TEMPERATURE DEPENDENCE
OF FLUORESCENCE.
7.1 Introduction:

The study of temperature dependence of emission provides a useful means for investigating energy conversion processes in phosphor systems in which there is competition between several recombination centres. As a result of balance between capture, thermalization and recombination kinetics in different temperature regions. ¹

Haake ² has considered some of the physical aspects of temperature dependence and pointed out that there are two important factors to be considered: (i) an increasing absorption with temperature leading to higher intensity of emission and (ii) a decrease in the efficiency of fluorescence with temperature due to competing phonon processes. Because the effects work against each other the brightness versus temperature curves often show a maximum, the position of which will depend on the relative importance of the two factors. The temperature at which quenching occurs may provide more information on the interaction of the electrons of the activator ions with the host lattice, e.g., high quenching temperature means weak coupling of the activator electrons with the surrounding host lattice ions. ³ Low quenching temperature may be associated with a high probability of non-radiative processes, which are thought to involve the creation and absorption of phonons in the lattice. Such processes have been extensively studied in fluorescent rare-earth chelates. ⁴
The study of temperature dependence also gives valuable information regarding luminescence and the processes accompanying it. For example, the effect of temperature on the fluorescence peak position and change in half width of emission band provides information about the nature of the emitting centres and its interactions with the lattice vibrations. In the case of ZnS-Cu phosphors Shionoya et al. have reported that the emission peak of R-Cu centres shift towards higher energies while those of R-Cu centres shift towards lower energies with rise of temperature right from 4°K. At the same time change in half width has also been reported by them.

In the case of ZnO : In phosphors some workers have reported that with increase of temperature (a) \( N \) band shifts to longer wavelength, (b) the intensity of visible band decreases more rapidly than that of \( N \) band.

The change in temperature of a phosphor may influence the intensity and the colour of luminescence and may broaden the emission band. Watchel derived a possible relation between the position of the absorption edge and the quenching temperature of the fluorescence of Niobates and this has been extended to other compounds also. The location of levels involved in the emission transition may be obtained from the measurements of the emission intensity as a function of temperature.

The temperature dependent fluorescence studies are also of
great importance for the materials used as dosimeters to get insight into the emission exhibited and its stable performance. Phosphors which maintain their fluorescence at high temperature and pressure, are useful in high pressure mercury vapour lamps, in highly loaded fluorescent lamps, in colour television screens etc. For example, europium activated pyrophosphates have been found very suitable for application in low as well as high pressure mercury vapour lamps.

7.2 Factors affecting the temperature dependence of Luminescence:

The temperature dependence characteristics (such as slope of initial rise of fluorescence, temperature of maximum intensity, efficiency and quenching temperature) are influenced by a number of factors such as crystal structure of the host material, thickness of the sample, nature and amount of activator, change in pressure, method of preparation and mode of excitation etc.

(1) Effect of host crystal and its structure - According to Blasse and J. devries the vibrations in the host lattice play an important part in the quenching process and at high temperatures the rate of multiphonon process varies approximately as \( T^n \) where \( T \) is the absolute temperature and \( n \) is the number of phonons involved, so that when high energy phonons are available \( n \) will be small and the variation of efficiency with temperature will be less pronounced.
The crystal structure of the phosphor also has a strong influence on temperature dependence characteristics. The wide variation in the behaviour of the same activator in different host lattices and of different activators with the same matrix suggest that temperature dependence characteristics are determined by the nature of the matrix. For example both \( \alpha - \text{Sr}_3(\text{PO}_4)_2 \cdot \text{Ce}^{3+} \) measured with C.R. excitation and \( \alpha - \text{Sr}_3(\text{PO}_4)_2 : \text{Eu}^{2+} \) show high quenching temperature. The introduction of a small amount of Mg into \( \text{Sr}_3(\text{PO}_4)_2 \) causes a transformation to the crystal structure and Gorbacheva noticed a much lower quenching temperature. Blasse et al. have also studied the temperature dependence of \( \text{Eu}^{2+} \) emission in alkaline earth pyrophosphates, silicates, aluminates, octaborates and borate phosphates and found that quenching temperature of these compounds increases usually as metal ion is changed from calcium to strontium to barium within an isomorphous series.

