

2.1: Sample Synthesis

2.1.1 : Overview

This chapter describes sample processing method and the experimental techniques, utilized in its characterisation. In the present investigations, samples were prepared by solid state reaction route and. Prepared compositions were characterized for their structural, magnetic and transport, optical properties.

2.1.2: Solid State Reaction Technique

The solid-state reaction route is the most widely used method for the preparation of polycrystalline solids from a mixture of solid starting materials. Solids do not react together at room temperature over normal time scales and it is necessary to heat them to much higher temperatures, often to 1000 to 1500 °C in order for the reaction to occur at an appreciable rate. The factors on which the feasibility and rate of a solid state reaction include, reaction conditions, structural properties of the reactants, surface area of the solids, their reactivity and the thermodynamic free energy change associated with the reaction. In solid state reaction technique reactant chemicals were taken in required stoichiometric ratio and mixed thoroughly. After mixing, the solid mixture was heat treated at higher temperature for several hours with intermediate grindings. Prior to heat treatment, pelletization of samples are preferred since it increases the area of contact between the grains. In solid state reaction technique, for CuMnO_2 , powders CuO , MnO and Fe_2O_3 were mixed in appropriate ratio and pressed into pellets. The pellets were then placed in an alumina crucible, sealed in quartz tube under high vacuum ($\sim 10^{-6}$ mbar) and heated at 950°C for 12 h.

2.2: Experimental Tools & Their Working Principle:-

2.2.1: X-ray diffraction pattern

Diffraction can occur when any electromagnetic radiation interacts with a periodic structure. The repeat distance of the periodic structure must be about the same wavelength of the radiation. X-rays are electromagnetic wave of very short wavelength on the order of a few angstroms (1 Angstrom = 0.1 nm). So they are very high energy electromagnetic wave. Bending of electromagnetic wave around the

corners of an obstacle is called diffraction. Size of apperture or obstacle must be comparable to wavelength of wave. These (1-10 Angstrom) are the typical inter-atomic distance in crystalline solids, making X-rays the correct order of magnitude for diffraction of atoms of crystalline materials. When X-rays are scattered from a crystalline solid they can constructively interfere, producing a diffracted beam. X-ray pattern of a given powder sample is obtained by measuring the intensity with the variation of the angle (2θ).

Braggs law:-

The relationship describing the angle at which a beam of X-rays of a particular wavelength diffracts from a crystalline surface was discovered by Sir William H. Bragg and Sir W. Lawrence Bragg and is known as Bragg's Law [1]

$$2d\sin\theta = n\lambda$$

λ = wavelength of the x-ray

θ = scattering angle or Braggs angle , measure from the crystal surface.

n = integer representing the order of the diffraction peak

d = inter-plane distance of (i.e atoms, ions, molecules)

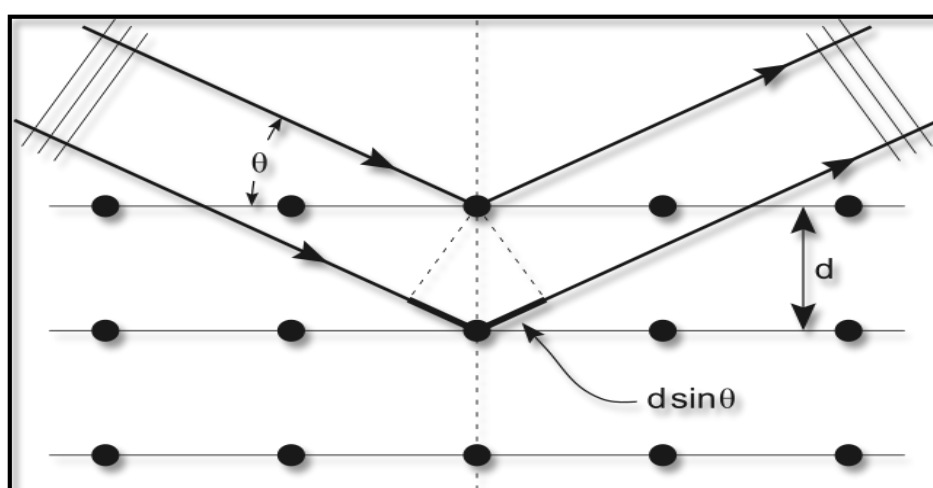


Fig. 2.1: Schematic diagram of X-ray diffraction [1]

