# Chapter 2

# Characterization Techniques

For any good analysis of the synthesized products good characterization is required to get an insight into the nature, type and characteristics of the product. The details of the experimental set up and the tools having been used for characterization of the synthesized phosphor have been elaborated in this chapter. The tools used for characterization in this study are as follows:

(a) X-ray diffraction technique

(b) Scanning Electron Microscopy

(c) Spectrofluorophotometer (SPF)

(d) Thermoluminescence (TL) Glow curve recorder

(e) Calculation of CIE coordinates

**2.1 X-ray Diffraction**

X-ray diffraction is one of the most promising and extensively used tools for any material characterization today. A tool used as a fingerprint for determination of crystalline material and for determination of their crystal structure. All crystalline materials have atoms in a regular periodic arrangement which is lacking in amorphous materials. Atoms are arranged in a three dimensional frame of points created by translation vector defined in terms of three fundamental translation vectors a, b and c known as lattice. A lattice is a periodic arrangement of a smallest chosen block, called unit cell. The crystalline solid can be classified within the seven crystal system, which are further sub divided into 14 Bravis lattices. The table-1 below explains all the groups point groups and figure the hierarchy of symmetries among the seven crystal systems.

| | Bravais Lattice (Basis of spherical Symmetry) | Crystal structure (Basis of arbitrary Symmetry) |
|---|---|---|
| Number of point groups: | 7 ("the crystal system") | 32 ("the crystallographic point groups") |
| Number of space groups: | 14 ("the Bravais Lattices") | 230 ("the 230 space groups") |

**Table -1: Point and space groups of Bravais Lattices and crystal structure.**

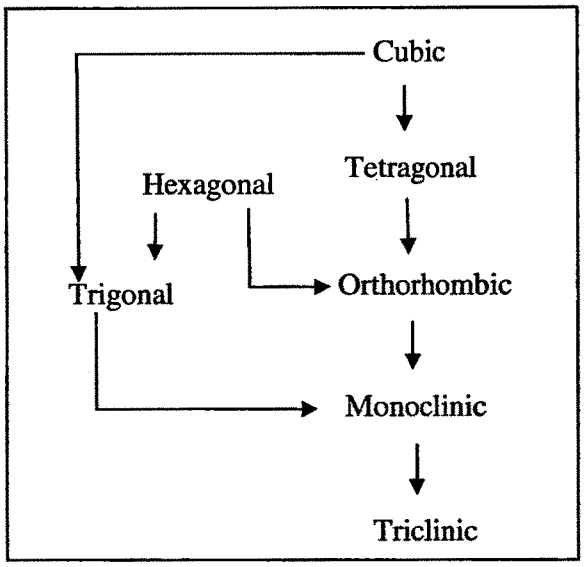



**Figure-1 The hierarchy of symmetries among the seven crystal systems. Each Bravais lattice point group contains all those that can be reached from it by moving in the direction of the arrows.**

### 2.1.1 Characterization of solid state materials

The basic properties of solid state, in particular, crystalline materials are well known. The characterization can thus be classified into several major headings like phase (compositional and structural), physical and chemical properties. The characterization of physical properties of materials is mostly pertaining to the electrical, dielectric, magnetic and optical properties. However, prior to any study of solid state materials main emphasis is paid on the phase and structural characterizations. Most of the techniques are complimentary to each other, but the phase characterization by X-ray diffractometer (henceforth denoted as XRD) has been of importance sine the observation of diffraction behaviour of X-ray in a periodic system. The fundamental properties of X-rays can be read from any solid state physics book. By analogy with diffraction of light by an optical grating, crystals with their regular repeating structures, should be capable of diffracting radiation that has a wavelength similar to the interatomic separation, ~1Å. Three types of radiation are used for crystal diffraction studies: X-rays, electrons and neutrons. Of these X-rays are by far the most useful. The X-ray wavelength commonly employed is the characteristic Kα radiation, $\lambda = 1.5418$Å, emitted by copper. When crystals diffract X-rays, it is the atoms or ions which act as secondary point sources and scatter the X-rays; in the optical grating, it is the

lines scratched or ruled on the glass surface which cause scattering. Historically, two approaches have been used to treat diffraction by crystals. These are as follows.

### 2.1.2 The X-ray diffraction experiment

When reduced to basic essentials, the X-ray diffraction experiment, figure-2, requires an X-ray source, the sample under investigation and detector to pick up the diffracted X-rays. Within this broad framework, there are three variables which govern the different X-ray techniques:

(a) radiation- monochromatic or of variable lambda;

(b) sample- single crystal, powder or a solid piece;

(c) detector- radiation counter or photographic film.