(ii) Effect of activator and its concentration - The temperature dependent emission was measured by Robbins et al. in the case of \( \text{Y}_3\text{Al}_5\text{O}_{12} \) crystals containing a series of concentrations of each of the ions Ce\(^{3+}\), Eu\(^{3+}\), Tb\(^{3+}\) and Gd\(^{3+}\) and concluded that Ce\(^{3+}\) (and to some extent Tb\(^{3+}\)) shows an approximately linear dependence of intensity on concentration at the lowest temperatures whereas intensity of Eu\(^{3+}\) luminescence is only weakly dependent on
concentration. Wannemaker et al. 15 have reported that the quenching temperature of Eu2+ activated alkaline earth pyrophosphates are much lower than those for Eu3+ activated phosphors where in contrast to the Eu2+ phosphors, no excitation of 4f electrons to outer shells takes place. Excitation to outer shells renders the phosphor more susceptible to the influence of the surroundings of the activator ion.

The temperature dependence of luminescence of ZnS : Mn phosphors with different activator concentrations has been studied by various workers. According to Vlasenko 33 an increase in concentration causes a monotonic decrease in the temperature at which quenching begins. According to Levshin and Tunitskaya 21 the absorption and hence emission in the region of fundamental band gradually decreases as the Mn concentration increases.

The effect of concentration of activator is different in different hosts. In EuAl3B4O12 there is no change due to Eu3+ activator concentration, while in LaAlO3 : Eu the quenching of emission occurs at lower temperature for higher europium concentration. 2,23 The effect of activator concentration on the quenching temperature is found to be small in both Ca2P2O7 : Eu and Sr2P2O7 : Eu phosphors. 15

(iii) Effect of mode of excitation — The temperature dependence of luminescence as a function of wavelength of exciting radiations has been studied by a number of workers. 22,24,33,34 Halperin et al.
observed in the case of ZnS : Cu : Cl crystals that luminescence disappears almost completely below 150 K on excitation with light of 3300 Å while temperature quenching occurs at about 250 K on exciting at 3400 Å and at still higher temperatures on exciting with light of longer wavelengths. Thus they concluded that the temperature at which temperature quenching takes place seems to shift towards higher values with increase in the wavelength of the exciting light.

(iv) Effect of preparatory conditions and thickness of the phosphor -

The temperature dependence of ZnS : Cu phosphors prepared in the temperature range 500°C to 1200°C has been studied by Garlick. 33 He observed a marked effect of preparation temperature on the temperature dependent luminescence characteristics of a phosphor. A marked improvement in temperature dependence with increase in firing time has been observed. 23 As reported by Halperin et al., 24 for wavelengths within the lattice absorption the luminescence is independent of the thickness of the specimen. It would rise, however, with the thickness of the specimen on excitation at longer wavelengths. This part of excitation spectrum would therefore become less pronounced on reducing the thickness of the specimen. According to Haake 2 thick phosphor layers peak at lower temperatures as compared to thin layers and slope of the initial fluorescence rise decreases with increasing thickness. In the case of
powder phosphors the average particle size also influences the slope and the position of maximum to some extent.

(v) **Effect of Pressure**

In the case of CaAl₂O₄: Eu,

Tyner et al. 19 observed an increase in quenching with increase in pressure in the temperature dependence study. They postulated the presence of a third state (besides the ground and excited states of the configuration coordinate model) which accounts for the observed thermal quenching.