From the X-ray pattern following information can be obtained: Phase identification can be done by matching the XRD pattern with reference patterns (JCPDS–ICDD file) of pure substances. Quantitative information on single phase and multi-phase materials can be obtained using pattern calculation and pattern fitting methods (so-called Rietveld refinement). In combination with the use of standard materials, this approach can supply accurate values for sample composition, crystal symmetry, unit-cell dimensions, atom positions, site-occupancy factors and many more for pure as well as doped samples. It has been assumed that a perfect crystal that would extend in all directions to infinity, so one can say that no crystal is perfect due to its finite size. The effect of this deviation from perfect crystallinity leads to the broadening of a diffraction peak. However, above a certain size (100-500 nm), this type of broadening is negligible. It was observed that small crystallite size could give rise to line broadening. A well-known equation relating the crystallite size to the line broadening, which is called 'Debye-Scherrer Formula and mathematically given as:

$$D = \frac{0.9\lambda}{\beta \cos \theta}$$

D is the average crystallite size, λ is the wavelength of the X-rays (1.5406 Å), and θ and β are the diffraction angle and full-width at half maximum (FWHM) of the peak in the XRD pattern, respectively. For β correction, β_{inst} (FWHM due to instrument) is removed using *Si* standard. It is termed as average crystallite size because the X-rays beam irradiates a large number of crystallites so that the value of d obtained represents the mean value of the actual size distribution.

In order to understand the structural analogue and site symmetry variation to influence the luminescence properties, their structural information has to be known more precisely. R.M. Rietveld [2] has firstly developed a structure profile refinement method for powder diffraction data of X-ray and Neutron radiations. Rietveld refinement method creates an effective separation of these overlapping data, thereby allowing an accurate determination of structure. In the Rietveld refinement the least square refinement is carried out until the best fit is obtained between the entire observed powder diffraction patterns taken as a whole and entire calculated pattern

based on simultaneously refined model for crystal structure. Therefore applying the Rietveld refinement method to a powder diffraction pattern, it is possible to obtain much more information about the structure factors of the material. The shape of a powder diffraction reflection is influenced by the characteristics of the beam, the experimental arrangement, and the sample size and shape. In the case of monochromatic neutron source the convolution of the various effects has been found to result in a Gaussian shape. If the distribution is assumed to be Gaussian, then the contribution of a given reflection to the profile y_i at position $2\theta_i$ is:

$$y_i = I_k \exp \left[\frac{-4 \ln(2)}{H_k^2} (2\theta_i^2 - 2\theta_k^2) \right]$$

where H_k is the full width at half peak height (full-width half-maximum), $2\theta_k$ is the centre of the reflex, and I_k is the calculated intensity of the reflex (determined from the structure factor, the Lorentz factor, and multiplicity of the reflection). At very low diffraction angles the reflections may acquire an asymmetry due to the vertical divergence of the beam. Rietveld used a semi-empirical correction factor, A_s to account for this asymmetry: where P is the asymmetry factor and s is +1,0,-1 depending on the difference $2\theta_i - 2\theta_k$ being positive, zero or negative respectively.

$$A_s = 1 - \left[\frac{sP(2\theta_i - 2\theta_k)^2}{\tan \theta_k} \right]$$

The width of the diffraction peaks are found to broaden at higher Bragg angles. This angular dependency was originally represented by

$$H_k^2 = U \tan^2 \theta_k + V \tan \theta_k + W$$

where U , V and W are the half width parameters and may be refined during the fit. The principle of the Rietveld Method is to minimize a function M which analyzes the difference between a calculated profile y_{calc} and the observed data y_{obs} . The function M is derived as:

$$M = \sum_i W_i \left\{ y_i^{\text{cal}} - \frac{1}{c} y_i^{\text{obs}} \right\}^2$$

where W_i is the statistical weight and c is an overall scale factor such that $y^{cal} = y^{obs}$. In present thesis, Rietveld refinement has been performed using Foolproof software.

2.2.2: Neutron diffraction :

Neutrons have been found to be extremely useful in studying magnetism in condensed matter. They give the most direct information on the arrangement of magnetic moments in a specimen. Neutrons are produced in great quantities by fission reactions inside the fuel elements of nuclear reactors. The beam of neutrons which emerges from a reactor has a spectrum of energies determined by the temperature T of the moderator, usually room temperature but T can be higher or lower if the moderator is heated or cooled. Neutrons emerging from the reactor therefore have a distribution of velocities given by

$$n(v) = v^3 \exp\left(-\frac{\frac{1}{2}M_n v^2}{K_B T}\right)$$

Where $n(v)dv$ is the number of neutrons through unit area per second and M_n is the mass of the neutron. The distribution contains a Boltzmann factor and a v^3 term which is the product of a phase space factor v^2 (as for the Maxwellian distribution of velocities in kinetic theory) and a factor of v due to effusion through the hole.

The maximum of this distribution is at

$$v = \sqrt{\frac{3K_B T}{M_n}}$$

which corresponds to the condition

$$\frac{1}{2}M_n v^2 = \frac{3}{2}K_B T$$

The de Broglie wavelength λ of a neutron with velocity v is

$$\lambda = \frac{h}{M_n v}$$

The distribution function is plotted as a function of wavelength. This demonstrates that thermal neutrons have wavelengths similar to atomic spacings, thus permitting diffraction measurements to be performed.

