NRL Report 6408

The Emission Spectra of Various Thermoluminescent Materials

S. G. Gorbics

Dosimetry Branch
Nuclear Physics Division

August 5, 1966

NAVAL RESEARCH LABORATORY
Washington, D.C.

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ABSTRACT

The thermoluminescence emission spectra of various materials have been determined using a quartz-prism spectrograph. The materials studied include: CaF_2:Mn, $CaSO_4$:Mn, $Li_2B_4O_7$:Mn, LiF(TLD-100), CaF_2(MBLE), and a terbium-activated lithium-aluminosilicate thermoluminescent glass. The spectra were measured photographically and corrected by means of an NBS quartz-iodine tungsten-filament standard of spectral irradiance. Precautions were taken to prevent spectral distortions resulting from the variation in sensitivity of the film as a function of wavelength, and from reciprocity-law failure. The present spectra are in general agreement with earlier measurements for CaF_2:Mn, $CaSO_4$:Mn, Lif(TLD-100), and CaF_2(MBLE).

The radioluminescence spectra of CaF_2:Mn and $CaSO_4$:Mn was determined and found to be similar in shape and peak position to the thermoluminescence spectrum but were narrower. The radioluminescence spectrum of LiF(TLD-100), however, was wider than the thermoluminescence spectrum. The radioluminescence spectra of CaF_2(MBLE) extended far into the ultraviolet region.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing.

AUTHORIZATION

NRL Problem H01-24
Projects RR 002-06-41-5009 and SF 011-05-04-6192
NASA S-16444G
AEC AT(49-7)-1864

Manuscript submitted March 15, 1966.

THE EMISSION SPECTRA OF VARIOUS THERMOLUMINESCENT MATERIALS

INTRODUCTION

Several experimentally observable parameters determine the usefulness of a thermoluminescent material as a radiation dosimeter. Among these are the temperatures of the glow peaks, the rate of decay of the thermoluminescent signal, the linearity of response as a function of dose, the dose at which damage effects become important, the tissue-equivalence of the material, and the spectrum of the light emission. Due to the low intensity of the emission, the measurement of the last of these, the spectrum, has been generally neglected. This report presents measurements of the thermoluminescence spectra of several of the more useful dosimetry materials, resulting from prior Co^{60} γ radiation. Included are lithium fluoride (TLD-100),* manganese-activated calcium fluoride,† manganese-activated calcium sulfate,† manganese-activated lithium borate ($Li_2B_4O_7$:Mn)‡ (1), terbium-activated lithium aluminosilicate glass† (2), and calcium fluoride (MBLE).§ In addition, the radioluminescence spectra of the LiF, CaF_2:Mn, $CaSO_4$:Mn, and CaF_2(MBLE) were measured, employing an OEG-60 beryllium-window x-ray tube operated at 45 kV (constant potential) for stimulating the phosphors.

From a practical point of view, the design of a reader of optimum performance in a thermoluminescence dosimetry system requires a knowledge of the spectral quality of the emitted light. One of the factors which determines the minimum measurable dose for such a system is the magnitude of the "heat signal" produced by the thermal emission of the heater (used to raise the temperature of the phosphor) or of the phosphor itself. The intensity of this interfering signal increases strongly toward the longer wavelengths; thus a phosphor which emits its thermoluminescence in the red portion of the spectrum is thereby basically less effective when used to measure low doses than one which emits in the blue.

METHOD

The spectra of these materials have been measured photographically using a Gaertner quartz-prism spectrograph. One of the major difficulties in photographic spectroscopy is that both the sensitivity and "gamma" (the slope of the density-versus-log-intensity curve) of a photographic emulsion are strongly wavelength dependent (3). An additional problem, at these low intensities, is reciprocity-law failure; equal exposures delivered at different rates result in different film densities.

Errors due to the variation of film response with wavelength are overcome by producing a film density-versus-exposure curve for each wavelength of interest in the spectrum. This is accomplished with a Standard of Spectral Irradiance¶ consisting of a

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*Obtained from Harshaw Chemical Company.

†Prepared by and obtained through the courtesy of R. J. Ginther.

‡Prepared by and obtained through the courtesy of R. D. Kirk.

§Obtained through the courtesy of Manufacture Belge De Lampes et de Materiel Electronique S/A (MBLE).