7.3 **Theoretical Model**

This model proposed by Blasse et al. 27,35,37 to establish some general rules for quenching temperature and efficiency of phosphors, is based on the configurational coordinate model. From Fig. 7.1(a) (i.e., Mott-Beitz model) it can be seen that after absorption A → B the energy is lost non-radiatively until the system reaches a minimum C of the excited state from where a fluorescent transition can occur. For a non-radiative transition it has to reach a point S (the point of intersection of two curves) from which it can relax to the ground state. The additional energy required to follow this path is measured by E, the activation energy which is related to the quenching temperature by an exponential law. If the intersection level lies below the level reached after absorption (Fig. 7.1(b) - Dexter-Klick Russell model) radiationless transition to the ground state is possible even at low temperatures. A third situation shown in Fig. 7.1(c), (The Beitz model) clearly
FIG: 7.1 - SCHEMATIC CONFIGURATION COORDINATE DIAGRAMS.
does not permit a radiative return to the ground state.

The difference between the equilibrium positions of the ground and excited states is denoted by $\Delta r$. The larger the value of $\Delta r$, the lower the quenching temperature of luminescence will be (as seen in Figs. 7.1 (a), (b) and (c)). More rigorously, $\Delta r$ and the radius and charge of the cations surrounding the relevant luminescence centre determine the quenching temperature of the fluorescence to a great extent.

The centres were divided into two groups:

(i) Those with $\Delta r > 0$ (charge transfer transitions) and

(ii) Those with $\Delta r < 0$ (Rydberg transitions).

If a high $T_q$ is desired, centres with $\Delta r > 0$ should be substituted for smaller ions e.g., Eu$^{3+}(0.93 \text{ Å})$ for Lu$^{3+}(0.85 \text{ Å})$ and centres with $\Delta r < 0$ for larger ions (e.g., Eu$^{2+}$ for Ga$^{2+}$).

The sign of $\Delta r$ depends on the nature of the luminescence centre. If a cation is excited the electronic charge distribution extends further away from the nucleus rendering it effectively positive. Upon excitation of the Tl$^+$ ion in KCl : Tl$^+$ system, the electron charge distribution of the ion moves somewhat further away from the nucleus. The negative charge cloud becomes more diffuse and as a result the cation effectively assumes a greater positive charge; it therefore attracts the negative charge more strongly so that equilibrium distance of the luminescence centre in the excited state is smaller than that of the ground state. Williams
found $\Delta r$ to have a negative value (0.3 Å). The value of $\Delta r$ is expected to be positive in the case of anion excitation as seen on excitation into charge transfer absorption band (Tungstate, Eu$^{3+}$).

The value of $\Delta r$ is affected by:

(i) The size of the host lattice cation for which the activator is substituted.

(ii) The size and charge of the cation in the neighbourhood of the activator.

If the activator ion is larger than the host lattice ion which it replaces [e.g., Eu$^{3+}$ (0.98 Å) in Lu$^{3+}$ (0.95 Å) host], surroundings of the activator will be forced to expand in order to make room for the activator. If the activator is raised to the excited state and if it is accompanied by an increase of the equilibrium distance (anion excitation $\Delta r > 0$) then the environment of the activator will have to expand still further. Since this expansion costs energy, the lattice will tend to oppose the expansion of the luminescence centre, i.e., $\Delta r$ will be relatively small (and $T_g$ will be high). The opposite is the case if the activator is located at a site which is occupied in the host lattice by a larger ion for example Eu$^{3+}$ (0.98 Å) in a La$^{3+}$ (1.14 Å) compound.

$\Delta r$ will be relatively small if the luminescence centre is surrounded by a rigid lattice, i.e., a lattice containing small cations with high charge. On certain assumptions, Glasser 11,39 has
shown that a necessary but not sufficient condition for efficient fluorescence is that \( \Delta r \) should be about 0.3 Å or less.