Particle nature:

Charge:- charge less

Mass:- $1.67 \times 10^{-27} kg$

Spin:- $1/2$

Magnetic moment:- $-1.913\mu_N$

Velocity:- (2200m/s for thermal neutrons of energy 25 meV)

Wave nature:

(1) Diffraction and interference pattern (2) Measurable wavelength (3) Measurable scattering length. As the neutron does not carry any electric charge, the neutron has no electrostatic interaction with the electron cloud of an atom. For this reason the neutron has higher penetration power comparable to X-ray or electrons.

Neutron has a spin $\frac{1}{2}$ and no charge, which is why the electron cloud are invisible to them. However if an atom has a net magnetic moment, the neutrons magnetic moment can directly couple to it. The result is that spin-up and spin- down electronic moments look different to neutrons. Hence, when a sample becomes magnetic, new peaks can appear in the neutron diffraction. The magnitude of the magnetic Braggs peaks can be used the measured of the strength of the magnetic order. Hence the magnetic order can be followed as a function of temperature.

The amplitude of the scattering from a magnetic moment depends on a direction of the alignment of the moment. Hence neutron diffraction can be used to determine the arrangement of the atomic magnetic moments in a magnetically ordered crystal.

2.2.3: Superconducting Quantum Interference Device

Superconducting quantum interference device is a mechanism used to measure extremely weak signals, such as changes in the human body's electromagnetic energy field. The superconducting quantum interference device (SQUID) consists of two

superconductors separated by thin insulating layers to form two parallel Josephson junctions. The device may be configured as a magnetometer to detect incredibly small magnetic fields small enough to measure the magnetic fields in living organisms.

VSM Measurement Theory:

VSM theory based on a 2ω detection principle, detection coils only generate a current in response to local magnetic field disturbances.

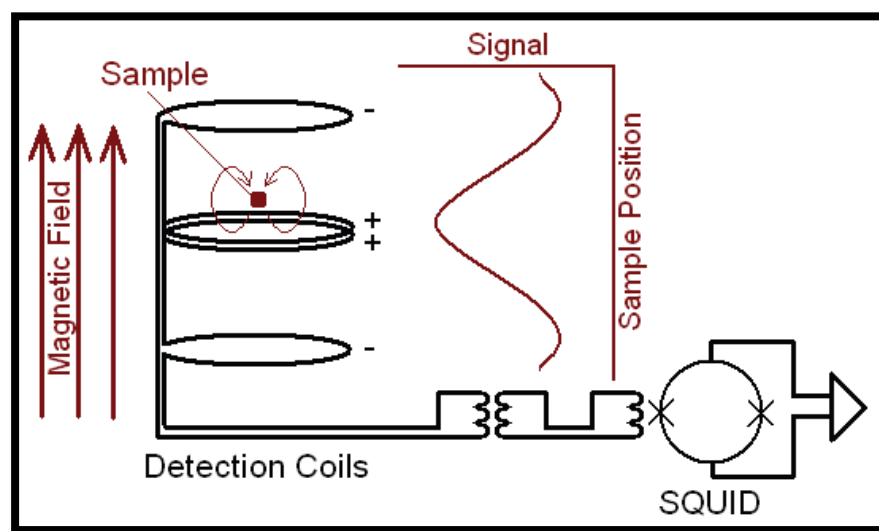


Figure 2-2. SQUID detection schematic[4].