¶Obtained from the National Bureau of Standards.

quartz-iodine tungsten coiled-coil-filament lamp with a known absolute irradiance* as a function of wavelength (4). A series of exposures of the output of this lamp are recorded, varying its distance from the spectrograph in such a way that the exposures differ by factors of two. To prevent errors from the changing angle of incidence of the light entering the spectrograph slit as the distance is changed, and also to reduce the light intensity to the range of the thermoluminescence intensities, the spectrograph is directed toward a magnesium oxide diffuse-reflector which is illuminated by the standard lamp. In this way, the spectrograph sees a uniformly illuminated surface both during the exposures with thermoluminescence, and with the standard light.

The range of exposure times required to obtain reasonable film densities (from about 0.2 to 3.0 above gross fog) with the available thermoluminescence signals can cause large reciprocity-law failures. In order to circumvent this problem, all exposures in a series must be made with the same exposure time and with the exposure rate as nearly constant as possible. In this way, at any given wavelength, equal film densities correspond to equal exposure rates and consequently to equal total exposures. The emission rate of the thermoluminescence may be maintained at a reasonably constant value by raising the temperature rapidly to a point somewhat below the temperature of the glow peak of interest and maintaining it there. The thermoluminescence output can be kept as constant as necessary at the expense of the intensity. In the case of the radioluminescence spectra the emission can be kept strictly constant throughout the exposure.

In each thermoluminescence measurement, the phosphor sample, after having been given 10^4 R of Co^{60} γ radiation, is placed in a copper cup. The cup is then set in the end of the preheated soldering iron which is positioned in front of the (shuttered) spectrograph slit (Fig. 1). After a reasonably constant output has been reached, the spectrograph shutter is opened and the exposure is started. The exposure of a single sample is terminated within about 20 seconds. In the case of the most-sensitive phosphors, a single readout is sufficient to give readable film densities, but in some of the less-sensitive ones the signal from several samples is required.

In order to make the results independent of variations in film-processing parameters, a full series of exposures is made on a single sheet of film (Fig. 2). Each negative includes exposures of the thermoluminescence or radioluminescence, the standard lamp series, and several helium line spectra spaced through the data as a wavelength calibration.

The resulting densities are read on a recording microdensitometer (Joyce, Loebl & Co., Ltd., Model MK IIIC) which produces the typical display shown in Fig. 3. Figures 4, 5, and 6 illustrate the reduction of the densitometer traces of Fig. 3 to the final spectral curves. Figure 4 is a smoothed reproduction of Fig. 3; the wavelength scale is nonlinear due to the wavelength-dependence of the spectrograph dispersion. The wavelengths are determined from the calibration line spectra of Fig. 2. A conveniently spaced series of wavelength in the region of the unknown spectrum is chosen (labeled λ_1 through λ_4 in Fig. 4) and a curve of density versus relative standard lamp intensity is produced for each such wavelength. The resulting set of curves is shown in Fig. 5.

The intensity of the thermoluminescence relative to the standard lamp output is determined from these curves as shown by the example in Fig. 5. The density produced by the thermoluminescence at λ_3, 12.3, is found from Fig. 5 to correspond to 59 percent of the intensity of the most intense standard lamp exposure. Repetition of this process for each of the chosen wavelengths produces the display of Fig. 6 (in an actual determination about four times as many wavelengths would be chosen than are shown in Figs. 5 and 6). The points form a curve of thermoluminescence intensity (expressed as a percentage of the maximum standard lamp exposure) as a function of wavelength. The relative

*Given in microwatts per square centimeter-nanometer ($\mu W/cm^2$-nm).

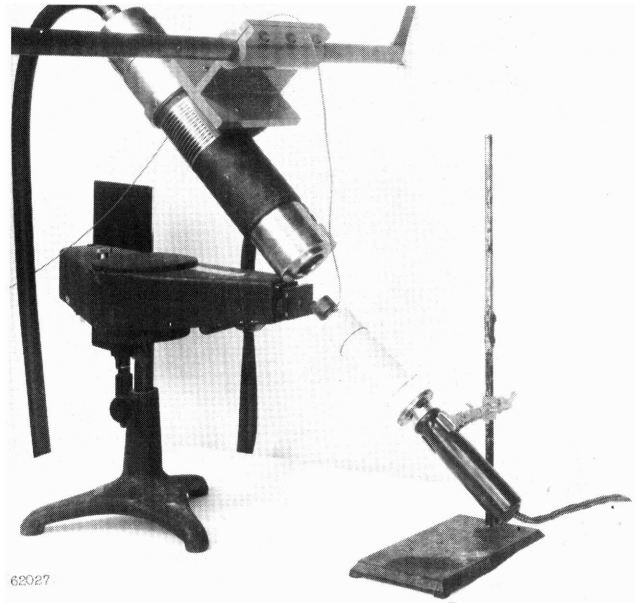


Fig. 1 - The experimental arrangement used in measuring the thermoluminescence spectra showing the modified soldering iron used in heating the samples, the electrical leads from a temperature controller to a thermocouple imbedded in the copper heater rod of the soldering iron, and the spectrograph. The x-ray tube above the spectrograph was used for excitation during radioluminescence measurements.