7.4 Theoretical aspect of thermal quenching of Luminescence

The luminescence efficiency \( \eta \) of a phosphor may be defined as the ratio of number of photons emitted from a phosphor layer to the number of photons absorbed by the (same) layer. The luminescence efficiency of a phosphor is a function of temperature. The nature of efficiency has been investigated by a number of workers. 40-44

If \( N_0 \) be the number of luminescence centres in an excited state that make a transition to the ground state by emitting luminescent radiation, the number \( N \) in the excited state at any time \( t \) may be given by:

\[
N = N_0 \exp \left( - \frac{t}{\tau_L} \right) \tag{7.1}
\]

If \( Pr \) be the probability of luminescence emission, then,

\[
Pr = \frac{1}{\tau_L} \tag{7.2}
\]

There may be a thermal process leading to radiationless transitions between the excited and the ground states, along with luminescent transition. The probability of non-radiative transition \( Phr \) may be given by:

\[
Phr = S \exp \left( - \frac{W}{kT} \right) \tag{7.3}
\]
where $W$ is the activation energy and is equivalent to the energy of the intersection point above the minimum of the excited state on the configurational coordinate plot ( $S$ is the frequency factor ).

The luminescence efficiency is given by:

$$\eta = \frac{P_F}{P_F + P_{nf}}$$  \hspace{1cm} (7.4)

Using equation (7.3c) this may be written as:

$$\eta = \frac{I}{I_0} = \left[ \frac{P_F + P_{nf}}{P_F} \right]^{-1}$$

$$= \left[ 1 + \frac{S}{P_F} \exp \left( -\frac{W}{KT} \right) \right]^{-1}$$  \hspace{1cm} (7.5)

Or

$$\eta = \frac{I}{I_0} = \left[ 1 + A \exp \left( -\frac{W}{KT} \right) \right]^{-1}$$  \hspace{1cm} (7.6)

where $A$ and $S$ are related quantities.

According to relation (7.6) the fluorescence intensity should be directly proportional to excitation intensity. Bislof and Kröger observed a deviation from this linear relation in the case of ZnS : Mn phosphor. Their results follow a relation of the form:

$$I = \text{Const} \times J^n$$  \hspace{1cm} (7.7)

where $I$ is the fluorescence intensity. $J$ is the excitation intensity, $n$ is a constant. Klasens has given the first satisfactory explanation of the non-linear increase of fluorescence with excitation intensity and gave an expression of the form:
\[ \eta = \frac{I}{I_0} = \left[ 1 + C \sqrt{\alpha J} \right] \] (7.9)

where \( I_0 \) is the intensity at low temperature at which positive hole migration is negligible.

\[ C = \sqrt{\exp \left( - \frac{W}{KT} \right)} \] and \( \alpha \) is a constant.

Garlick \(^{35}\) replaced equations (7.7) and (7.9) by the following empirical formula:

\[ \eta = \frac{I}{I_0} = \left[ 1 + \frac{b \exp(-\frac{W}{KT})}{J^n} \right] \] (7.9)

where \( b \) is a constant and value of index \( n \) varies between 1 and 2. He found a better agreement of this relation with his experimental results.

7.5 **Evaluation of activation energy** :

\[ \frac{I}{I_0} = \left[ 1 + A \exp \left( - \frac{W}{KT} \right) \right]^{-1} \]

\( I \) and \( I_0 \) being emission intensities at temperature \( T \) and temperature corresponding to maximum intensity respectively. \( A, W \) and \( K \) have their usual meaning as shown above.

Equation (7.5) can again be written as:

\[ \left( \frac{I_0}{I} - 1 \right) = A \exp \left( - \frac{W}{KT} \right) \]

\[ \log \left( \frac{I_0}{I} - 1 \right) = \log A - \frac{W}{KT} \] (7.10)
if the slope is large i.e., \( A \exp \left( - \frac{W}{kT} \right) \gg 1 \), equation (7.5) can be written as:

\[
\frac{I_2}{I} = A \exp \left( - \frac{W}{kT} \right) \quad (7.11)
\]

Or \( \log \frac{I_2}{I} = \log A - \frac{W}{kT} \) \( (7.12) \)

Hence a plot of \( \log \left( \frac{I_2}{I} \right) \), or \( \log \left( \frac{I_2}{I} \right) \), as the case may be, versus \( \frac{1}{T} \) will be a straight line and its slope will provide the value of \( \frac{W}{k} \) from which \( W \) can be calculated.