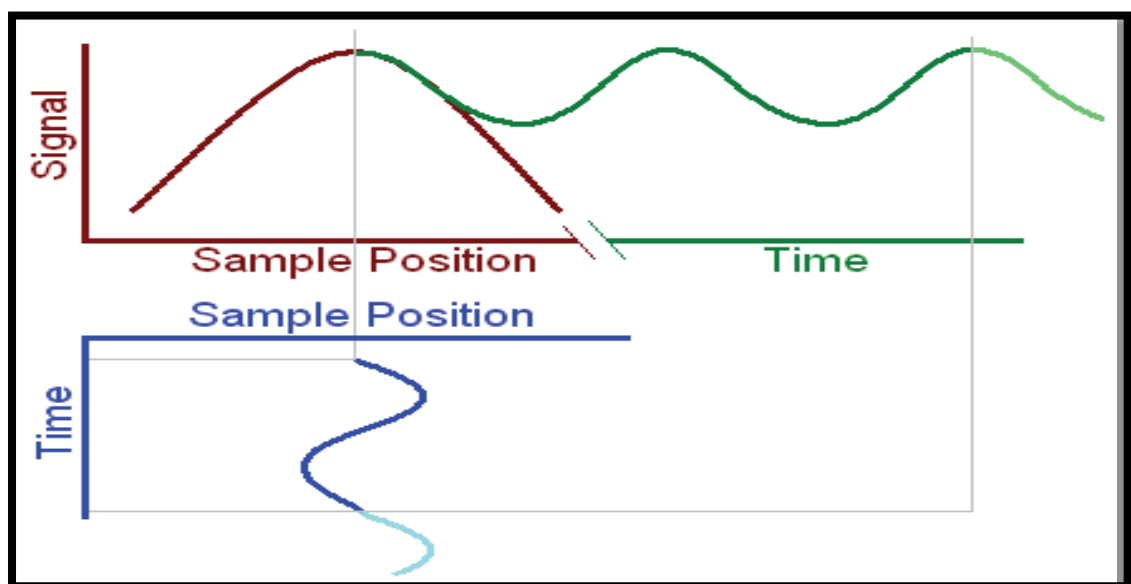


Figure 2-3. 2ω detection principle[4].

The current in the detection coils is inductively coupled to the instrument's SQUID, which serves as an extremely sensitive current-to-voltage converter. The SQUID voltage is amplified and digitized by the instrument electronics. The SQUID VSM measurement technique vibrates the sample at frequency ω about the very center of the detection coils, where the signal peaks as a function of sample position, z . This generates a SQUID signal, V , as a function of time, t :

$$V(t) = AB^2 \sin^2(\omega t)$$

because $V(Z) = Az^2$ for small vibration amplitudes, and $z(t) = B \sin(\omega t)$. Here, A is a scaling factor relating to the magnetic moment of the sample. B is the amplitude of sample vibration. Since $\sin^2(\omega t) = \frac{1}{2} - \frac{1}{2} \cos(2\omega t)$ the techniques of a lock-in amplifier may be applied to isolate and quantify the signal occurring at frequency 2ω .

DC susceptibility:

In the dc measurement, the magnetic moment of the sample does not change with time. Thus, a static magnetic measurement is performed. The sample is magnetized by a constant magnetic field and the magnetic moment of the sample is measured, producing a DC magnetization curve $M(H)$.

AC susceptibility:

In AC In the ac measurement, the moment of the sample is actually changing in response to an applied ac field, allowing the dynamics of the magnetic system to be studied. In magnetic measurements, a small AC drive magnetic field is superimposed on the DC field, causing a time-dependent moment in the sample. The field of the time-dependent moment induces a current in the pickup coils, allowing measurement without sample motion. One advantage of the AC measurement is already evident: the measurement is very sensitive to small changes in $M(H)$. Since the AC measurement is sensitive to the slope of $M(H)$ and not to the absolute value, small magnetic shifts can be detected even when the absolute moment is large.

(1) At very low frequencies: In order to understand what is measured in AC magnetometry, where the measurement is most similar to DC magnetometry.

In this case, the magnetic moment of the sample follows the $M(H)$ curve that would be measured in a DC experiment. As long as the AC field is small, the induced AC moment is

$$M(AC) = \left(\frac{dM}{dH}\right) H_{AC} \sin(\omega t)$$

Where H_{AC} is the amplitude of the driving field, ω is the driving frequency, and $\chi = \frac{dM}{dH}$ is the slope of the $M(H)$ curve called the susceptibility. As the DC applied magnetic field is changed, different parts of the $M(H)$ curve are accessed, giving a different susceptibility.

(2) At higher frequencies:

The AC moment of the sample does not follow along the DC magnetization curve due to dynamic effects in the sample. For this reason, the AC susceptibility is often known as the dynamic susceptibility. In this higher frequency case, the magnetization of the sample may lag behind the drive field, an effect that is detected by the magnetometer circuitry. Thus, the AC magnetic susceptibility measurement yields two quantities: the magnitude of the susceptibility, χ , and the phase shift, ϕ . Alternately, susceptibility as having an in-phase, or real, component χ' and an out-of-phase, or imaginary, component χ'' . AC susceptibility is a complex value expressed as

$$\chi_{AC} = \chi' - \chi''$$

where the χ' real component related to the reversible magnetization process, stays in-phase with the oscillating field. $H(t) = H_0 A \cos(2\pi f t)$. The imaginary component χ'' is related to losses due to the irreversible magnetization process and energy absorbed from the field, as the phase shift θ may occur in magnetization $M(t)$ in respect of $H(t)$ given

$$M(t) = M_0 + B \cos(2\pi f t - \theta),$$

$$\chi' = \frac{B \cos\theta}{A},$$

$$\chi'' = \frac{B \sin\theta}{A}$$

where A and B is the amplitude and H_0 is the static bias field. The real component χ' represents the component of the susceptibility that is in phase with the applied ac field, while χ'' represent the component that is out of phase. The imaginary component χ'' is related to the energy losses, or in other words, the energy absorbed by the sample from the ac field. Relaxation and irreversibility in spin-glasses give rise to a nonzero χ'' . Irreversibility is a result of relaxation processes of various origin, like the irreversible movement of domain walls, small hysteresis loop in ferromagnets, spin lattice relaxation in paramagnets, relaxation of superparamagnets. Additional information on phase transition may be obtained from nonlinear susceptibilities, as in general case.