Fig. 2 - An enlargement (~2X) of a typical negative which includes a full set of exposures. The line spectra for wavelength calibration shown are Geisler-tube spectra of helium; the series of six broad spectra (three at the top and three at the bottom) are the standard light exposures; while the four bands in the center are, in this case, radioluminescence spectra of $CaSO_4$:Mn for different exposures obtained by graded x-ray intensities.

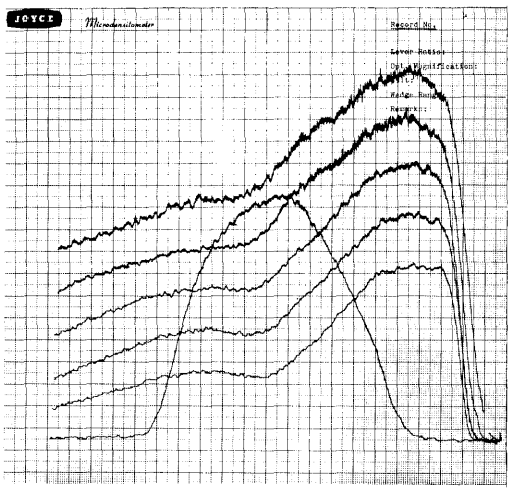


Fig. 3 - A set of curves produced by reading a typical negative (such as shown in Fig. 2) on the recording microdensitometer. The five similar curves are five standard light exposures with intensities differing by factors of two, and the remaining curve is the thermoluminescence spectrum of $CaSO_4$:Mn. The line spectra used for wavelength calibration (see Fig. 2) have been omitted for clarity.

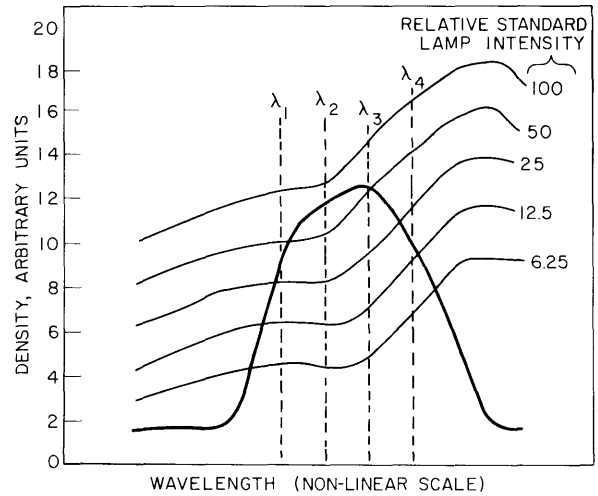


Fig. 4 - A schematic reproduction of Fig. 3 showing a set of wavelengths (λ_1 through λ_4) chosen for analysis

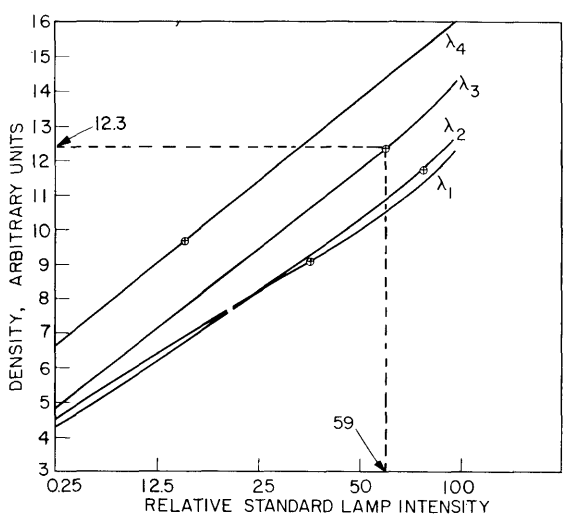


Fig. 5 - Density-versus-relative-intensity curves for the chosen wavelengths of Fig. 4. The density values of the thermoluminescence spectrum at the four chosen wavelengths determine the position of the point indicated on each curve.