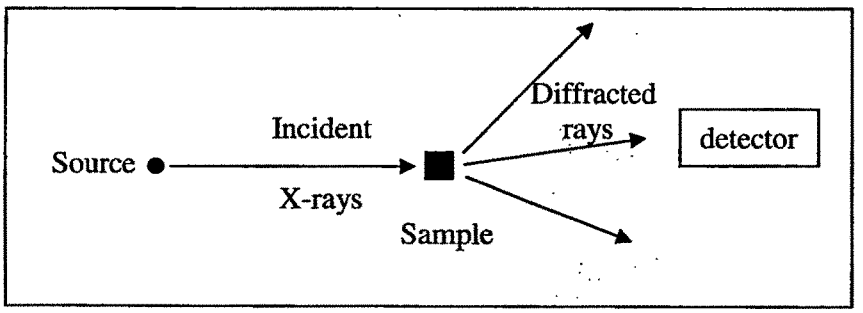



**Figure-2 The X-ray diffraction experiment**

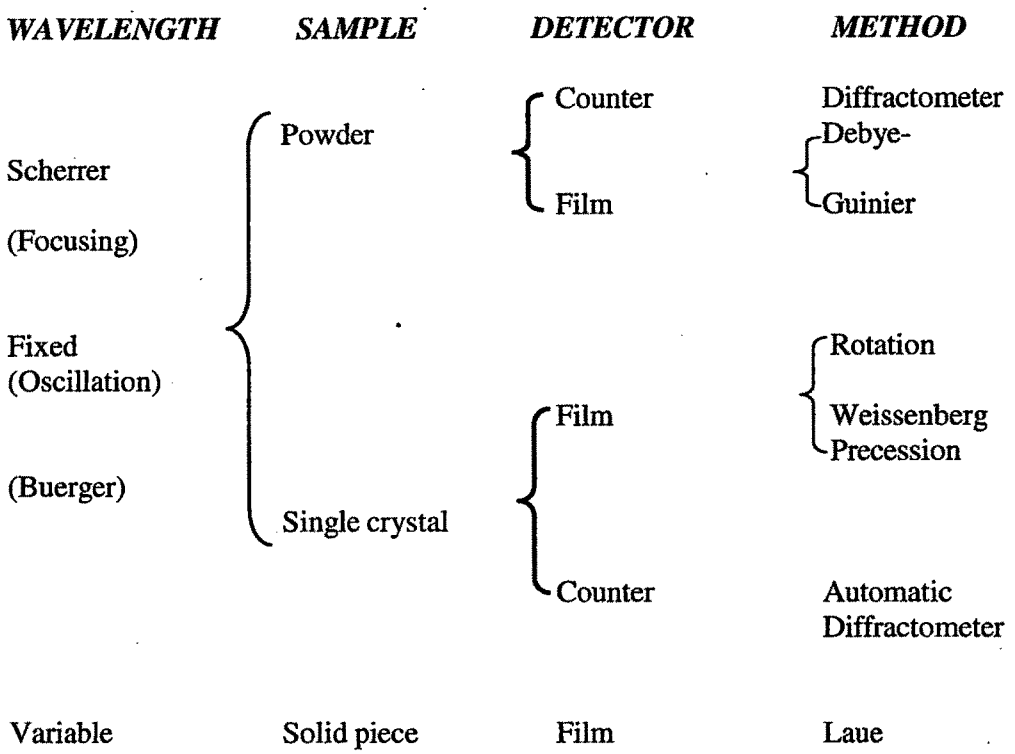



**Figure-3 The different X-ray diffraction techniques**

Important techniques have been summarized in figure-3 with the exception of Laue method, which is used almost exclusively by metallurgists and is not discussed here, monochromatic radiation is nearly always used. An outline of the powder and single crystal method is given in this section with a more comprehensive account of powder method.

### 2.1.3 The powder method-principles and uses

The principles of the powder method are shown in figure-2. A monochromatic beam of X-rays strikes a finely powdered sample that, ideally, has crystals randomly arranged in every possible orientation. In such a powder sample, the various lattice planes are also present in every possible orientation. For each set of planes, therefore, at least some crystals must be oriented at the Bragg angle, $\theta$, to the incident beam and thus, diffraction occurs for these crystals and planes. The diffracted beams may be detected either by surrounding the sample wit a strip of photographic film (Debye-Scherrer and Guinier focusing methods) or by using a movable detector, such as a Geiger counter, connected to a chart recorder

(diffractometer). The original powder method, the Debye-Scherrer method, is little used nowadays, but since it is simple it is instructive to consider its mode of operation. For any set of lattice planes, the diffracted radiation forms ate surface of a cone, as shown in figure-5.29. The only requirement for diffraction is that the planes be at angle θ to the incident beam; no restriction is placed on the angular orientation of the planes about the axis of the incident beam. In the finely powdered sample, crystals are present at every possible angular position about the incident beam and the diffracted beams that result appear to be emitted from the samples as the cone of radiation.

A powder pattern has three main features that may be measured quantitatively. In decreasing order of relative importance, these are (a) d-spacings, (b) intensities and (c) line profiles.

### 2.1.4 Effect of crystal size on the powder pattern-particle size measurement

Phase identification: Each crystalline substance has its own characteristics powder diffraction pattern which may be used for the identification. Standard patterns are given in the Powder Diffraction File (known as the JCPDS File or, formerly, as ASTM Files). The inorganic section of the File now contains over 35000 entries and is increasing at the rate of about 2000 per year. The powder X-ray method may be used as a rough check on purity provided the impurities are present as a separate crystalline phase(S). The lower limit of detection of impurity phases in routine work is usually in the range of 1 to 5 percent.