$$M(H) = M_0 + \chi_1 H + \chi_2 H^2 + \chi_3 H^3 + \dots \dots \dots$$

where χ_1 first order, χ_2 second order, χ_3 third order susceptibilities. Nonlinear χ_2 and χ_3 , determined from the signals detected at the frequency 2f and 3f, are called second and third harmonics and are expressed as $\frac{1}{2}\chi_2 h$ and $\frac{3}{4}\chi_3 h$ respectively.

Typical measurements to access this information are χ vs. temperature, χ vs. driving frequency, χ vs. DC field bias, χ vs. AC field amplitude, and harmonic measurements.

2.2.4: Dielectric Measurement:

The dielectric spectroscopy is very sensitive and useful technique to analyzing the insulating and semiconducting materials to probe various phenomena's like dipolar relaxation, dipolar ordering, electrical conduction. The dielectric results generally presented in the electrical permittivity form both real and imaginary parts

$\varepsilon^* = \varepsilon' - i\varepsilon''$. The ε' (ε'') is known as real (imaginary) permittivity, and depends on several physical properties other than frequency e.g., temperature,

electric/magnetic fields, pressure etc. There are many important features related to the dielectric spectroscopy. Dielectric relaxation (using ε^*), Impedance spectroscopy (using Z^*), and Electrical relaxation spectroscopy (using M^*) are all interrelated; experiments actually measure ($Z^* = \frac{1}{\sigma}$) in all the cases.

Working Principle of Analyzer: Alpha-A High Performance Frequency Analyzer from NOVO-CONTROL has been used for dielectric studied. The specimen is typically placed in between two metal electrodes, forming a parallel-plate type configuration. For the measurement, specimen is energized by a harmonic signal $V_s(f)$ with the help of a voltage generator, and the current $I_s(f)$ and phase shift are measured across the sample with two phase-sensitive voltammeters.

The impedance Z^* is calculated from simple Ohm's law

$$Z^* = \frac{V_s(f)}{I_s(f)}$$

The measured sample impedance is connected with the sample capacitance as follows.

$$C^* = \frac{-i}{2\pi f Z^*}$$

Dielectric permittivity is determined ($\varepsilon^* = \varepsilon' - i\varepsilon'' = \frac{C^* d}{\varepsilon_0 A}$)

2.2.4.1: The Analytical Approach:

Debye (1927) recognized that dielectric relaxation, which appears as dispersion of the real permittivity (ε') and of the dielectric absorption (ε'') peaks in the f -domain for dipolar liquids and solids, was due to the reorientational motion of the dipoles.

In the Debye theory, the exponential decay of the dipolar correlation function is

$$\varphi(\tau) = \exp\left(-\frac{\tau}{\tau_D}\right)$$

Here τ_D is a characteristic relaxation time, depends on the temperature and the material-nature. Fourier transform, complex dielectric permittivity is written in the frequency domain as follows.

$$\epsilon^*(\omega) = \epsilon_\infty + \left[\frac{\epsilon_s - \epsilon_\infty}{1 - i\omega\tau_D} \right]$$

Here ϵ_s and ϵ_∞ low and high frequency responses in the permittivity. The complex permittivity has both the real(ϵ') and imaginary (ϵ'') parts;

$$\epsilon'(\omega) = \epsilon_\infty + \left[\frac{\epsilon_s - \epsilon_\infty}{1 + \omega^2\tau_D^2} \right] \quad \text{and} \quad \epsilon''(\omega) = \left[\frac{(\epsilon_s - \epsilon_\infty)\omega\tau_D}{1 + \omega^2\tau_D^2} \right]$$

$\epsilon_s - \epsilon_\infty = \Delta\epsilon$ is known as the dielectric strength.

Ideal Debye-like relaxation is rarely observed, and relaxation peak associated with relaxation broader and asymmetric in nature contraire to Debye theory. The symmetrical broadening of relaxation peak can be described by the **Cole-Cole function**.

$$\epsilon_{CC}^* = \epsilon_\infty + \left[\frac{\epsilon_s - \epsilon_\infty}{1 + (i\omega\tau_{CC})^\alpha} \right]$$

Here α is symmetrical broadening parameter and has the value in the limit $0 < \alpha \ll 1$ when $\alpha = 1$ its again equivalent Debye function.

