Chapter 3
Characterization

Fundamental understanding and various potential applications increasingly demand the ability and instrumentation to explore, observe and manipulate the properties of nanomaterial and nanostructures. Characterization of nanomaterials includes the determination of size, shape, and spectroscopic properties of nanostructures. Some characterization methods are used to study the sizes, shapes, and morphology whereas others are used to obtain detailed structural as well as spectroscopic information nanostructures. To explore these properties of nanoparticles, the samples have been subjected to the following characterizations.

3.1 Dimensional and Structural characterization

Characterization of nanomaterials and nanostructures have been largely based on the surface and dimension analysis techniques. These have been explored by using following techniques:

1. X-ray diffraction study (XRD) and
2. Transmission Electron Microscopy (TEM)

3.2 Optical characterization

Optical characterization is a powerful technique to reveal the spectroscopic (energy states and related optical behavior) behavior of nanoparticles. Among these, followings are very important.

1. Fourier Transform Infrared Spectroscopy (FTIRS)
2. Optical Absorption Spectroscopy (OAS) and
3. Photoluminescence spectroscopy (PL)

In this chapter, sample characterization by the above mentioned methods have been discussed.

Next consecutive sections explain the theoretical details of each of the test mentioned above.
3.3 Theoretical background

3.3.1 X-ray Diffraction study (XRD)

X-ray diffraction (XRD) study is the most essential tool used to characterize crystal structures. Evaluation of crystal structure is important even for nanoscale materials. It is also an important tool for finding different crystal parameters like size, d-spacing, diffraction planes, phase and lattice constants. The intensities and the angles of diffracted X-ray beams are related to atomic arrangement of the crystal. The principle of powder XRD is based on the well-known Bragg's law ($\lambda = 2d \sin \theta$).

In this study, X-ray diffractometer detects the X-ray, diffracted by crystal and gives the diffractogram, which is a plot between intensity and diffraction angle. Intensity is given in terms of counts and the angle is in degrees.

Fig. 3.1 shows a pattern of such X-ray diffractogram.

Fig.3.1 XRD pattern

Next we explain how ray diffractogram is used in finding various crystal parameters of metal nanoparticles, which is prepared in our laboratory.
3.3.1.1 Sample identification

To identify any specimen, the diffraction angles produced by a particular sample are compared with the standard diffraction angles of the same material. A good match between experimental and standard values of diffraction angles is required to identify the specimen. The most commonly used database for the identification of crystal structures is the Joint Committee on Powder Diffraction Standards–International Center for Diffraction Data (JCPDS-ICDD) system.

3.3.1.2 Size (diameter) estimations

X-ray diffractogram is extensively used to calculate particle size using Debye-Scherrer equation which gives reasonably accurate particle diameter (size) ‘D’. The equation is written as

\[ D = \frac{0.9 \lambda}{W \cos \theta} \] \hspace{1cm} (3.1)

Where \( \lambda \) is the wave length of X-ray used (0.1541), \( W \) is the full width at half maximum (FWHM) and \( \theta \) is the diffraction angle or glancing angle in radians.

![Fig. 3.2: Single XRD Peak](image)

The different parameters used in equation (1) can be obtained from X-ray diffractogram in the following way.
I. Full width at Half Maximum (FWHM)

In the example shown in fig. 3 the maximum height of XRD peak is BC and OB is the noise. Half of the maximum height is either AB or AC. That is, the middle point of the peak is A. Two more points P and Q are taken on the plot collinear to point A. Two perpendiculars from points P and Q are drawn on the abscissa, which is cut by the perpendicular lines at point R and S. The segment RS is full width at half maximum (FWHM) in degrees. Finally this is converted into radians, which is the actual required FWHM (W)[7]. In general, the XRD peaks of nanocrystals are much broader compared to those of the bulk.

II. Diffraction angle or glancing angle (θ) and X-ray wave length

In the diffractogram, the angle axis is calibrated in terms of “2θ/degree”. From this, glancing angle θ can be obtained. The X-ray wavelength ‘λ’ used in the X-ray diffractometer is 0.1541 nm.

In practice, the experimental data obtained from XRD study of any specific specimen may slightly differ from the standard values due to the following reasons:

1. Calibration error
2. Instrumental error
3. Sudden power fluctuation during experiment and
4. External noises

In this work, Bruker AXS model X-ray diffractometer has been used.

3.3.2 Transmission Electron Microscopy

Transmission Electron Microscopy (TEM) has opened a new door to nanoparticle research by providing pictorial view of high resolution and magnification. This study provides the information about size, shape and surface morphology of the specimen.

A transmission electron microscope examines a structure by passing electrons through the specimen. An image is formed as a shadow of the specimen on a
phorescent screen. For electrons to pass through the specimen it must be very thin usually less than 100 nm. Limitation of resolving power by light microscopy can be modified and applied to the electron microscope by using de Broglie's formula. In 1924 Louis de Broglie suggested that the electron had a dual nature, with characteristics of a particle or a wave. The de Broglie wavelength, $\lambda$, for these "matter waves" is:

$$\lambda = \frac{h}{mv} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.4)$$

$h$ is Planck’s constant ($6.63 \times 10^{-34}$ J x s), $m$ is the mass of the particle ($9.11 \times 10^{-31}$ kg for electrons) and $v$ is the velocity in m/s. The wavelength of electrons in a beam produced from an electron gun can be computed from the accelerating potential, $V$, and the electron charge, $e$ ($1.60 \times 10^{-19}$ C), using the classical expression:

$$E = V \times e = \frac{1}{2} mv^2 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.5)$$

Therefore,

$$v = \left( \frac{2Ve}{m} \right)^{\frac{1}{2}} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.6)$$

Substituting into the de Broglie equation and collecting all the constants ($m$, $e$, and $h$) for the wavelength gives:

$$\lambda = \frac{1.23}{\sqrt{V}} \text{ nm} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.7)$$

The equation above shows that the wavelength of an electron beam is a function of the accelerating voltage used. By increasing the accelerating voltage, a shorter wavelength is obtained. For an accelerating potential of 1 kV (1000 V), the wavelength associated with the electrons is 0.0388 nm, compared to the wavelength of violet light, about 400 nm. Shorter the wavelength, smaller is the limit of resolution of the microscope. In TEM, electrons are accelerated to 100 KV or higher up to 1 MeV and projected onto a thin specimen by means of the condenser lens system and penetrate the sample thickness either undeflected or deflected. The transmitted beam is projected onto the viewing screen, forming an enlarged image of the slide. The images strikes the phosphors image screen and light is generated, allowing the user to
see the image. The darker areas of the image represent those areas of the sample that fewer electrons are transmitted through. The lighter areas of the image represent those areas of the sample that more electrons are transmitted through. In the electron microscope accelerated electrons strike the object to be examined. Images are formed because the thicker portions of the sample absorb more of the electron stream than the thinner portions.