X-ray powder diffraction may be used to measure the average crystal size in a powdered sample, provided the average diameter is less than about 2000A. The lines in a powder diffraction pattern are of finite breadth but if the particles are very small the lines are broader than as usual. The broadening increases with decreasing particle size. In the absence of extra broadening due to small particle size, powder lines or peaks have a finite breadth for several reasons: the radiation is absolutely monochromatic, the Kα line has an intrinsic breadth due to Heisenberg's uncertainty principle and the focusing geometry of the instrument may not be perfect for a variety of reasons. In order to understand why small particle size leads to broadening it is necessary to consider the conditions under

which diffraction may occur if the incident angle is slightly different from the Bragg angle, $\theta_B$.

The commonly accepted formula for calculating particle size is the Scherrer formula:

$$d = \frac{0.9\,\lambda}{\beta \cos\theta_B}$$

where d is the thickness of the crystal (in angstroms), $\lambda$ the X-ray wavelength and $\theta_B$ the Bragg angle and $\beta$ is the Line Broadening (Full width Half-maximum in radians).

The main advantages and importance of X-ray diffraction are as follows:

(a) A powder pattern is a crystal's 'fingerprint'.

(b) Qualitative phase analysis can be efficiently done.

(c) The shape and size of the unit cell can be estimated.

(d) The atomic number and position of the various atoms in a cell.

(e) From the d-spacing of the X-ray diffraction pattern the crystallite size can be determined.

(f) Determination of the lattice parameters, like, a, b, c, $\alpha$, $\beta$, $\gamma$ and thus the crystal structure.

## 2.2 Scanning Electron Microscopy (SEM)

Electron microscopy is an extremely versatile technique capable of providing structural information over a wide range of magnification. At one extreme scanning electron microscopy (SEM) compliments optical microscopy for studying the texture, topography and surface feature of powders or solid pieces; features up to tens of micrometer in size can be seen and, because of depth of focus of SEM instruments, the resulting pictures have a definite three-dimensional quality. The scanning electron microscope is an instrument, which is used to observe the morphology of a sample at higher magnification, higher resolution and depth of the focus compared to an optical microscope. Herein, an accelerated beam of mono-energetic electrons is focused on to the surface of the sample and is scanned over it on a small area. Several signals are generated and appropriate ones are collected depending on the mode of operation. The signal is amplified and made to form a synchronous image on a cathode ray tube, the contrast resulting from the morphological changes and variation of atomic number over the area probed. A camera is used to photograph the image or it may be digitized and processed on a computer. The characteristics X –ray emitted may be analyzed for their energy and intensity (EAX), the energy being the signature of the element emitting them and the intensity as to how much of it is present.

### 2.2.1 Typical Resolutions

Resolution is related to probe size and its value is typically ~0.1mm for human eye. The probe size is ~2000A for a UV microscope ~0.1A for high energy electro-magnetic radiation (X-rays) and ~ 0.037A for 100 KeV electrons.

### 2.2.2 Set up and working of Scanning Electron Microscope (SEM)

SEMs are patterned after Reflecting Light Microscopes and yield similar information:

**(a) Topography**

The surface features of an object or "how it looks", its texture; detectable features limited to a few nanometers

**(b) Morphology**

The shape, size and arrangement of the particles making up the object that are lying on the surface of the sample or have been exposed by grinding or chemical etching; detectable features limited to a few nanometers

**(c) Composition**

The elements and compounds the sample is composed of and their relative ratios, in areas ~ 1 micrometer in diameter

**(d) Crystallographic Information**

The arrangement of atoms in the specimen and their degree of order; only useful on single-crystal particles >20 micrometers

### 2.2.3 Requirement for SEM and typical operating parameters

(1) Electrons, being charged particles, require vacuum environment for traversing without change in their number and density.

(2) The sample to be analyzed need to be electrically conducting, otherwise there is a charge buildup due to the impinging electrons which gives rise to jumping of the beam and hence its instability.

Thus the sample has to be vacuum compatible and electrically conducting.

Typical operating parameters are: Vacuum~ $10^{-6}$ Torr; Electron energy~ up to 50 KeV; depth probed ~ 100A to 1 μm, resolution~ 60 A and depth focus ~ 15 μm at 10000X.

X-radiation mode (EAX)

In this mode, one employs (i) large beam diameters up to 1 μm; (ii) large beam currents and (iii) long integration time for adequate signal to noise ratio. Sampling volume is rather large and the resolution limited. X-rays may be

collected either in dispersive or non-dispersive mode. In the dispersion mode, one uses a spectrometer equipped with various analyzer crystal combinations (e.g. LiF/ADP; RAP/Lead Sterate) together with a proportional flow counter detector and each element is collected, one at a time, at a separate angle setting. On the other hand, in non-dispersive mode, a liquid nitrogen cooled Li drifted silicon or germanium detector along with a multi-channel analyzer, is made use of to detect all the elements simultaneously. Each of the methods is amenable to obtain images corresponding to the distribution of single element.

### 2.2.4 Sample preparation

Biological samples are specially treated to immobilize them and render them vacuum compatible without appreciable change in their surface morphology. Surface of nonconductive materials are rendered conductive usually by coating a thin (100A) metal film of aluminium / gold / gold-palladium / carbon, the last one being specifically suited for EDAX. The materials can also be observed at low primary energy, at which the coefficient for secondary emission is ~ 1 and charge buildup is negligible. Entire sample preparation consists of mounting the sample on a metallic platform via a conducting path.