In some materials asymmetry broadening is also observed particularly on low molecular glass-forming materials or liquids their dielectric spectra can be described **Cole-Davidson function**

$$\epsilon_{CD}^*(\omega) = \epsilon_\infty + \left[\frac{\epsilon_s - \epsilon_\infty}{1 + (i\omega\tau_{CD})^\gamma} \right]$$

Here γ is symmetrical broadening parameter and has the value in the limit $0 < \gamma \ll 1$ when $\gamma = 1$. Its again equivalent Debye function. The most frequently observed time-domain behaviour to describe the asymmetric broadening is the empirical Kohlrausch/Williams/Watts-function

$$\varphi(\tau) = \exp \left[- \left(\frac{\tau}{\tau_{KWW}} \right)^{\beta_{KWW}} \right]$$

Where β_{KWW} is the asymmetric-broadening parameter ($0 < \beta_{KWW} \ll 1$) pure exponential decay corresponds to the Debye process ($\beta_{KWW} = 1$). $\varphi(\tau)$ is the superposition of individual exponential-relaxation times.

In ω –domain, the most general non-Debye relaxation is described by the Havriliak-Negami (H-N) formulation the KWW behaviour in t -domain, as a combination of Cole-Cole and Cole-Davidson spectral-functions

$$\epsilon_{HN}^*(\omega) = \epsilon_{\infty} + \left[\frac{\epsilon_s - \epsilon_{\infty}}{(1 + (i\omega\tau_{HN})^{\alpha})^{\gamma}} \right]$$

α and γ respectively parameterize the broadening and asymmetry associated with the relaxation peak.

2.2.5: UV- Visible absorption measurement

A double beam UV-VIS spectrometer has been used to record the absorption spectrum in the range 200 – 1100 nm. The simple block diagram of the spectrometer is shown in Figure 2.6. Two light sources, a tungsten halogen lamp and a deuterium lamp, are used in most of the spectrometer to cover the given wavelength range. A lamp selection mechanism is present to select desired light source. In this case, radiation from continuous light source passes through a mono-chromator and resolved into its constituent wavelengths. A chopper is used to split the incoming light into two beams. One beam is passed through the reference sample and the other beam through the sample. The signals from the reference and the main sample are detected at photodiode 1 and 2, respectively. The difference amplifier is used to amplify the difference of signals detected by detector1 and 2. The obtained spectrum is displayed on the computer as a function of wavelength Vs absorbance. The intensity of sample and reference beam is defined as I and I_0 . A ratio of I/I_0 is measured verses wavelength. The UV and visible scan is performed in the range 200-400 nm and having range from 400-800 nm, respectively. Absorption is expressed as:

$$A = \log_{10} \left(\frac{I_0}{I} \right)$$

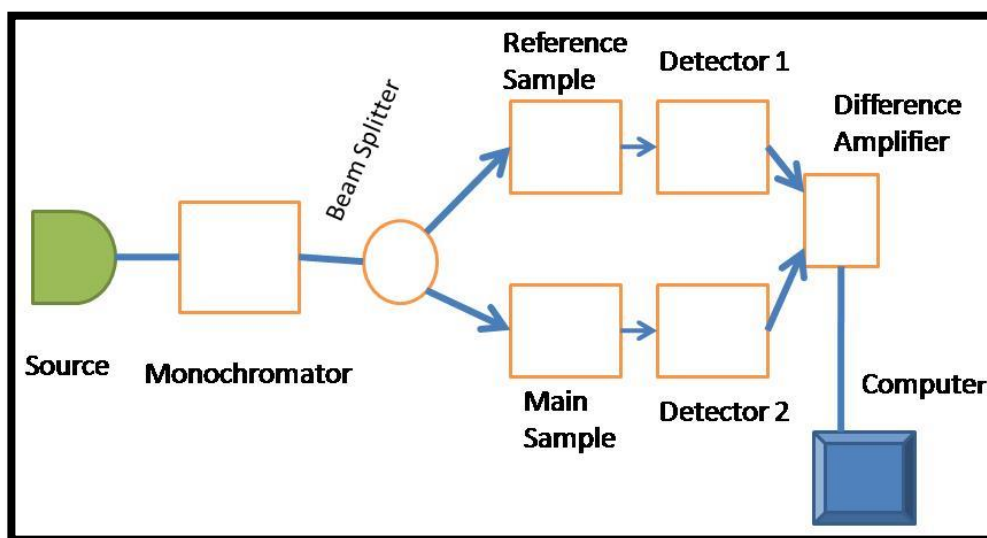


Figure 2.4: Block diagram showing the principle of UV-VIS spectrometer.