A more technical explanation of typical of how TEMs work is as follows (Figure 3.3):

1. The electron gun at the top produces a stream of monochromatic electrons.
2. The double condenser lenses focus the electron beam onto the specimen.
3. The beam is constrained by the condenser aperture taking out high angle electrons (those far from the optic axis).

---

**Fig. 3.3 : Working structure of TEM**
4. The electron beam strikes the sample, depending on the density of the material present, some of the electrons are scattered and disappear from the beam and parts of it are transmitted.

5. This transmitted portion is focused by the objective lens into an image.

6. Unfocused electrons are blocked out by the objective aperture, resulting in an enhancement of the image contrast.

7. The image is passed down the column through the intermediate and projector lenses, and becomes enlarged.

8. At the bottom of the microscope the unscattered electrons hit the phosphor image screen, and light is produced, allowing the user to view a “shadow image” of the specimen with its different parts displayed in varied darkness according to their density. The darker areas of the image represent those areas of the sample that fewer electrons were transmitted through which are thicker or denser areas. The brighter areas of the image represent those areas of the sample that more electrons were transmitted through (they are thinner or less dense). Although the electron microscope is an improvement over the optical microscope, the image it produces is two-dimensional.

In this work, JEM 1000 C X II model instrument has been used.

3.3.3 Fourier Transform Infrared Spectroscopy (FTIR)

Infrared spectroscopy (IR spectroscopy) deals with the infrared region of the electromagnetic spectrum based on absorption spectroscopy. A common laboratory instrument that uses this technique is a Fourier transform infrared (FTIR) spectrometer. Fourier transform infrared (FTIR) spectroscopy is a technique that is extremely useful for the characterization of organic materials (including polymers) and certain inorganic compounds.

FTIR provides the following information:

- It can identify unknown materials
- It can determine the quality or consistency of a sample and
- It can determine the amount of components in a mixture
In infrared spectroscopy, IR radiation is passed through a sample. Some of the infrared radiation is absorbed by the sample and some of it is passed through (transmitted). The resulting spectrum represents the molecular absorption and transmission, creating a molecular fingerprint of the sample. An infrared spectrum represents a fingerprint of a sample with absorption peaks which correspond to the frequencies of vibrations between the bonds of the atoms making up the material. Because each different material is a unique combination of atoms, no two compounds produce the same infrared spectrum. Therefore, infrared spectroscopy can result in a positive identification (qualitative analysis) of every different kind of material. In addition, the size of the peaks in the spectrum is a direct indication of the amount of material present.

An FT-IR is typically based on a Michelson Interferometer. A simple spectrometer layout is shown in Fig 3.4. The interferometer consists of a beam splitter, a fixed mirror, and a mirror that translates back and forth, very precisely. The beam splitter is made of a special material that transmits half of the radiation striking it and reflects the other half. Radiation from the source strikes the beam splitter and separates into two beams. One beam is transmitted through the beam splitter to the fixed mirror and the second is reflected off the beam splitter to the moving mirror. The fixed and moving mirrors reflect the radiation back to the beamsplitter. Again, half of this reflected radiation is transmitted and half is reflected at the beam splitter, resulting in one beam passing to the detector and the second back to the source. Because the path that one beam travels is a fixed length and the other is constantly changing as its mirror moves, the signal which exits the interferometer is the result of these two beams “interfering” with each other. The resulting signal is called an interferogram which has the unique property that every data point (a function of the moving mirror position) which makes up the signal has information about every infrared frequency which comes from the source. This means that as the interferogram is measured, all frequencies are being measured simultaneously. Thus, the use of the interferometer results in extremely fast measurements.
Fig. 3.4 Schematic diagram of FTIR

As we require a frequency spectrum (a plot of the intensity at each individual frequency) in order to make an identification, the measured interferogram signal cannot be interpreted directly. A means of “decoding” the individual frequencies is required. This can be accomplished via a well-known mathematical technique called the Fourier transformation. This transformation is performed by the computer which then presents the user with the desired spectral information for analysis. A schematic diagram is shown in the fig 3.4.

The normal instrumental process is as follows:

1. **The Source:** Infrared energy is emitted from a glowing black-body source. This beam passes through an aperture which controls the amount of energy presented to the sample (and, ultimately, to the detector).
2. **The Interferometer**: The beam enters the interferometer where the "spectral encoding" takes place. The resulting interferogram signal then exits the interferometer.

3. **The Sample**: The beam enters the sample compartment where it is transmitted through or reflected off of the surface of the sample, depending on the type of analysis being accomplished. This is where specific frequencies of energy are absorbed.

4. **The Detector**: The beam finally passes to the detector for final measurement. The detectors used are specially designed to measure the special interferogram signal.

5. **The Computer**: The measured signal is digitized and sent to the computer where the Fourier transformation takes place. The final infrared spectrum is then presented to the user for interpretation and any further manipulation.

   In this work, FTIR study has been done in Spectrum BX series instrument.

### 3.3.4 Optical absorption spectroscopy (OAS)

The word 'spectroscopy' is used as a collective term for all the analytical techniques based on the interaction of light and matter. Electronic absorption spectroscopy involves measuring the attenuation of a beam of light after it passes through a sample or after it is reflected from the sample surface. This attenuation may arise from absorption, scattering, reflection, or interference.

The intensity of light which propagates through a medium containing small particles is reduced by scattering and absorption\(^1\). The extinction of the light beam is given by

\[
I(x) = I_0 \exp(-n_0 \sigma_{ext} x) \ldots \ldots (3.8)
\]

Where \(I(x)\) is the intensity of the incoming beam after a distance \(x\), \(n_0\) the number of particles per unit volume and \(\sigma_{ext}\) the extinction cross section of a single particle. It holds

\[
\sigma_{ext} = \sigma_{abs} + \sigma_{sca} \ldots \ldots \ldots (3.9)
\]
Where $\sigma_{abs}$ and $\sigma_{sca}$ are the absorption and scattering cross section of single particle respectively.