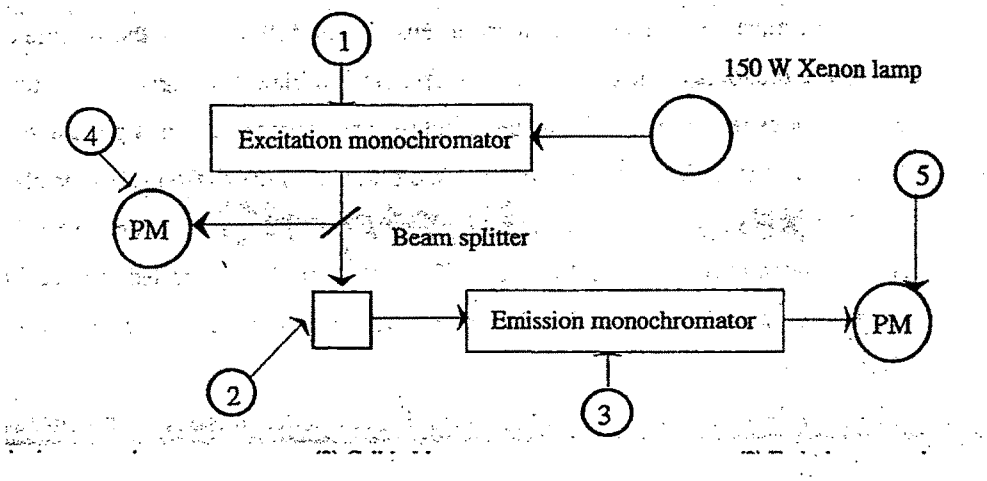
### 2.2.5 Stability of the sample

Electron beam current has to be within suitable limits. Most of the incident power is dissipated in the form of heat, which may induce changes in the sample composition due to decomposition and / or diffusion. For a target of good thermal conductivity, the heating effect is negligible whereas poor conductivity samples may pose problems. A thin, grounded conducting layer, normally deposited, simultaneously serves as a charge bleeder and a heat sink. The layer will, however, decelerate the incident electron beam and may also attenuate the escaping x-ray radiation, thus posing an upper limit for the film thickness, which depends on the incident electron energy, the absorption edge energy and the mass absorption coefficient in the film material.

## 2.3 SPECTROFLUOROPHOTOMETER

### 2.3.1 Optical System of Spectrofluorophotometer

The spectrofluorophotometer irradiates a sample with excitation light and measures the fluorescence emitted from the irradiated sample to perform a qualitative or quantitative analysis. A typical configuration of the spectrofluorophotometer is schematically described below (see Figure-4 taking the RF-5301 PC instrument as an example.




(1) Excitation monochromator, (2) Cell holder, (3) Emission monochromator, 4) Monitor side photomultiplier tube, (5) Fluorescence side photomultiplier tube

**Figure-4 Constitution of RF-5301 PC**

The excitation monochromator (1) isolates a band of a particular wavelength from the light from the Xenon lamp to obtain excitation light. Since brighter excitation light will contribute to higher sensitivity of the spectrofluorophotometer, the excitation monochromator incorporates a diffraction grating with a larger aperture to collect the largest possible amount of light.

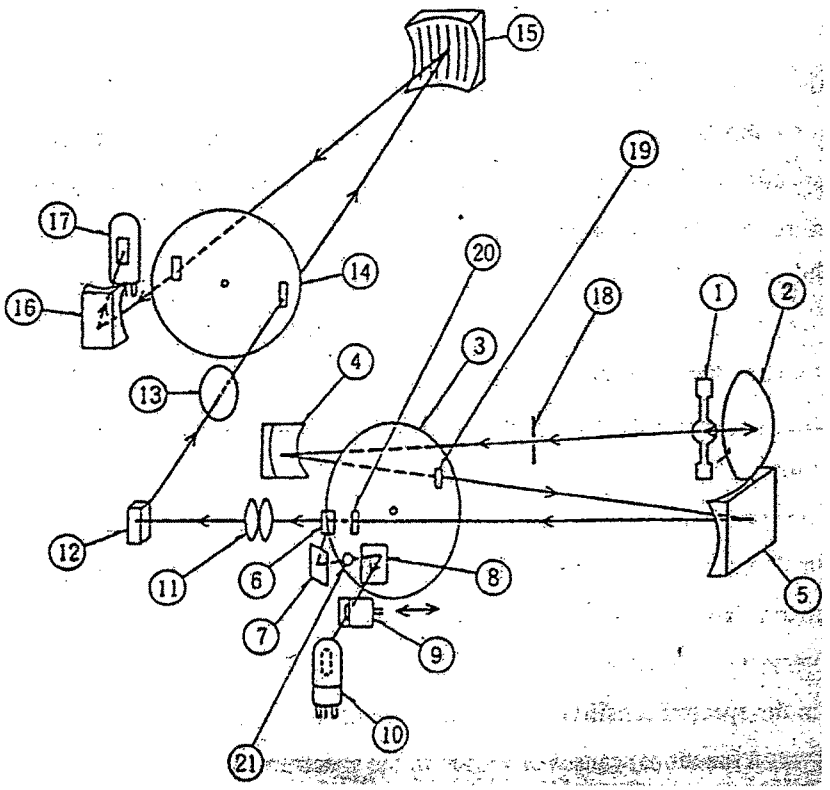
The cell holder (2) holds a cell filled with sample. The emission monochromator (3) selectively receives fluorescence emitted from the sample and its photomultiplier tube measures the intensity of the fluorescence. This monochromator has a diffraction grating whose size is the same as that of the excitation monochromator to collect the greatest possible amount of light. The photomultiplier tube (4) is for monitoring. Generally, the Xenon lamps used on spectrofluorophotometers are characterized by very high emission intensity and