7.6 Quantities related with the temperature dependent Luminescence:

In order to explain these quantities a general form of temperature dependence curve is given in Fig. 7.2. which shows that intensity of fluorescence first rises to a maximum and then falls rapidly with rise of temperature (usually the shape of the curve, particularly before maximum, depends on the wavelength of exciting radiation).

1) Quenching range \( \Delta T \) - The quenching range may be defined as the temperature range within which the luminescence intensity decreases with temperature after non-radiative transitions begin to dominate and is given by:

\[
\Delta T = T_2 - T_1 = \frac{3W}{k} \left[ (\log S - \log 4)^{-1} - (\log S + \log 4)^{-1} \right] \quad (7.13)
\]
FIG: 7.2. - TEMPERATURE DEPENDENCE OF FLUORESCENCE.
(ii) Quenching temperature $T_q$ - It is defined as the point of intersection of the abscissa and a straight line drawn through the points at which the intensity has fallen to 80% and 20% of the maximum value. In Fig. 7.2, $T_q$ is represented by $T_2$ (hence $T_2$ and $T_q$ are one and the same).

$$T_q = \frac{w}{3k} \left[ 4 (\log S - \log 4) - 1 - (\log S + \log 4) \right]$$

(7.14)

(iii) Breaking point temperature $T_B$ - It is a (well defined) temperature at which non-radiative transitions set in \(^{48}\) and is approximately given by:

$$T_B = \frac{w/k}{\log S + 0.9}$$

(7.15)

(iv) Half value temperature $T_H$ - It is a temperature at which the intensity has decreased to half its maximum value within the quenching range $\Delta T$. \(^{49}\) It is given by the expression:

$$T_H = \frac{w/k}{\log S}$$

(7.16)

When the value of frequency factor $S$ is large, $T_q$ and $T_B$ both change to $T_H$ which can be calculated most conveniently.

7.7 Experimental arrangement:

Experimental set up for temperature dependence of
fluorescence has been given by Botden, Kreher, Yu and Park. They have studied the temperature dependence of various phosphors between 4 K and room temperature. The basic idea lying behind their experimental set up is (i) an arrangement to keep phosphors below room temperature, (ii) suitable source of excitation and (iii) an arrangement for recording the emission and corresponding temperature of the phosphor.

7.8 Present method:

In the present method the experimental arrangement is made to study the temperature dependence of luminescence of Eu and Sm activated ZnO:MgO phosphors from 300 K to 500 K.

The arrangement consists of the following parts:

(i) Source of excitation.

(ii) Sample holder with heating arrangement.

(iii) Current regulator and temperature controller.

(iv) IP21 photomultiplier tube.

(v) Galvanometer

(vi) B.S. Spectrometer with photometer.

(This unit along with temperature controller is used only when emission spectrum at different temperatures is to be recorded.)

All these components are the same as used in emission, phosphorescence decay and thermal luminescence studies and are already
described at appropriate places.

(a) Experimental procedure  —  The components described above were arranged according to Fig. 3.1 (of decay study). The assembly was aligned in a way similar to that described in Chapter V. A small quantity of phosphor under investigation was pressed in the brass sample holder and X-ray shutter was opened so as to excite the phosphor (X-ray machine was operated at 30 kV, 10 mA and white radiations were used). The emitted fluorescent radiations were detected and recorded by a photomultiplier tube (IP21) and polyflex galvanometer (type PL 50) connected with the assembly.