### 3.3.4.1 Absorption Spectrophotometer

An absorption spectrometer measures the light absorbed by a compound which varies across the UV and visible spectrum. The instrument used in ultraviolet-visible spectroscopy is also called a UV/Vis spectrophotometer. Spectrophotometry investigates the absorption of the different substances between the wavelength limits 200 nm and 800 nm.

The basic parts of a spectrophotometer are a light source, a holder for the sample, a diffraction grating in a monochromator or a prism to separate the different wavelengths of light, and a detector. The radiation source is often a Tungsten filament (300-2500 nm), a deuterium arc lamp, which is continuous over the ultraviolet region (190-400 nm), The detector is typically a photomultiplier tube, a photodiode, a photodiode array or a charge-coupled device (CCD).

![Schematic of double beam UV-Vis spectrophotometer](image)

Fig. 3.5 Schematic of double beam UV-Vis spectrophotometer
A spectrophotometer can be either single beam or double beam. In a single beam instrument all of the light passes through the sample cell. \(I_o\) must be measured by removing the sample. In a double-beam instrument, the light is split into two beams before it reaches the sample. One beam is used as the reference; the other beam passes through the sample. A simple double beam spectrometer is shown in the Fig 3.5.

Metal nanoparticles show absorption band due to surface Plasmon resonance, which is different from general absorption. One can obtain information about the size and shape of metal nanocrystals by measuring the position and nature of the surface plasmon absorption bands in the UV-visible region.

3.3.4.2 Plasmon modes in metal nanoparticles- Surface Plasmon Resonance

Collective oscillations of the quasi-free electrons in metals are called plasmons \(^1\). Because electrons carry a charge, these oscillations are inherently associated with an electromagnetic field. Surface plasmons are the waves that propagate along the surface of a conductor, usually a metal. These are essentially light waves that are trapped on the surface because of their interaction with the free electrons of the conductor \(^2\). In this interaction, the free electrons respond collectively by oscillating in resonance with the light wave. The resonant interaction between the surface charge oscillation and the electromagnetic field of the light constitutes the surface plasmon and give rise to its unique properties. Such collective oscillation is also known as surface plasmon polariton \(^1, 10\). The term plasmon is used to refer to plasma oscillations in metals where as the term polariton refers to a plasma oscillation excited by electromagnetic waves and the term surface is used because a surface polarization is the origin of the plasma oscillation.

When this plasma oscillation takes place in metal nanoparticles, it is called as localized surface plasmon resonance, particle plasmon polariton resonance or Mie resonance\(^1, 10\). This particle plasmon is the resonant excitation of a collective oscillation of the conduction band electrons in the particles. Generally the term surface plasmon in the context of metal nanoparticles refers to the particle plasmon.
3.3.4.3 Simple semi-classical model for surface plasmon in metal nanoparticles

Many properties of particle plasmons are qualitatively understood in the following semi-classical model. A schematic representation of the interaction between an incoming electromagnetic field and a metallic particle is shown in Fig. 3.6.

![Fig 3.6: Interaction of a small metal nanoparticle with light](image)

Since the diameter of the particle is of the order of a few nanometer and the penetration depth of electromagnetic waves in metals at optical frequencies is of about a few nanometer, the incident light is able to propagate through the particle. The electric field inside the particle drives the conduction band electrons collectively with respect to the fixed positive lattice ions.

As a result, a net charge difference appears on the surface at one side of the particle. Its attraction with the lattice ions on the opposite side lead to a restoring force. Thus, a plasma oscillation is excited as a consequence of this charge density difference. If the frequency of the incident light is in resonance with this plasma oscillation, even a small incident field leads to considerable amplitude, limited only by the damping involved, which can be both radiative and nonradiative. The resonance frequency is mainly determined by the strength of the restoring force. This force depends on the separation of the surface charges, that is, the particle dimensions and the polarizability of the medium between and around the charges. In other words, it depends on the polarizability of the embedding medium and on that of the electrons of the metal particles. The alternating surface charges form an oscillating dipole, which radiates electromagnetic waves. This simple model for particle plasmons is reminiscent of an “optical antenna”.

41
3.3.4.4 Light scattering and absorption by metal nanoparticles:

Metal nanoparticles strongly absorb and scatter light at the plasmon resonance frequency, which results in their strong color. Large particles scatter light very efficiently, whereas the color of small particles is mainly caused by absorption. Since the colour of most strongly coloured substances (dyes) is due to absorption, scattering is usually neglected and the change in transmission, the so-called extinction, is solely attributed to absorption\textsuperscript{11}. For metal particles with dimensions above 30 nm, scattering becomes very important\textsuperscript{[10,11]}.

3.3.4.5 Damping mechanisms of surface plasmons

The amplitude of the collective electron oscillation and the width of the particle plasmon resonance depends on the amount of damping. In a quasi-particle picture, damping is described as population decay. This decay can be either radiative, i.e. by emission of a photon, or nonradiative.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig_3.7}
\caption{a) Particle dipolar radiation. \hfill b) Quadruple radiation of larger particle}
\end{figure}

The radiative damping takes place through dipole radiation from smaller nanoparticles (<20 nm) and quadrupole radiation from bigger nanoparticles as shown in the Fig. 3.7.

The nonradiative damping is thus due to a dephasing of the oscillation of individual electrons. In terms of the Drude-Sommerfeld model this damping is described by scattering events with phonons, lattice ions, other conduction or core electrons, the metal surface, impurities, etc.\textsuperscript{11}. Because of the Pauli-exclusion principle, the electrons can only be excited into empty states in the conduction band.
These excitations can be divided into inter- and intraband excitations by the origin of the electron either in the d-band or the conduction band (Fig. 3.8).

Fig 3.8: Particle plasmons decay either radiatively (left) or nonradiatively by creation of electron-hole pairs (right). The electron is either excited within the conduction band (intraband) or from the deeper lying d-band into the conduction band (interband).