an uninterrupted radiation spectrum. However, their tendency to unstable light emission will result in greater signal noise if no counter measure is incorporated. In addition, the non-uniformity in the radiation spectrum_ of the Xenon lamp and in the spectral sensitivity characteristics of the photomultiplier tube (these criteria are generally called instrument functions) causes distortion in the spectrum. To overcome these factors, the photomultiplier tube (4) monitors a portion of excitation light and feeds the resultant signal back to the photomultiplier tube (5) for fluorescence scanning. (This scheme is called the light-source compensation system).

### 2.3.2 Design of the Spectrofluorophotometer

The optical system of the RF-5301PC instrument is illustrated in figure-5. A 150 W Xenon lamp (1) serves as the light source. The uniquely designed lamp housing contains generated ozone in it and decomposes the ozone by means of the heat produced by the lamp. The bright spot on the Xenon lamp is magnified and converged by the ellipsoidal mirror (2) and then further converged on the inlet slit of the slit Assy. (excitation side) (3) by the concave mirror (4). A portion of the light isolated by the concave grating (5) passes through the outlet slit, travels through the condenser lens (11) and illuminates the sample cell. (The concave grating in both the monochromators is a highly-efficient ion-blazed holographic grating). To achieve light -source compensation, a portion of the excitation light is reflected by the beam splitter quartz plate (6) and directed to the Teflon reflector plate 1 (7). The diffusely reflected light from the reflector plate I (7) then passes through the aperture for light quantity balancing (21) and illuminates the Teflon reflector plate 2 (8). Reflected by the reflector plate 2 (8), the diffuse light is attenuated to a specific ratio by the optical attenuator (9) and then reaches the photomultiplier for monitoring (10). The fluorescence occurring on the cell is directed through the lens (13) to the emission monochromator that comprises the slit Assy. (14) and the concave grating (15). Then, the isolated lights introduced through the concave mirror (16) into the photomultiplier for photometry (17) and the resultant electrical signal is fed to the preamplifier. The spectra recorded using the above instrument displays the spectra along with the

peak data the same can be copied to any other format, which is user-friendly software.




1. Xenon lamp, 150 W
2. Ellipsoidal mirror, SiO2-coated
3. Slit Assy., excitation side
4. Concave mirror
5. Concave grating (for excitation)
6. Beam splitter quartz plate
7. Teflon reflector plate I
8. Teflon reflector plate 2
9. Optical attenuator
10. Photomultiplier for monitoring, R212-14
11. Condenser lens (dual-lens)
12. Cell
13. Condenser lens
14. Slit Assy., emission side
15. Concave grating (for emission)
16. Concave mirror
17. Photomultiplier for photometry, R3788-02
18. Focal point
19. Inlet Slit
20. Outlet slit
21. Aperture for light quantity balancing

**Figure-5 Optical System of RF-5301PC**

From routine analysis to research, employing highest level of sensitivity in the world compared to absorbance methods, fluorescence sensitivity is tens to thousands times better – this means that one can analyze nano grams to pico gram samples with great results. Fluorescence can be used also to identify a specific molecule in a complex background. When the compound of interest does not exhibit natural fluorescence, functional group-specific probes may be used to label the compound & assist our research, the synchronous scanning mode allows mixtures of fluorochromes to be analyzes. The personal computer directly controls the instrument for data acquisition & processing. The windows friendly operating environment allows us to perform measurement, data processing, editing & recording in one continuous operation with a click of the mouse. Using the copy graph function, measurement data or spectra may be easily transferred to word processing or spreads heat software for preparation of documents or additional calculations. The essence of fluorescence analysis is sensitivity, the high throughput optical system in the RF-5301PC employs a blazed holographic grating, photomultiplier & digital circuit to provide the highest level S/N ratio attainable. High speed scanning up to 5500nm/min allows us to measure a spectrum in seconds. And since monochromator slewing is conducted at an ultra-high speed of about 20000nm/min, setting of two or more wavelengths can be performed quickly & easily. High resolution and extended range The band pass on the RF-5301PC may be set as narrow as 1.5nm, which makes is possible to distinguish fluorescent peaks from the background emission. The wave length range of 220 to 750nm can be extended to 900nm with an optional R-928 photomultiplier. When the instrument is switched on, operating conditions of the spectrophotometer are automatically verified. Separately, a noise level (S/N ratio) & the light source (xenon lamp) usage are built in features to help maintain the instrument in its optimum condition, providing absolute confidence in either quality of the data. The sample compartment measuring 140mm, 170mm deep & 140mm high, enables use of micro cells, high sensitivity cells, or low cells, etc., for a wide range of applications. Unique high performance features in the RF-5301PC. Wavelength search functions allow the optimum excitation & emission wavelengths to be found in about two minutes. Vertical optics with dynode feedback, Vertical optics in the RF-5301PC minimize light loss in measurement with an LC flow cell a micro cell or small test tube. This design assures