The phosphor was heated from room temperature to 500°C with a Kanthol heater strip attached just behind the sample holder at a constant rate by supplying a current of constant value (3.5 Amp.). The temperature at each stage was calculated as in the case of thermoluminescence study.

In order to study the emission spectrum at different temperatures a Bellingham and Stanley spectrometer with P.M. tube and photometer was used. The emitted fluorescence from the phosphor was analysed by B.S. Spectrometer, detected by P.M. tube and finally recorded by photometer. In order to keep the phosphor at different constant temperatures for a certain time, a temperature controller was attached with the Kanthol heater strip.
To prevent the thermal radiations from reaching the P.M. tube a water filter was inserted in the path of the emergent fluorescent radiations just before the P.M. tube. The temperature dependence for some phosphors was also studied under 3650 Å (UV) excitation. The same quantity of phosphor was taken every time.

7.9 Results:

The observed effect of temperature on fluorescence emission of various prepared phosphors under different conditions of excitation are given below.

(a) E-Series: The variation of total quantum emission under X-ray excitation of these phosphors is as shown in Figs. 7.3 (A and B). It is seen that right from ZnO : Eu to ZnO : MgO (4:6) : Eu the emission intensity first decreases rapidly as the temperature is increased beyond room temperature. After 340 K the rate of fall of intensity is relatively slow. This rate decreases continuously from ZnO : Eu to ZnO :MgO (4:6) : Eu phosphor. For ZnO : MgO (3:7) : Eu to MgO : Eu phosphors the results are different and the intensity increases with rise of temperature up to a certain temperature and then decreases slowly as shown in Fig. 7.3(B).

The nature of temperature dependence of 593 nm and 511 nm i.e., peak wavelengths of emission bands under X-ray excitation is shown in Fig. 7.4. ZnO : MgO (3:7) : Eu to MgO : Eu phosphors
FIG. 7.3 [A] - VARIATION OF TOTAL QUANTUM EMISSION WITH TEMPERATURE OF ZnO : MgO : Eu$^{3+}$ PHOSPHORS UNDER X-RAY EXCITATION.

$(1-x)/x$
FIG. 7.3 (B) - VARIATION OF TOTAL QUANTUM EMISSION WITH TEMPERATURE OF ZnO : MgO : Eu$^{3+}$ PHOSPHORS UNDER X-RAY EXCITATION.

$(1-x) (x)$
FIG. 7.4 - TEMPERATURE DEPENDENCE OF [A] 593 nm AND [B] 611 nm LINES OF ZnO : MgO : Eu$^{3+}$ PHOSPHORS UNDER X-RAY EXCITATION.

([1-x] (x))
show peaks at the same places as in the case of total emission.

Emission spectra at various temperatures between 300 K to 500 K of these phosphors under X-ray excitation was studied. Such emission spectra for some of these phosphors are shown in Figs. 7.5 (A, B and C). A common property found in all cases is that there is no shift in emission peaks with rise of temperature. The intensity of the broad band near 550 nm decreases rapidly beyond room temperature. The intensity of 593 nm and 611 nm emission bands of ZnO : Eu to ZnO : MgO (4:6) : Eu phosphors decreases, while those of ZnO : MgO (3:17) : Eu to MgO : Eu increases with rise of temperature to a certain temperature and then decreases slowly afterwards. No appreciable change in half width with rise of temperature is observed.

Fig. 7.6 shows the effect of temperature on the 593 nm emission line of ZnO : MgO (3:17) : Eu, ZnO : MgO (1:9) : Eu and MgO : Eu (a) under only UV (365 nm) excitation and (b) under UV (365 nm) excitation after 5.0 minutes X-ray excitation respectively. These results show that in the first case the emission intensity decreases with rise of temperature, while in the second case the shape of curves remain nearly same as that found under only X-ray excitation but there is a decrease in intensity.