3.3.4.6 Quasi-static approximation — Rayleigh Theory

This simple quasi-static model is attributed to Lord Rayleigh for particle plasmons neglecting effects due to self-induction of electromagnetic fields (retardation). This approach effectively means that a region in space is investigated which is much smaller than the wavelength of light, so the electromagnetic phase is constant throughout the region of interest. For small metal particles with diameters below 40 nm, this proves to be a reasonable simplification. It has the advantage that simple electro-statics can be used to calculate the response of a metal sphere to an electric field. For nanoparticles which are much smaller than the wavelength of the interacting light, only the dipole oscillation contributes significantly to the extinction cross section. The extinction cross section can be calculated under this quasistatic approximation. Within this approximation, the electric field inside the particle is uniform and induces a dipole oscillation.

The electric field $\mathbf{E}(t)$ of an incoming light wave on a nanoparticle, with dimensions much smaller than the wave length and embedded in a medium with dielectric constant $\varepsilon_m$, induces a dipole moment which is given by

$$\mathbf{P}(t) = \varepsilon_0 \varepsilon_m \alpha \mathbf{E}(t) \quad \text{(3.10)}$$
Where \( \varepsilon_0 \) is the vacuum dielectric constant and \( \alpha \) is the polarizability of the particles. This polarizability is obtained from the frequency dependent dielectric constant of the particle and of the embedded medium as well as from the dimensions of the particle.

For a sphere of volume \( V \), the polarizability is given by the Clausius Mosotti expression \([10,13]\)

\[
\alpha = 3V \frac{\varepsilon - \varepsilon_m}{\varepsilon + 2\varepsilon_m} \quad \ldots \ldots \quad (3.11)
\]

Where \( \varepsilon = \varepsilon_1 + i\varepsilon_2 \) is the complex dielectric function of the sphere \([10,14]\). The real and imaginary parts of the dielectric function describe the polarization of matter and the energy dissipated under interaction with an electro-magnetic field respectively.

The scattering and absorption cross-sections are respectively \([10]\)

\[
\sigma_{sca}(\omega) = \frac{8\pi^2 \omega^4}{2c^4} |\alpha(\omega)|^2 \quad \ldots \ldots \quad (3.12)
\]

\[
\sigma_{abs}(\omega) = \frac{2\pi \omega}{c} I_m\{\alpha(\omega)\} \quad \ldots \ldots \quad (3.13)
\]

and

\[
\sigma_{ext}(\omega) = \sigma_{abs}(\omega) + \sigma_{sca}(\omega) \quad \ldots \ldots \quad (3.14)
\]

Where \( c \) is the speed of light and \( \omega \) is the angular frequency.

The absorption of light is proportional to the polarizability, in other words, to the volume of the particle, while scattering goes with the square of the volume. Therefore, the scattering dominates the extinction of light for large particles, while the absorption dominates for small particles \([10]\). Since the particles in this work are smaller than \( 30 \) nm, the scattering can be neglected \([10,15,16]\). So it can be assumed that

\[
\sigma_{ext} \simeq \sigma_{abs} \quad \ldots \ldots \quad (3.15)
\]
3.3.4.7 Effect of dielectric constant

From equation (3.11), the polarizability and therefore, the absorption, show a resonance behavior if the denominator vanish. Since $\varepsilon_m$ is taken as a real constant at optical frequencies, it is possible to find a resonance under the condition

\[
[\varepsilon_1(\omega) + 2\varepsilon_m]^2 + [\varepsilon_2(\omega)]^2 = \text{Minimum} \quad (3.16)
\]

This means that a negative $\varepsilon_1$ is necessary. Moreover in the case of a small $\varepsilon_2$, that is, $\varepsilon_2 << 1$, the resonance condition follows the common relation$^{[10,14]}

\[
\varepsilon_1 = -2\varepsilon_m \quad (3.17)
\]

If $\Omega$ is defined as the resonance frequency that fulfils this condition, in the case of a free surface, that is, $\varepsilon_m = 1$, the absorption cross-section can be expressed as$^{[17]}

\[
\sigma_{\text{abs}}(\omega, \Omega) = \frac{V\omega}{c} \frac{[\varepsilon_1(\Omega)-1]^2\varepsilon_2(\omega)}{[\varepsilon_1(\omega)-\varepsilon_1(\Omega)]^2 + [\varepsilon_2(\omega)]^2} \quad (3.18)
\]

The material parameter particularly the complex dielectric function $\varepsilon(\omega)$ of metal nanoparticle are needed to describe the linear optical properties of small metal particle$^{[10,18]}$. In order to understand the inter-action of light with matter, the structure of the matter should be taken into consideration. As an example of a noble metal, silver has the following electronic configuration $[\text{Kr}]4p^64d^{10}5s^1$. The physical properties of silver are determined by the outer electrons. The bulk band energy structure derived from this electronic configuration, which is schematically depicted in fig. 3.9.
In a good approximation, the bands corresponding to the 4p-states can be considered inert, as the inner electrons. However, the d-electrons lie below the Fermi-energy and above the bottom of the s-p conduction bands. Such band structures have important consequences for the optical properties of silver.

Nobel metal atoms have a single s-electron in the upper orbital occupied. Therefore, in a N-atom cluster there will be 2N s-energy levels, which corresponds in the bulk limit with the conduction band. The energy width of both the conduction band in the solid and these 2N-energy levels in the cluster should be comparable. This condition is roughly fulfilled if the separation between the levels becomes comparables to the thermal energy \( \sim k_B T \) which is equal to 0.026 eV at room temperature\(^1\). The Fermi energy of silver is 5.49eV which indicates the conduction band width\(^1\). Therefore transition takes place when \( N \) is larger than \( N \sim \frac{5.49eV}{0.026eV} \approx 200 \) atoms, which corresponds to a spherical cluster with a radius of about \( R \sim \sqrt[3]{N r_{Ag}} \approx 1 \) nm, being the atomic radius of silver \( r_{Ag} \sim 0.14 \) nm \(^1\). Indeed, particles
with a radius of about 2nm exhibit well established electronic bands \(^{19,20}\). Therefore, the most important optical properties of bulk can be applied to the metal nanoparticles taking always particles with a size larger than 1nm.

### 3.3.4.8 Drude- Lorentz- Sommerfield model

Drude-Lorentz-Sommerfield model describe the optical properties of metals \(^{115,16}\). Sommerfield added corrections to the classical models of Lorentz and Drude considering the Pauli -exclusion principle. Later on, it was modified to include the influence of the band structure of solids.