The wavelength corresponding to maximum absorbance is a characteristic value termed as $\lambda_{\max}$. For highly absorbing compounds, absorption is performed in dilute solution. For these highly transparent solvents is required. The most commonly used solvents are namely water, ethanol, hexane and cyclohexane. One can generally avoid the use of solvents having double or triple bonds or heavy metals as S, Br and I. Since the absorbance of a sample is proportional to its molar concentration in the sample cuvette under consideration. In order to compare the different spectra of the compound, a corrected absorption value known as molar absorptivity is used. This is defined as Beer-Lambert law:

$$\text{Absorbance } A = \varepsilon cL$$

$$\text{Molar absorptivity, } \varepsilon = \frac{A}{cL}$$

Where c is sample concentration in mole/liter and L is the path length of the beam through the cuvette in centimetre.

2.2.6: X-ray Photoelectron Spectroscopy

X-ray photoelectron spectroscopy (XPS or ESCA) owes its quantification to Einstein's explanation of the photoelectric effect in 1905. X-ray photoelectron

spectroscopy (XPS) is a quantitative spectroscopic technique that measures the elemental composition, empirical formula, chemical state and electronic state of the elements that exist within a material [3]. XPS spectra are obtained by irradiating a material with a beam of X-rays while simultaneously measuring the kinetic energy and number of electrons that escape from the top 1 to 10 nm of the material being analyzed. XPS requires ultra-high vacuum (UHV) conditions, typically $\sim 10^{-10}$ torr. This facilitates the transmission of the photoelectrons to the analyzer but more importantly minimizes the re-contamination rate of a freshly cleaned sample. In XPS, the sample is irradiated with low-energy (~ 1.5 keV) X-rays, in order to provoke the photoelectric effect. The energy spectrum of the emitted photoelectrons is determined by means of a high-resolution electron spectrometer. A typical XPS spectrum is a plot of the number of electrons detected (sometimes per unit time) (Y-axis, ordinate) versus the binding energy of the electrons detected (X-axis, abscissa). Each element produces a characteristic set of XPS peaks at characteristic binding energy values that directly identify each element that exist in or on the surface of the material being analyzed. These characteristic peaks correspond to the electron configuration of the electrons within the atoms, e.g., 1s, 2s, 2p, 3s, etc. The number of detected electrons in each of the characteristic peaks is directly related to the amount of element within the area (volume) irradiated. To generate atomic percentage values, each raw XPS signal must be corrected by dividing its signal intensity (number of electrons detected) by a "relative sensitivity factor" (RSF) and normalized over all of the elements detected.

The electron binding energy of each of the emitted electrons can be determined by using an equation that is based on the work of Ernest Rutherford (1914):

$$E_{\text{Binding}} = E_{\text{Photon}} - (E_{\text{Kinetic}} + \phi)$$

where E_{Binding} is the binding energy (BE) of the electron, E_{Photon} is the energy of the X-ray photons being used, E_{Kinetic} is the kinetic energy of the electron as measured by the instrument and ϕ is the work function of the spectrometer (not the material).