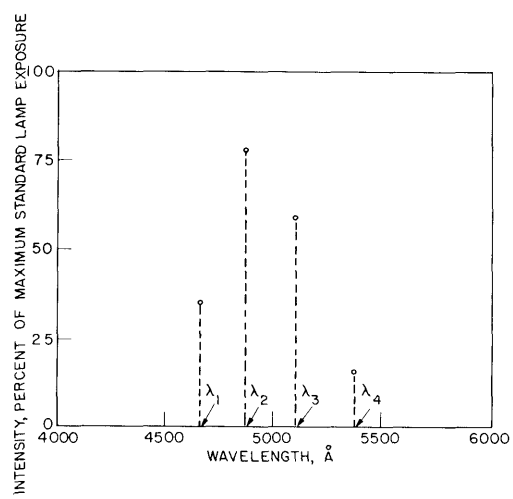


Fig. 6 - The intensity (as a percentage of the maximum standard lamp exposure) of the thermoluminescence spectrum at the chosen wavelengths uncorrected for the spectral irradiance of the standard lamp

intensity per unit wavelength of the thermoluminescence spectrum is obtained by multiplying each point by the irradiance of the standard lamp at the corresponding wavelength. This curve is normalized to a peak height of one unit and displayed as the thermoluminescence spectrum..

As a check on the accuracy of the method, the ultraviolet-stimulated fluorescence spectrum of magnesium tungstate was measured and compared to previous measurements by others of the spectrum of this material. The magnesium tungstate was pressed into a flat disc, placed before the spectrograph slit, and illuminated by the 2537Å mercury line from a small quartz discharge tube, the light from which had been passed through a monochromator. Figure 7 shows the results of this measurement. The differences between the results of Forsythe and Adams (5), Claffy and Kirk (NRL), and the present measurement are not significant.

As an additional check on the magnitude of possible errors due to reciprocity-law failures from not having a strictly constant light source during the thermoluminescence measurements, deliberate timing errors were made on a series of standard light exposures. It was found that timing errors of 50 percent caused errors of about 20 percent in the final spectrum. Measurements of the thermoluminescence output as a function of time, with the method used for these measurements, show variations of less than 20 percent, which should cause errors of less than 10 percent in the final spectra.

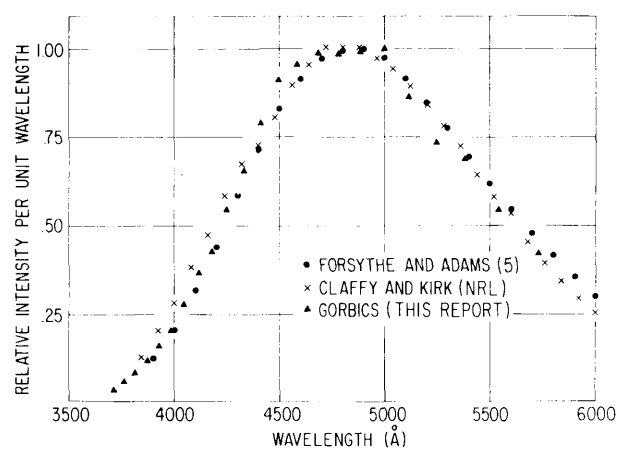


Fig. 7 - Comparison of the fluorescence spectrum of magnesium tungstate determined by the method of this report with the spectrum determined by previous measurements

RESULTS

The solid curve in Fig. 8(a) is the thermoluminescence spectrum of CaF_2:Mn. This material has a single glow peak occurring at about 260°C (6). The spectrum shows a peak at 4950Å with a width at half-maximum of 580Å. The radioluminescence spectrum of the same phosphor is shown by the dashed curve. The shape and peak position are similar to the thermoluminescence curve, but the width is about 15 percent narrower.

The thermoluminescence spectrum of $CaSO_4$:Mn, the solid curve in Fig. 8(b), is very nearly the same as the preceding spectrum for manganese-activated calcium fluoride. The glow curve for calcium sulfate contains a single peak at a temperature of about 90°C (7). The radioluminescence spectrum (the dashed curve) appears to be narrower than the thermoluminescence spectrum, as it was for calcium fluoride.

Figure 8(c) shows the thermoluminescence spectrum of $Li_2B_4O_7$:Mn. The glow curve of this material shows two separate peaks at 55°C and 200°C (1). The low temperature

peak is unstable, and the light from that part of the glow curve is not included in the spectrum of Fig. 8(c). This spectrum, peaking at about 6000Å, is the longest in wavelength of the phosphors measured. The spectrum could not be measured above about 6200Å with the present apparatus, since both the spectrograph dispersion and the film sensitivity become inadequate in this region. No radioluminescence spectrum was obtained due to the low efficiency of this phosphor for that process.