Within the Lorentz model, the electrons in an insulator are treated as simple damped harmonic oscillator, subject to the driving force of an applied electromagnetic field \(^{10}\). The resulting dielectric function of an insulator is described as

\[
\varepsilon_{\text{Lorentz}} = 1 + \frac{\omega_p^2}{\left(\omega^2 - \omega_p^2\right) - i\gamma \omega} \quad \ldots \ldots \ldots \quad (3.19)
\]

Where \(\Omega\) is the resonant frequency of the oscillator, \(\gamma\) is a damping constant, which represents the loss of energy of the oscillating bound electron due to emission of electromagnetic radiation \(^{10}\).

The plasma frequency \(\omega_p\) is determined by the density of conduction electron \(n_e\) and their effective mass \(m^*\) as

\[
\omega_p = \sqrt{\frac{n_e e^2}{m^* \varepsilon_0}} \quad \ldots \ldots \ldots \quad (3.20)
\]

Here \(e\), being the electronic charge.

The real and imaginary parts of the complex di-electric functions are

\[
\varepsilon_1 = 1 + \omega_p^2 \cdot \frac{\left(\Omega^2 - \omega^2\right)}{\left(\Omega^2 - \omega_p^2\right)^2 + \gamma^2 \omega^2} \quad \ldots \ldots \ldots \quad (3.21)
\]

\[
\varepsilon_2 = \omega_p^2 \cdot \frac{\gamma \omega}{\left(\Omega^2 - \omega_p^2\right)^2 + \gamma^2 \omega^2} \quad \ldots \ldots \ldots \quad (3.22)
\]
In the model of Drude, ideal metal has a cloud of independent and free electrons moving randomly until they collide with a collision centre (lattice defects, phonons). Under an external field, the electrons are accelerated and a general drift occurs despite of the random collisions\(^\text{10}\). Under this model, the dielectric function of a metal is described as

\[
\varepsilon_{\text{Drude}} \equiv \varepsilon_{\text{free}} = 1 - \frac{\omega_p^2}{\omega^2 + i\omega \tau} \quad \text{(3.23)}
\]

Where \(\tau\) is the relaxation time of the electrons\(^\text{13}\).

Again the real and imaginary parts are

\[
\varepsilon_1 = 1 - \frac{\omega_p^2 \tau^2}{1 + \omega^2 \tau^2} \quad \text{……(3.24)}
\]

\[
\varepsilon_2 = \frac{\omega_p^2 \tau}{\omega (1 + \omega^2 \tau^2)} \quad \text{……(3.25)}
\]

Drude model is obtained directly from the Lorentz model by equating the resonant frequency of the oscillator to zero, that is, the conduction electrons of a metal are not bound. Moreover, the damping constant of the metal is expressed as \(\gamma = \frac{1}{\tau}\).

For this reason, the optical properties of a free electron in metal resemble those for an insulator at high frequencies\(^\text{10}\).

A schematic band diagram for a noble metal is shown in the fig. 3.10.

**Fig. 3.10** a) Band diagram for an insulator and b) a noble metal

48
It presents a partly filled conduction band and a set of lower and relatively flat, filled d-bands.

3.3.4.9 Intraband transition

In the fig.3.12.b, two different transitions are illustrated. The first one is known as intraband transitions, since it involves only one band. It corresponds to the excitation of an electron close to the Fermi level to another state in the same band, above the Fermi level. Indeed such transition is only possible via phonon interaction. In other words, for Drude like metals, electron collision is the only mechanism of energy absorption. Such transitions are described by the Drude model and only happen in metals.

3.3.4.10 Interband transition

The second transition, called interband transition, is the excitation of an electron to a different band from lower filled d-band to the Fermi surface. Such interband transitions have threshold energy. This is illustrated for an insulator in fig. 12.a. For noble metals, the d-bands lie several electron volts below the Fermi energy. This means that interband transitions take place in the near ultra-violet or even in the visible.

In this work, Perkin Elmer Lambda 351.24 model has been used for the study of absorption spectra of different samples.

3.3.5 Photoluminescence Spectroscopy

Photoluminescence (PL) is a process in which a substance absorbs photons (electromagnetic radiation) and then re-radiates photons. Quantum mechanically, this can be described as an excitation to a higher energy state and then a return to a lower energy state accompanied by the emission of a photon.

There are primarily two types of photoluminescence.

1. Phosphorescence: If the time interval between excitation and emission is long it is called phosphorescence.
2. Fluorescence: If the time interval is short (less than $10^{-5}$ s), it is called fluorescence.

In the present work, we have studied the fluorescence properties of metal nanoparticles. Though, sometimes the term "photoluminescence" has been used, but it indicates the fluorescence phenomena only.

Fluorescence spectra are recorded by measuring the intensity of emitted radiation as a function of either the excitation wavelength or the emission wavelength.

### 3.3.5.1 Fluorometer

A typical block diagram for fluorescence spectrophotometer, which is popularly called as "fluorometer", is shown in Fig. 3.11. In contrast to instruments for absorption spectroscopy, the optical paths for the source and detector are usually positioned at an angle of 90°.

![Fig. 3.11 Schematic diagram of a fluorimeter](image)

In this work, fluorescence spectra have been performed on Hitachi; F-2500 model.
3.4 Characterization of our noble metal nanoparticles

3.4.1 Silver Nanoparticles

Chemical formula : Ag  
Method of preparation : Chemical route  
Chemicals used : Sodium linoleate and Linoleic acid  
Reduction reagents : Ethanol  
Dispersed in : Chloroform  

3.4.1.1 X-ray diffraction study

The structure of prepared silver nanoparticles has been investigated by X-ray diffraction (XRD) study. The X-ray diffraction pattern of silver nanoparticle prepared by present reduction method is shown in fig.3.12.