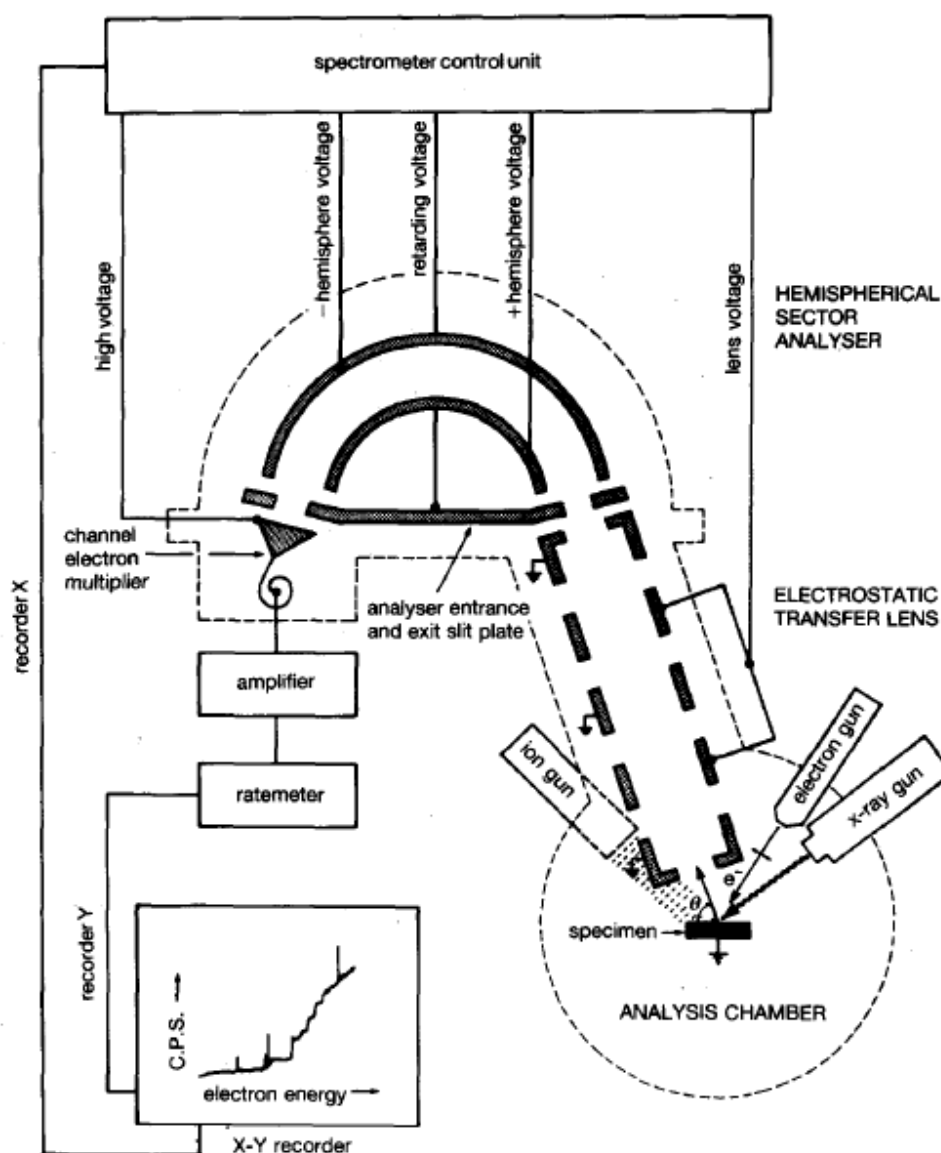


Fig.2.5: Schematic diagram of X-ray photoemission spectroscopy.

2.2.7: Resistivity Measurement

Measuring the value of a resistor with an ohmmeter is pretty simple. You connect the meter to the resistor, and read off the measurement from the meter. But what if the resistance you want to measure is very low (in the milli- or micro-ohm range)? In this case, the two-point method is not satisfactory because test contact resistance becomes a significant factor. A similar problem occurs, when making ground mat resistance tests, because long lead lengths (up to 1000 feet) are used. Here also, the lead

resistance, due to long lead length, will affect the measurement results. The four-point resistance measurement method eliminates lead resistance or contact resistance.

An ohmmeter measures all resistance in the circuit loop, which includes the resistance of the wires connecting the ohmmeter to the component being measured. Such a scenario would be problematic if the connecting wires are very long, and/or the component to be measured has a very low resistance, and then the measurement error introduced by wire resistance will be substantial.

An ingenious method of measuring the subject resistance in a situation like this involves the use of both an ammeter and a voltmeter. We know from Ohm's Law that resistance is equal to voltage divided by current ($R = V/I$). Thus, we should be able to determine the resistance of the subject component if we measure the current going through it and the voltage dropped across it. Current is the same at all points in the circuit, because it is a series loop. Because we are only measuring voltage dropped across the subject resistance (and not the wire's resistances), though, the calculated resistance is indicative of the subject component's resistance alone.

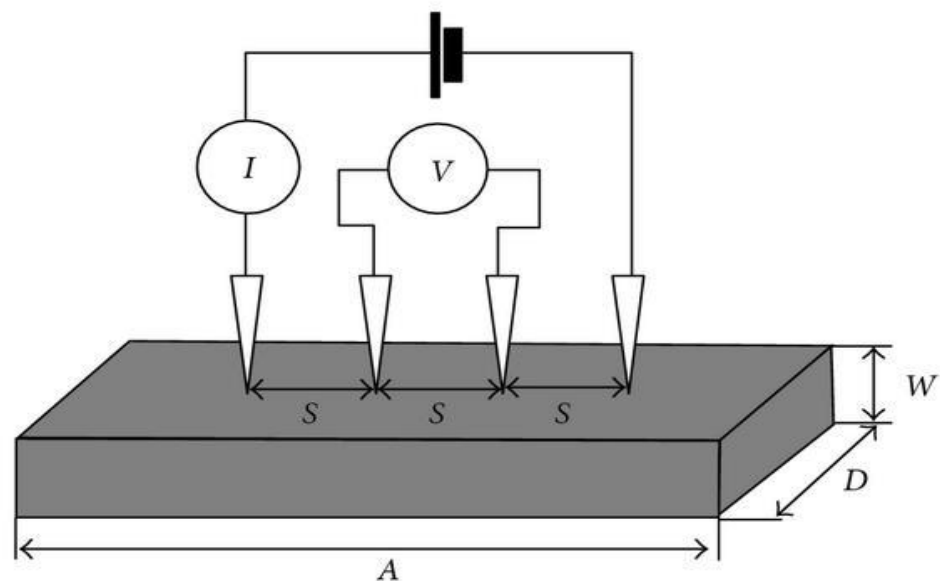


Fig.2.6: Schematic diagram of test circuit for measuring resistivity with the four-point probe method.

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