exceptionally high signal to noise ratio and provides the ability to attain excellent analysis results using very small volumes of precious samples. The dynode feedback enhances RF-5301PC performance by raising or lowering negative high voltage to the detector in response to differences in the excitation energy at wavelengths. Dynode feedback which expands the dynamic range of the signal detecting system is significantly superior to ratio methods. Automatic shutter protects sample an automatic shutter in the RF-5301PC excitation path closes immediately when measurement ceases, thereby protecting the sample from photodecomposition. The software is driven by pull-down menus displayed at the top of your screen, which can be selected with just a click of the mouse. Many convenient and time saving features. The RF-5301PC software is the ideal software to meet all our research needs, from teaching to method development and quality assurance. Follow changes in intensity over time for kinetic assays or perform quantitative analysis on several samples. One can save time & effort with features that allow for onscreen data manipulation.

Spectrum measurement mode perform emission & excitation scans with ease, or overlay the two for interpretation. Obtain & differentiate, excitation & emission spectra using color & line Pattern assignments. Zoom in using the mouse or zoom out with the radar function to auto scale all data on-screen. The software picks & tabulates peaks & valleys automatically and if one needs a fast spectral scan in any measurement mode, the pop up scan function displays it on- screen in seconds. This is a simple but powerful for extensive data processing. Operations such as first through fourth order derivative, mathematical smoothing functions, log conversions & offsets are easily performed with the RF-5301PC software. Display up to ten spectral curves simultaneously or use mathematical transformations to maximize our results. Select the source & destination channels along with the desired calculation & the results are redisplayed on the screen. The following is the photograph (Figure 6 & 7) of the 5301R PC along with solid sample holder.

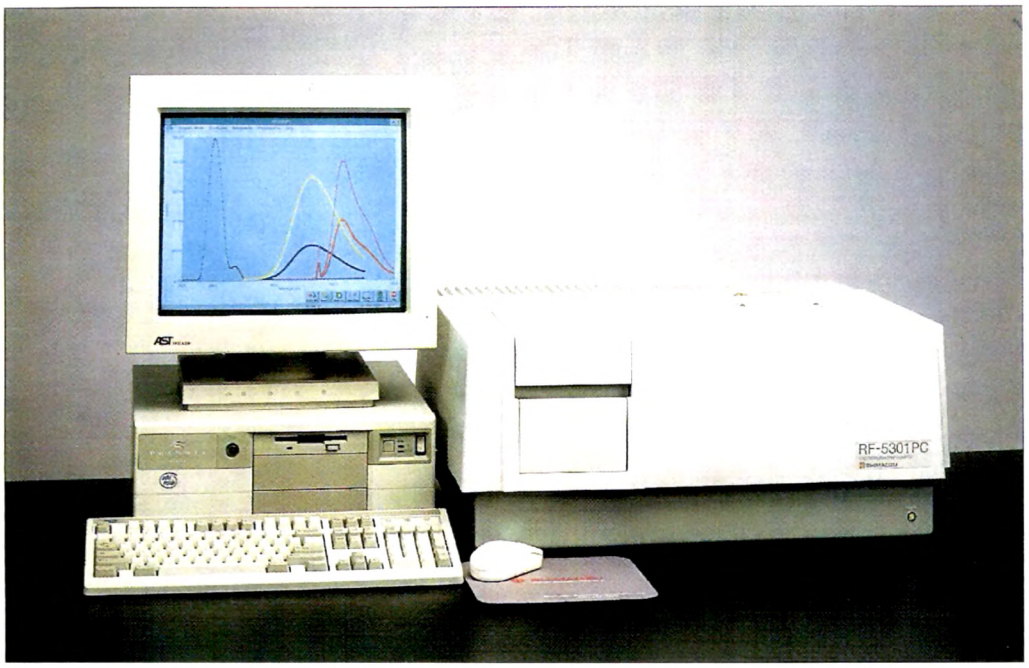



**Figure-6 Spectrofluorophotometer, RF-5301 PC.**

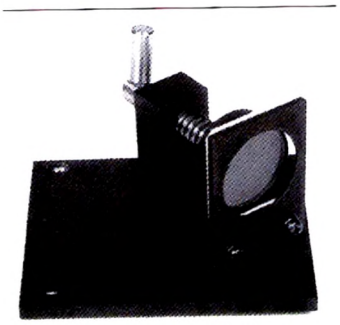


**Figure-7 Spectrofluorophotometer Powder Sample Holder.**

### 2.3.3 Measurement Procedure

A solid sample holder is provided with the fluorometer. It enables collection of front face fluorescence at an angle of 22.5°. The powder sample was spread on it. The sample holder was fixed into sample compartment. When analyzing the sample, optical axis runs along the centerline of powder surface. First the excitation spectra were recorded by setting the emission wavelength at the zero order and keeping other parameters as specified in the manual. The excitation bands were identified from these spectra and the emission spectra were scanned for identified excitation wavelength. This was necessary to know the approximate nature of EX spectrum, so it is necessary to select a particular band in the emission for scanning the excitation. Therefore for proper excitation spectra the emission wavelength was set at the position as identified from the earlier emission spectrum. The excitation and emission spectra were recorded with spectrometer slit fixed at 1.5 mm.