![XRD pattern of silver nanoparticles](image)

The XRD pattern clearly indicates the crystallinity of the particles as the peaks at 45 degrees and 64.7 degrees match with those of a face centered cubic (fcc) Ag as in JCPDS (Joint committee of powder diffraction standard) correspond to the planes of (200) and (220) respectively. From this study, considering the peaks at 45 and 64.7 degrees, the average particle size is estimated by using Debye–Scherrer formula \(^{[8]}\). Here, the instrumental broadening at 45 and 64.7 degrees are 0.00632 and 0.00912. Considering these, the average particle size is calculated to be **14.3 nm**
with 13% error in the measurement. Experimental and standard diffraction angle for silver nanoparticles is shown in table 3.1 with diffraction plane in table 3.2

Table 3.1: Experimental and standard diffraction angles of Ag specimen

<table>
<thead>
<tr>
<th>Experimental diffraction angle (2θ in degrees)</th>
<th>Standard diffraction angle (2θ in degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>44.3</td>
</tr>
<tr>
<td>64.7</td>
<td>64.7</td>
</tr>
</tbody>
</table>

Table 3.2: Size and diffraction plane of Ag sample

<table>
<thead>
<tr>
<th>Diffraction angle (degree)</th>
<th>FWHM (radians)</th>
<th>Diffraction plane</th>
<th>Size (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>0.0151</td>
<td>200</td>
<td>13</td>
</tr>
<tr>
<td>64.7</td>
<td>0.0190</td>
<td>220</td>
<td>15.6</td>
</tr>
</tbody>
</table>

3.4.1.2 Transmission Electron Microscopy (TEM)

Size and shape of the silver nanoparticles have been obtained from Transmission Electron Microscopy (TEM micrograph), which is performed on a JEM 1000C X II model instrument. A drop of silver nanoparticles dispersed in chloroform is taken on a carbon coated grid and when evaporation takes place, transmission electron microscope (TEM) image is recorded. TEM image of the prepared colloidal solution of silver nanoparticles is shown in Fig.3.13 (a)
Fig. 3.13: (a) TEM image of Ag nanoparticles

The Ag nanoparticles (black portion) are spherical in shape with a smooth surface morphology. The average diameter (size) of the nanoparticle is found to be approximately 12 nm. This TEM image suggests that no clustering of nanoparticles takes place and they are well separated from each other with very narrow size distribution as shown in the fig.3.13 (b). Various data obtained from TEM measurement is shown in table 3.3

Table 3.3: Various data obtained from TEM study of Ag sample

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Particle shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 nm</td>
<td>Spherical</td>
</tr>
</tbody>
</table>
3.4.1.3 Fourier Transform Infrared spectroscopy (FTIR)

Capping of linoleic acid on silver nanoparticle has been examined by FTIR spectroscopy. The FT-IR absorption spectra of the samples are shown in Fig. 3.14 with resolution of 4 cm\(^{-1}\), which has been performed in Spectrum BX series. The peak at 3441 cm\(^{-1}\) of the FTIR spectra contains OH stretching modes. The peak around 3018 cm\(^{-1}\) is due to C=C stretching mode. The lack of broad peak due to OH stretching of the free ligand in the range 3000 cm\(^{-1}\) to 3100 cm\(^{-1}\) is due to the chemisorptions of linoleic acid on the silver nanoparticles, which is an indicator for the conformational ordering of the metal-linked alkyl chains of linoleic acid.

![FT-IR spectra of linoleic acid protected silver nanoparticles dispersed in chloroform](image)

Fig. 3.14. FT-IR spectra of linoleic acid protected silver nanoparticles dispersed in chloroform

3.4.1.4 Ultraviolet Visible spectroscopy

Noble metal nanoparticles (Ag, Au, etc) show a strong absorption band in the visible range due to surface plasmon resonance (SPR). When the dimensions of nanoparticles become smaller than the wavelength of the exciting light, energy can be confined in small spatial regions through the local excitation of surface plasmon resonances (SPR). In metal nanoparticles such as in silver, the conduction band and valence band lie very close to each other in which electron moves freely. These free electrons give rise to a SPR absorption band \([15, 18, 20, 22]\), occurring due to the
collective oscillation of electrons of metal nanoparticles in resonance with the light wave. This absorption strongly depends on the particle size, dielectric medium and chemical surroundings. For small metal particles (diameter < 20 nm), absorption spectra significantly depend only on the dipole oscillation.

![UV-Visible spectrum of silver nanoparticles](image)

**Fig. 3.15: UV-Visible spectrum of silver nanoparticles**

This reduction method by ethanol produces spherical silver nanoparticles around 12 nm (from TEM image). When the frequency of the light wave become resonant with the electron motion, a strong absorption occurs which is the origin of observed colour of colloids. In this case, silver nanoparticles dispersed in chloroform show reddish brown colour due to this absorption. The UV-Vis the absorption spectra of the silver nanoparticles dispersed in chloroform is shown in Fig.3.15. The absorption (SPR) peak is obtained in the visible range at 422 nm. A good symmetry of the absorption spectra around the peak position indicates nearly the uniform distribution of the particles produced. From UV-Vis study it is found that silver nanoparticles remain stable for one month.
3.4.1.5 Fluorescence spectroscopy

The electronic structure of a silver atom can explain the fluorescence spectra of Ag nanoparticles. In the case of silver, 4d valence and 5sp conduction electrons play the role for all the optical properties observed. The outermost d and s electrons of all the constituent atoms of the nanoparticles create 6 bands. Five of these bands lie below the Fermi level, which are denoted as d bands, and the 6th band, the last band that lies above the Fermi level is known as the conduction band or sp band. In silver nanoparticle, capped by linoleic acid, excitation at 350 nm from a xenon laser lead to the excitation of d-band electrons into sp-conduction band, which is due to interband transition. Radiative recombination of electron–hole pair between d band and sp-conduction band is followed by initial electronic relaxation, producing luminescence \[25, 26\], which occurs practically at 490 nm. Fluorescence spectra for silver nanoparticles are shown in Fig.3.16.