The peaks in all the curves of temperature dependence of ZnO : MgO (3:17) : Eu to MgO : Eu are found to be close to their
Fig. 7.5 [A,B] - Emission Spectrum of $E_1$ & $E_3$ Phosphors at Various Temperatures.
FIG. 7.5 (c) - EMISSION SPECTRUM OF $E_g (\text{ZnO: MgO (1:9): Eu (10^{-1}\%})}$ PHOSPHOR AT VARIOUS TEMPERATURES.
FIG 7.6- TEMPERATURE DEPENDENCE OF FLUORESCENCE EMISSION OF 593 nm LINE OF ZnO MgO Eu (a)- UNDER U.V. (365 nm) EXCITATION , (l-x) (x) (b)- UNDER U.V. (365 nm) EXCITATION AFTER 5.0 MINUTES X-RAY EXCITATION. DOSAGE.
thermoluminescence peaks. The results of Figs. 7.4 to 7.6 show that the efficiency of phosphors depend on the nature of exciting radiation as well as on the temperature.

(b) S-Series: The temperature dependence of total quantum emission of these phosphors under X-ray excitation is shown in Fig. 7.7. The emission intensity of all these phosphors decreases first rapidly (up to 350 K) and then slowly with rise of temperature. Effect of increase of MgO proportion on quenching temperature (Tq) seems to be inappreciable. Nature of variation in emission intensity of 575 nm and 512 nm lines with rise of temperature under X-ray excitation was found approximately similar to that of total emission (Fig. 7.8). The only difference is that the rate of fall of intensity with rise of temperature is relatively slow.

The emission spectrum at various temperatures under X-ray excitation were observed and some of them are shown in Fig. 7.9. A broad band near 550 nm (like in E-Series), lines at about 576 and 512 nm and a band of relatively poor intensity peaking at about 660 nm were found. As the temperature is increased the intensity of 550 nm band quenches rapidly while those of other lines and bands quench at a relatively slow rate.

(c) ex-Series ZnO: MgO(x); (Eu 0.05%, Sm 0.01%) -

The temperature dependence of total fluorescence emission
Figure 7.7 - Total quantum emission of ZnO: MgO: Sm phosphors under X-ray excitation.
FIG. 7.8 - TEMPERATURE DEPENDENCE OF [A] 576 nm AND [B] 612 nm LINES OF ZnO: MgO: Sm PHOSPHORS UNDER X-RAY EXCITATION.

\( I_x \) (x)
$S_1 \rightarrow \text{ZnO: MgO (9:1): Sm (10^2 \%)}$

(a) = 300*K
(b) = 328*K
(c) = 343*K
(d) = 380*K
(e) = 443*K

FIG: 7.9 [A] - FLUORESCENCE EMISSION SPECTRUM OF ZnO: MgO (9:1): Sm UNDER X-RAY EXCITATION AT VARIOUS TEMPERATURES.
FIG. 7.9 [B1] - FLUORESCENCE EMISSION OF ZnO : MgO (5:5): Sm AT VARIOUS TEMPERATURES UNDER X-RAY EXCITATION.

EMISSION INTENSITY (ARB. UNITS)

WAVELENGTH $\lambda$ (nm)

(a) = 300 K
(b) = 328 K
(c) = 343 K
(d) = 413 K
(e) = 443 K
(f) = 443 K

ZnO : MgO (5:5) : Sm (10^2%)
of this series of phosphors under X-ray excitation is shown in Fig. 7.10. Comparison of Fig. 7.10 with Figs. 7.3 and 7.7 shows that nature of curves of this series is similar to that of E-Series. The presence of Sm does not appear to affect the temperature dependence of the europium samples appreciably.

All these results have been discussed in the concluding Chapter.
FIG. 7.10 - TOTAL QUANTUM EMISSION OF ZnO: MgO: [ Eu 0.05 %, Sm 0.01 % ]
PHOSPHORS UNDER X-RAY EXCITATION.


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