## 2.4 Thermoluminescence (TL) Glow Curve Recorder

**Figure-8 Thermoluminescence Setup.**


**Figure-9 Kanthal Strip and TL detection head. Left side is the Sr-90 beta source used in the present investigation.**

The thermoluminescence glow curve reader consists of a specimen holder along with heater, a temperature programmer, a photomultiplier tube as detector, a high voltage unit, a D.C. amplifier and a suitable displaying or recording device, as shown in figure-8. Also figure-9 presents the TL detection head and a Sr-90 beta source. The specimen is spread uniformly (5mg weighed) over a metallic strip of Kanthal (Fe-72 %, Ce-23 %, Al-3 %, and Co-2 %). The strip is narrow and has a circular depression of 15mm at its center. A chromel-alumel thermocouple is spot welded to record the temperature of the specimen. The uniform heating rate that is controlled by the temperature programmer maintains a linear relationship between the rise in temperature versus time. The photomultiplier tube is housed in a light-tight cylinder and a high voltage is applied to it. When the kanthal strip is loaded with the irradiated specimen which is placed in front of the photomultiplier window, the light emitted by the specimen during heating is recorded through the photomultiplier window. The light emitted by the specimen

during heating is detected by a photomultiplier tube and is recorded through auto ranging D.C. amplifier by the output device. In the present study, the thermoluminescence glow curves of the samples were taken on a Nucleonix make Windows Based thermoluminescence reader. The system consists of a PMT housing with drawer assembly, high voltage module, AM576 TL data acquisition module with auto ranging facility, Temperature programmer controller unit, power supply unit, AD-DA card and a personal computer system along with required hardware and software. Block diagram is shown in figure-10.

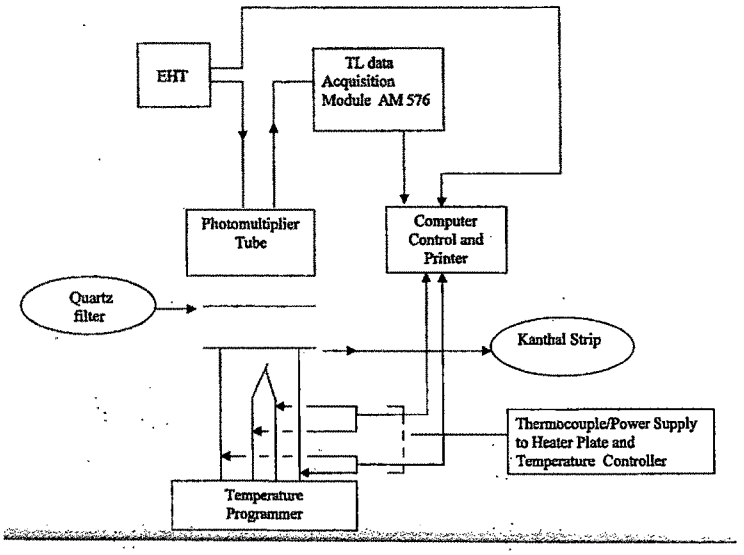



**Figure-10 Block Diagram of TL Set-up.**

## 2.5 Photometry, Colorimetry and CIE measurement

The measurement of colour and intensity of radiative transition and their relation with human eye susceptibility constitute an integral part of luminescence. An essential tool known as photometry is used to measure radiation of only visible region of the electromagnetic spectrum. It forms a basis for determining the qualitative relationships existing between the physical concepts of radiation and the psycho-physical concepts like 'sensation' caused in the observer's eye by the radiation under the study. This type of approach becomes inevitable when properties related to emission colours, persistence etc. are to be studied thoroughly. The effectiveness of light radiation for stimulating the human eye is given by the relative eye sensitivity V (λ), which is a function of wavelength. Figure-11 indicates the relative eye sensitivity, as defined for a 2°-viewing angle by the Commission Internationale de l'Eclairage (CIE) for normal photopic vision. The value of V (λ) is highest at 555nm and falls to nearly zero at the extreme ends of the visible spectrum at 390 and 770nm. The effectiveness of the available radiant energy on vision (luminosity) at wavelength 555nm is 680 lumen (lm) $W^{-1}$. In other words, for normal photopic (bright environment) vision at the peak sensitivity of eye (555nm), 1 W of radiant energy is equivalent to 680 lm. However, for a scotopic (dark environment) vision the eye sensitivity is maximum at 507nm and radiant energy is equivalent to 1700 lm $W^{-1}$. Hence, development of long persistent phosphors emitting in this region gains utmost importance. The colours that can be treated and measured in terms of chromatic response of the eye to pure colours of different wavelengths are called psycophysical colours. These can be specified by using the coordinates of a chromaticity diagram, as shown in Figure-12. Although there are various systems to specify the coordinates, XYZ system is most accepted and adapted system. In the present study, the *Equidistant-Wavelength method* has been used to determine the coordinates on the colorimetric chromaticity diagram. The CIE coordinates for the samples have been calculated for CIE 1931, CIE 1960 and CIE 1976. Though the most common among them is the CIE 1931 but it suffers from drawbacks that are less with the CIE 1976, also known as uniform chromaticity scale diagram or the CIE 1976 UCS diagram commonly referred to as the u′, v′ diagram, which again is not free from errors but still has some better

methodology to depict the graphs. A simple example would be of maps of the world, as it is not an easy job to represent a curved surface accurately on flat piece of paper, distortions occur. In some maps the countries near the one pole, such example Greenland, are represented too far compared to one near the equator like INDIA. On such maps, pairs of locations equally distant from one another on the earth's surface are represented by points that are much closer together in India than in Greenland. No map on a flat piece of paper can avoid this problem entirely, but some types of map are better than others in minimizing the effect.