![Fluorescence spectra of Ag nanoparticles dispersed in chloroform](image)

Fig. 3.16 . Fluorescence spectra of Ag nanoparticles dispersed in chloroform
3.4.2 Gold Nanoparticles

- Chemical formula: Au
- Method of preparation: Chemical route
- Chemicals used: Sodium linoleate and Linoleic acid
- Reduction reagents: Ethanol
- Dispersed in: Chloroform

3.4.2.1 X-ray diffraction study

The X-ray diffraction patterns (XRD pattern) of the sample prepared by the present reduction method are shown in Fig. 3.17. The XRD pattern clearly indicates the crystallinity of the particles as the peaks at 38.2 degrees and 45.3 degrees match with those of a face centered cubic (fcc) Au as in JCPDS (Joint committee of powder diffraction standard) correspond to the planes of (100) and (200) respectively. From this study, considering the line broadening at 38.2 and 45.3, average particle size is estimated using the Debye–Scherrer formula. Here the instrumental broadenings at 38.2 and 45.3 are 0.00463 and 0.00632, respectively. Considering these, the average particle size is calculated to be around 12.3 nm with 10% error in the measurements. Experimental and standard diffraction angle for silver nanoparticles is shown in table 3.4 with diffraction plane in table 3.5

![XRD pattern of gold nanoparticles](image)
Table 3.4: Experimental and standard diffraction angles of Au specimen

<table>
<thead>
<tr>
<th>Experimental diffraction angle (2θ in degrees)</th>
<th>Standard diffraction angle (2θ in degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.2</td>
<td>38.3</td>
</tr>
<tr>
<td>45.3</td>
<td>44.7</td>
</tr>
</tbody>
</table>

Table 3.5: Size and diffraction plane of Au sample

<table>
<thead>
<tr>
<th>Diffraction angle (degree)</th>
<th>FWHM (radians)</th>
<th>Diffraction plane</th>
<th>Size (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>38.2</td>
<td>0.0149</td>
<td>100</td>
<td>11.8</td>
</tr>
<tr>
<td>45.3</td>
<td>0.0152</td>
<td>200</td>
<td>12.9</td>
</tr>
</tbody>
</table>

3.4.2.2 Transmission Electron Microscopy (TEM)

Samples for Transmission electron microscopy (TEM) studies are prepared by placing a drop of the gold colloidal solution on TEM carbon coated copper grid. The films on the TEM grids are allowed to dry for a few hours after removing the extra solution using blotting paper. TEM micrograph of the prepared colloidal solution of gold nanoparticles is shown in Fig. 3.18 (a) with a graphic of statistical size distribution of particles in Fig. 3.18 (b).

![Fig.3.18](image)

Fig.3.18 : (a) TEM image of Au nanoparticles
The Au nanoparticles (black portion) are spherical in shape with smooth surface morphology. Though the size of the nanoparticles lie between 8 and 15 nm, about 80% of the nanoparticles were found to have size approximately 10 nm. Various data obtained from TEM study of Au sample is shown in table 3.6.

![Particle size distribution](image)

**Fig. 3.18 (b) Particle size distribution**

**Table 3.6: Various data obtained from TEM study of Au sample**

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Particle shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 nm</td>
<td>Spherical</td>
</tr>
</tbody>
</table>

### 3.4.2.3 Fourier Transform Infrared spectroscopy (FTIR)

The FT-IR absorption spectra of linoleic capped gold nanoparticles dispersed in chloroform are shown in Fig. 3.19 with resolution of 4 cm\(^{-1}\), which was performed in Spectrum BX series.
The peak in 3437 cm$^{-1}$ of the FTIR spectra contains OH stretching modes. The peak around 3018 cm$^{-1}$ is due to C=C stretching mode. The lack of broad peak due to OH stretching of the free ligand in the range 3000 cm$^{-1}$ to 3100 cm$^{-1}$ is due to the chemisorptions of linoleic acid on the gold nanoparticles. The antisymmetric and symmetric stretching at 2928 cm$^{-1}$ and 2856 cm$^{-1}$ is an indicator for the conformational ordering of the metal-linked alkyl chains of linoleic acid.

3.4.2.4 Ultraviolet Visible absorption spectroscopy:

This reduction method by ethanol produces spherical gold nanoparticles around 10 nm. The UV/Vis absorption spectra of the gold nanoparticles dispersed in chloroform is shown in Fig. 3.20. The absorption (SPR) peak is obtained in the visible range at 510 nm which matches well with others' results.
3.4.2.5 Fluorescence spectroscopy

In case of gold, 5d valence and 6sp conduction electrons play the role for all the optical properties observed.

![Fluorescence spectra of Gold nanoparticles](image)

**Fig. 3.21: Fluorescence spectra of Gold nanoparticles**

The radiative recombination of electron hole pair between this d-band and sp-conduction band produces emission \[^{[23-26]}\] which occurs practically at 770 nm for linoleic acid protected gold nanoparticles (8-15 nm), when excited with 550 nm of optical source \(^8\). Fluorescence spectra for gold nanoparticle are shown in Fig.3.21.

3.4.3 Copper Nanoparticles

<table>
<thead>
<tr>
<th>Chemical formula</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method of preparation</td>
<td>Chemical route</td>
</tr>
<tr>
<td>Chemicals used</td>
<td>Sodium linoleate and Linoleic acid</td>
</tr>
<tr>
<td>Reduction reagents</td>
<td>Ethanol</td>
</tr>
<tr>
<td>Dispersed in</td>
<td>Chloroform</td>
</tr>
</tbody>
</table>

61
3.4.3.1 X-ray diffraction study

The structure of prepared copper nanoparticles has been investigated by Bruker AXS model X-ray diffractometer. The XRD patterns of the sample prepared by the present reduction method are shown in the Fig. 3.22

![XRD pattern of copper nanoparticles](image)

**Fig.3.22: XRD pattern of copper nanoparticles**

The XRD pattern clearly indicates crystallinity of the particles as the peaks at 43.2 degrees and 50.4 degrees match with those of a face centered cubic (fcc) Cu as in JCPDS (Joint committee of powder diffraction standard) correspond to the planes of (111) and (220) respectively. From this study, measuring the line broadening at 43.2 degrees and 50.4 degrees, average particle size is estimated by using Debye-Scherrer formula $^{[13-9]}$. Considering the instrumental broadening at 43.2 degrees and 50.4 degrees as 0.00431 and 0.00621 respectively, the average particle size is calculated to be around 6.7 nm with 9% error in the measurement.

