in the cuvette. A certain wavelength of light is chosen by the monochromator, allowing it to pass through the sample. The detector measures the amount of transmitted light and converts it into absorbance or transmittance values. To account for solvent absorption and guarantee precise readings, a reference cuvette filled with the solvent is utilised.

Applications of UltraViolet-Visible Spectroscopy (UV-Vis) in quantitative analysis include pharmaceuticals, environmental monitoring and food Science. UltraViolet-Visible Spectroscopy (UV-Vis) is often used to quantitatively analyse analytes in these and other domains. According to the Beer-Lambert equation, a sample's absorbance and concentration are correlated, making it possible to use calibration curves to determine unknown concentrations [31,37]. UltraViolet-Visible Spectroscopy (UV-Vis) offers essential insights into the chemical makeup and composition of substances in chemical characterisation. It is employed for functional group identification, organic compound analysis and the investigation of molecular interactions such as complex formation and binding phenomena. UltraViolet-Visible Spectroscopy (UV-Vis) is a vital tool in the study of biological macromolecules such as proteins, nucleic acids and pigments, in biological and biomedical research. Deoxyribonucleic acid (DNA) and protein concentrations, protein folding, enzyme kinetics and drug interactions with biomolecules may all be studied using this technique [7]. UltraViolet-Visible Spectroscopy (UV-Vis) is used in Material Science to characterise materials such as nanoparticles, semiconductors and polymers. It enables the analysis of materials surface plasmon resonance (SPR), bandgap determination and electronic transitions [30].

Time-resolved UltraViolet-Visible Spectroscopy (UV-Vis) has recently advanced and adopted new methods. By tracking changes in the absorption spectra over time, this approach can provide details about the dynamics of molecular activities. Fast reactions, excited-state lifetimes and photochemical reactions may be studied using it. Nanoscale materials and structures can be characterised using UltraViolet-Visible Spectroscopy (UV-Vis) in conjunction with scanning probe microscopy methods. To investigate localised surface plasmon resonances (SPR) and the optical characteristics of specific nanostructures, it delivers spatially resolved optical spectra.

UltraViolet-Visible Spectroscopy (UV-Vis) is a flexible and essential analytical method utilised for various purposes in scientific study and analysis. Its concepts, tools and applications have made

major contributions to a variety of disciplines including Chemistry, Biology, Materials Science and more. With new developments and methods, UltraViolet-Visible Spectroscopy (UV-Vis) is continuing to develop and offer insightful information on the electronic composition, concentration, and interactions of various materials, fostering innovation and discovery.

6.2 Fourier Transform Infrared Spectroscopy (FTIR)

The sophisticated analytical method known as Fourier Transform Infrared Spectroscopy (FTIR) is utilised extensively in a wide range of scientific fields including Chemistry, Materials Science, Biology and environmental research. By measuring a sample of infrared light absorption, emission or reflection, Fourier Transform Infrared Spectroscopy (FTIR) can provide important details about a sample's molecular makeup, structure and functional groups. This essay examines the foundations, uses and most recent developments of Fourier Transform Infrared Spectroscopy (FTIR), emphasising its importance in scientific investigation and evaluation. The Fourier transform mathematical technique is used in Fourier Transform Infrared Spectroscopy (FTIR), which is based on the interferometry concept. An interferometer is used in Fourier Transform Infrared Spectroscopy (FTIR) to create an interferogram, which records information about the intensity of all wavelengths simultaneously. A high-resolution infrared spectrum is produced by applying the Fourier transformation to the interferogram after which it is converted into a spectrum. The sample transmission or absorption of infrared light is represented by its spectrum, which reveals details on the molecular makeup and structural characteristics of the sample [16].

The Fourier Transform Infrared Spectroscopy (FTIR) method and equipment use a spectrometer that includes an infrared source, an interferometer, a sample compartment, and a detector. The interferometer splits the wide spectrum of infrared radiation such that the infrared source generates two beams. The sample is the target of one beam, while the reference mirror is the target of the other. The recombining of the two beams creates an interferogram. The infrared spectrum is then extracted from the interferogram using Fourier analysis, and it is shown as a plot of intensity versus wavenumber of wavelength [5].

Fourier Transform Infrared Spectroscopy (FTIR) has several uses in chemical investigation, including the identification and characterisation of both organic and inorganic substances. It makes it possible to determine functional groups, analyse chemical structures and identify unidentified molecules. According to Krafft and Popp [24], it is especially helpful in industries like pharmaceuticals, forensic research, and environmental monitoring. In the study of materials such as polymers, coatings, minerals and nanomaterials, Fourier Transform Infrared Spectroscopy (FTIR) is essential. It permits the characterization of a material's surface characteristics, crystallinity, polymer structure and chemical content. It is employed in product development, quality assurance and the comprehension of material behaviour. Fourier Transform Infrared Spectroscopy (FTIR) is used in biological and biomedical research to analyse biological systems such as proteins, nucleic acids, lipids and cells. It details molecular conformations, secondary structures, and interactions between biomolecules. It is utilised to diagnose illnesses, produces new medications, and comprehend biological functions. Fourier Transform Infrared Spectroscopy (FTIR) is used in environmental investigations such as assessing the quality of the air and water, the soil and pollution monitoring. It makes it possible to identify and measure contaminants, analyse environmental samples, and determine their influence on the environment.

Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR) is a recent development in Fourier Transform Infrared Spectroscopy (FTIR) that enables sample analysis without sample pretreatment. It is helpful for quick analysis and in-place measurements since it

allows for directly inspecting solid, liquid and semi-solid materials [24]. Micro-Fourier Transform Infrared Spectroscopy (Micro-FTIR), which combines Fourier Transform Infrared Spectroscopy (FTIR) with microscopy in microscopic FTIR, allows for the high-resolution study of tiny sample regions. Heterogeneous sample characterisation, chemical component imaging and molecular distribution mapping are all made possible by it. Fast chemical reactions and dynamic processes may be examined in Time-Resolved Fourier Transform Infrared Spectroscopy (Time-Resolved FTIR). According to Clark and Hester [9], it offers real-time insights into reaction kinetics, molecular dynamics, and conformational changes.

In actuality, Fourier Transform Infrared Spectroscopy (FTIR) is a flexible analytical method that offers insightful data on the molecular makeup, structure and functional groups of various substances. Fourier Transform Infrared Spectroscopy (FTIR) continues to advance scientific knowledge with its wide variety of applications in Chemical Analysis, Material Science, Biology and environmental investigation. Its capabilities have recently been enhanced by developments in methods like ATR-FTIR, Micro-FTIR and Time-Resolved FTIR, opening new vistas for research and discovery.

6.3 Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM)is a potent imaging method that is widely employed in many scientific fields including Forensic Science, Biology, Geology, Nanotechnology, Materials Science and Forensics. Using a concentrated electron beam, Scanning Electron Microscopy (SEM) creates high-resolution three-dimensional pictures of sample surfaces. This essay examines the foundations, uses and most recent developments in Scanning Electron Microscopy (SEM), emphasising the importance of this technique for characterising and analysing scientific data. The interaction between a focused electron beam and the sample is the basis for Scanning Electron Microscopy (SEM) operating principles. An electron source emits a stream of extremely high-energy electrons that is focused on the sample surface. Several signals are produced by the interaction of the electrons with the material including secondary electrons, backscattered electrons, and distinctive X-rays. Detailed information on the sample topography, morphology and elemental composition is provided by the signal collection, amplification, and translation into a picture [15].

An electron source (typically a tungsten filament or field-emission source), electromagnetic lenses for focusing the electron beam, a sample stage, detectors and a display system make up a typical Scanning Electron Microscope (SEM) instrumentation and technique. In order to improve electron conductivity, the sample is prepared by covering it with a thin layer of conductive substance. High-resolution pictures are produced by detecting and processing the signals that are produced as the electron beam sweeps across the sample surface. According to Goldstein *et al.,* [15], Scanning Electron Microscopy (SEM) can function in a variety of ways including secondary electron imaging, backscattered electron imaging and X-ray microanalysis.

Scanning Electron Microscopy (SEM) is often used in Materials Science to characterise materials including metals, ceramics, polymers and composites. It offers thorough details on the distribution of phases and components, particle size and shape, grain structure and surface topography. Understanding material characteristics, failure analysis and quality control all depend on Scanning Electron Microscopy (SEM) [18]. Scanning Electron Microscopy (SEM) is an essential tool for nanotechnology research and development. It makes it possible to photograph and characterise nanostructures like nanoparticles, nanotubes, and nanowires. Insights into the shape, size and organisation of nanomaterials are provided by Scanning Electron Microscopy (SEM), assisting in the creation of novel nanotechnologies [13]. Scanning Electron Microscopy (SEM) is used in a variety of

biological and biomedical applications in the life Sciences. It enables high-resolution visualisation of biological materials such as cells, tissues and microbes, in domains including cell biology, microbiology and tissue engineering. Scanning Electron Microscopy (SEM) is a valuable tool for learning about cellular morphology, surface characteristics and interactions. Scanning Electron Microscopy (SEM), a technique used in Forensic Science is used in forensic investigations to analyse trace evidence, such as fibres, hair, pigments and gunshot residues. It facilitates the identification and comparison of microscopic characteristics and offers significant evidence for criminal investigations [9].

Environmental Scanning Electron Microscopy (ESEM), a technique that combines Scanning Electron Microscopy (SEM) with a chamber that can maintain a regulated environment, is a recent development in Scanning Electron Microscopy (SEM). It enables the imaging of materials such as moist or hydrated samples, that are incompatible with high vacuum. Without requiring intensive sample preparation, ESEM offers insights into dynamic processes and biological specimens. The concepts of Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) are combined in Scanning Transmission Electron Microscopy (STEM). It allows for the high-resolution imaging of tiny sample sections and can offer data on elemental mapping and electron diffraction [11].

Actually, Scanning Electron Microscopy (SEM) is a flexible and essential method for visualising and characterising a variety of materials across several scientific fields. Scanning Electron Microscopy (SEM) offers comprehensive information regarding surface shape, structure and elemental composition because of its high-resolution imaging capabilities. The capabilities of Scanning Electron Microscopy (SEM) have been increased by recent developments in methods like Environment Scanning Electron Microscopy (ESEM) and Scanning Transmission Electron Microscopy (STEM), which enable the investigation of dynamic processes and nanoscale structures. Scientific investigation, the creation of new materials and technological development are all still driven by Scanning Electron Microscopy (SEM).

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