**Uniform chromaticity diagrams**

Although the most common and most widely used notations in the field of colour representation are the chromaticity diagrams, but these suffer from serious disadvantage; the distribution of the colours on it is very non-uniform. Thus the representation of the same can be done by other ways, of them, the CIE 1976 uniform chromaticity scale diagram or the CIE 1976 UCS diagram, commonly referred to as the u′, v′ diagram.

$$u=\frac{4x}{-2x+12y+3}\ ,\quad v=\frac{6y}{-2x+12y+3}\qquad\text{----------1}$$

$$u'=\frac{4x}{-2x+12y+3}\ ,\quad v'=\frac{9x}{-2x+12y+3}\qquad\text{----------2}$$

The values of the u′ and v′ for the spectral locus are given. The u′, v′ diagram was recommended by the CIE in 1976; prior to that a similar diagram, the u, v diagram was used in which u = u′, and v = (2/3)v′. All chromaticity diagrams, whether x, y or u′, v′.or u, v have the property that additive mixtures of colours are represented by points lying on the straight line joining the points representing the constituent colours. The position of the mixture point has to be calculated by the method given in section 3.5, and in the u′, v′ diagram the weights used are $m_1/v_1'$ and $m_2/v_2'$; and in the u, v diagram the weights are $m_1/v_1$ and $m_2/v_2$. The u′, v′ diagram is useful for showing the relationships between colours whenever the interest lies in their discriminability.

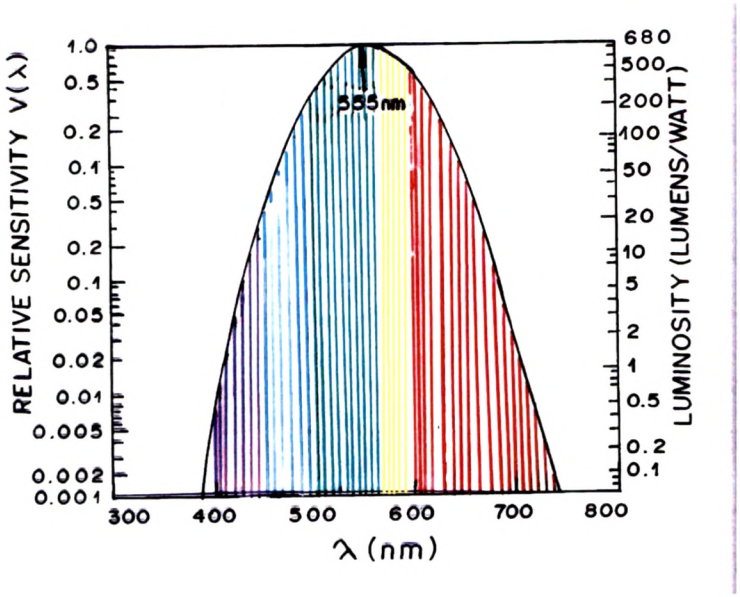



**Figure-11 Relative luminosity function as defined by the CIE for normal photopic vision.**

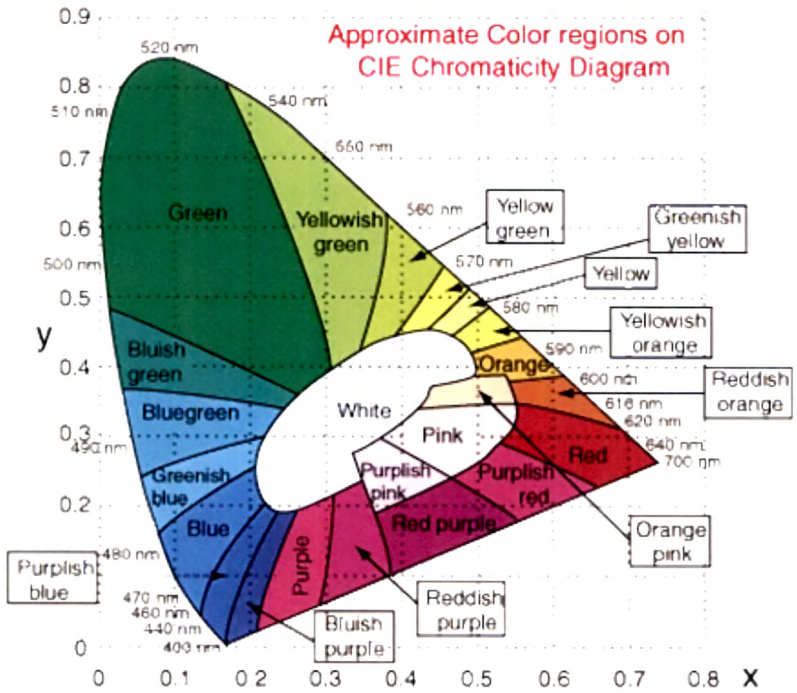



**Figure-12 CIE chromaticity diagram indicating division of colour planes into areas corresponding to the individual colour only for the CIE portion.**

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