**Table 3.7: Experimental and standard diffraction angles of Cu specimen**

<table>
<thead>
<tr>
<th>Experimental diffraction angle (2θ in degrees)</th>
<th>Standard diffraction angle (2θ in degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.2</td>
<td>43.7</td>
</tr>
<tr>
<td>50.4</td>
<td>50.1</td>
</tr>
</tbody>
</table>

62
Table 3.8: Size and diffraction plane of Cu sample

<table>
<thead>
<tr>
<th>Diffraction angle (degree)</th>
<th>FWHM (radians)</th>
<th>Diffraction plane</th>
<th>Size (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>43.2</td>
<td>0.0289</td>
<td>111</td>
<td>6.3</td>
</tr>
<tr>
<td>50.4</td>
<td>0.0232</td>
<td>200</td>
<td>7.1</td>
</tr>
</tbody>
</table>

3.4.3.2 TEM image analysis:

Size and shape of the copper nanoparticles has been obtained from TEM micrograph, which was performed on a JEM 1000C X II model instrument. TEM micrograph of the prepared linoleic acid capped copper nanoparticles is shown in Fig. 3.23 (a) with a graphic of statistical size distribution of particles in Fig. 3.23 (b).

Fig. 3.23: (a) TEM image of Cu nanoparticles

Fig. 3.23. (b) Particle size distribution
Table 3.9: Various data obtained from TEM study of Cu sample

<table>
<thead>
<tr>
<th>Particle size</th>
<th>Particle shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 nm</td>
<td>Spherical</td>
</tr>
</tbody>
</table>

This micrographs show that copper nanoparticles are spherical in shape with a smooth surface morphology having an average size of 5 nm. This TEM images also suggests that no clustering of nanoparticles takes place and these nanoparticles are well separated from each other with a very narrow size distribution (1-10 nm).

3.4.3.3 Fourier Transform Infrared spectroscopy (FTIR)

The conformational structure of the linoleic acid capped Cu nanoparticle has been examined by FTIR spectroscopy. The FT-IR absorption spectra of the samples are shown in Fig. 3.24 with resolution of 4 cm⁻¹, which was performed in Spectrum BX series.

![FT-IR spectra of linoleic acid protected copper nanoparticles dispersed in chloroform](image)

The peak in 3439 cm⁻¹ of the FTIR spectra contains OH stretching modes. The peak around 3019 cm⁻¹ is due to C=C stretching mode. The lack of broad peak due to OH stretching of the free ligand in the range 3000 cm⁻¹ to 3100 cm⁻¹ is due to
the chemisorptions of linoleic acid on the Cu nanoparticles. The antisymmetric and symmetric stretching at 2930 cm$^{-1}$ and 2857 cm$^{-1}$ is an indicator for the conformational ordering of the metal-linked alkyl chains of linoleic acid $^{27}$.

3.4.3.4 Ultraviolet Visible spectroscopy

Colloidal dispersion of metal exhibits absorption bands or broad regions of absorption in the ultra violet-visible range $^{[1, 18, 20, 28]}$. Width of the absorption band and wavelength corresponding to the absorption peak strongly depend on size, shape, dielectric constant of metal nanoparticle as well as on the surrounding medium $^{[1, 18, 20, 24, 28]}$. This absorption is due to the excitation of surface plasmon resonance (SPR) and is a characteristic property of the metallic nature of the particle. Nanosized Cu particles (size >20 nm) typically exhibit a surface plasmon resonance peak at around 560 nm $^{[29, 30]}$. On the contrary, UV/Vis absorption spectra of the prepared linoleic acid capped copper nanoparticles (average size of 5 nm) dispersed in chloroform show a featureless Mie scattering profile without the appearance of SPR$^{[9, 31]}$ as shown in the Fig. 3.25.

![Fig. 3.25: UV-Vis spectra of copper nanoparticles](image)

The absorption peak in the UV/Vis spectra, which was performed on Perkin Elmer Lambda 351.24 model, is obtained at 241 nm$^9$ and is in good agreement with the others results $^{[25, 31]}$. Linoleic acid capped copper nanoparticles dispersed in chloroform show light greenish colour due to this absorption$^9$. A good symmetry of the absorption spectra around the peak position indicates the narrow distribution of the particles produced, which has also been confirmed from TEM micrograph.
3.4.3.5 Fluorescence spectroscopy

In noble metal nanoparticles, the energy band splits into a series of energy levels in terms of the quantum size effect\(^6\). Further, the splitting of energy levels will be more distinct as the size of the nanoparticles becomes smaller\(^6\). The relationship between level spacing (\(\delta\)) and particle size is given by \(\delta \propto 1/d^2\), where \(d\) is the particle size (for a spherical particle)\(^9,25\). So the energy level splitting makes the electronic transition abundant in nanoparticles. As collective oscillation of electrons (SPR) is no longer available for dissipating the incident energy, transition from discrete valence states to excited states takes place in the Cu nanoparticle atoms\(^25\).

In case of copper, 3d valence and 4sp conduction electrons play the role for fluorescence. The outermost d and s electrons of all the constituent atoms of the nanoparticles create 6 bands. Five of these bands lie below the Fermi level, which are denoted as d bands and 6\(^{th}\) band, the last band which lie above the Fermi level is known as conduction band or sp band. In this sp band, there lies a lowest unoccupied molecular orbital (LUMO) and a highest occupied orbital (HOMO)\(^32\). Fig. 3.26 shows the solid state model for the origin of two emission peak.

![Solid-state model for the origin of the two PL bands](image)

Fig. 3.26. Solid-state model for the origin of the two PL bands

In copper nanoparticle capped by linoleic acid, an excitation at 250 nm lead to the excitation of d-band electrons into sp-conduction band. A radiative recombination of electron hole pair between d-band and sp-conduction band produces luminescence which occurs practically at 450 nm\(^9\). This high energy band is due to radiative
interband transition. In addition to this, a low energy band centered on 625 nm is observed\textsuperscript{9}, which can be attributed to the intraband transition between the HOMO-LUMO gaps\textsuperscript{32}.

![Flourescence spectra of Copper nanoparticles](image)

**Figure 3.27: Flourescence spectra of Copper nanoparticles**

Flourescence spectra for copper nanoparticle are shown in Fig. 3.27 which was performed on Hitachi; F-2500 model

**3.5 Conclusion:**

Particle sizes are estimated by XRD, TEM. All these studies give similar particle size.

Optical characterization has been done by FTIR, UV-Vis and photoluminescence (PL) study. FTIR study confirms the capping of linoleic acid to the silver, gold and copper nanoparticles. UV-Vis study shows that these nanoparticles gives absorption peak in the visible range and fluorescence of these nanoparticles gives emission peak in the visible range.
References


68