The solid curve of Fig. 8(d) is the thermoluminescence spectrum of LiF(TLD-100). No attempt was made to separate the several peaks in the glow curve of this material (8). The spectrum has its maximum at 4000Å with a width at half-maximum of 1200Å. The radioluminescence spectrum, the dashed curve, is, contrary to the previous cases of CaF_2:Mn and $CaSO_4$:Mn, somewhat broader than the thermoluminescence spectrum.

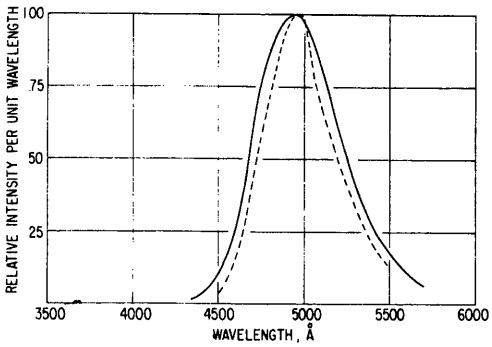
The glow curve for CaF_2(MBLE) shows three separate peaks, at 95, 180, and 260°C (9). Visual evidence indicated that the spectrum of each of these peaks was different, and an attempt was made to separate them in this measurement. The 260°C peak is by far the most intense and is the one normally used for dose measurements. The spectrum of this peak is shown in Fig. 8(e). The intensities of the two lower-temperature glow peaks were insufficient to give adequate film densities for complete analysis, but it was possible to determine the wavelengths and the relative intensities of the spectral peaks contained in each of the glow peaks. It was found that the 95°C glow peak consisted mainly of the spectral component labeled peak III in Fig. 8(e) (with a small contribution from peak II), the 180°C glow peak was made up of all three spectral peaks, while the main 260°C glow peak consisted almost entirely of the major spectral peak at 3750Å together with a small amount of peak II.

Initial attempts at the measurement of the radioluminescence spectrum of CaF_2(MBLE) were made using an MBLE Model PNP-080 dosimeter, consisting of an evacuated glass bulb containing an indirectly heated cylindrical element onto which the phosphor is bonded. The analysis of the emitted light revealed an intense peak whose maximum occurred at about 3200Å. The previous measurements of the radioluminescence spectra on the other phosphors led to the conclusion that this emission must be due either to the glass envelope of the dosimeter or to the binder used with the phosphor. Later measurements on loose powder supplied by MBLE showed this not to be the case. The emission was from the phosphor itself and extended even further into the ultraviolet region, since the absorption due to the glass and binder was eliminated. The spectrum shown in Fig. 8(f) is the result of indirect methods of analysis, since the standard light used could not cover the ultraviolet range involved here. Thus the precision of this spectrum is not comparable to that of the other measurements in this report.

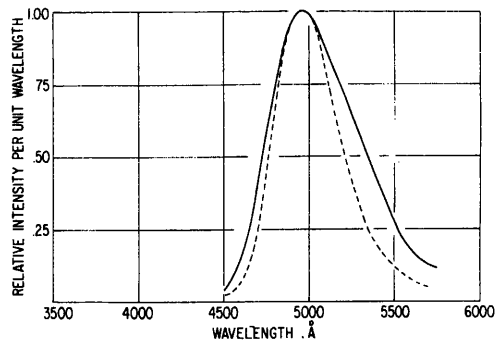
Figure 8(g) shows the thermoluminescence spectrum of a typical sample of terbium-activated lithium aluminosilicate glass (2). This spectrum is one of a series taken on glasses of varying compositions and activator concentrations.

COMPARISONS WITH OTHER MEASUREMENTS

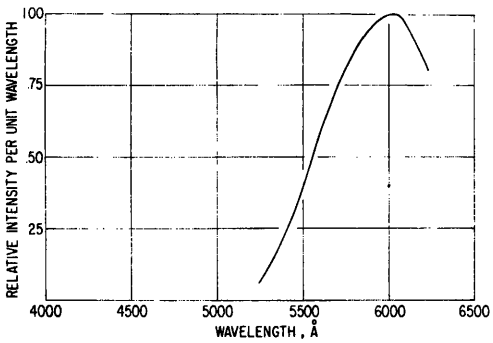
Only a few earlier spectral measurements have been reported for the materials included in the present study; none have been done for $Li_2B_4O_7$:Mn or terbium-activated lithium aluminosilicate glass, as neither of these has been available previously. Figure 9 (from Ref. 10 with curve D corrected to conform to later results from Ref. 11) shows the thermoluminescence spectra obtained by others for $CaSO_4$:Mn, LiF(TLD-100), CaF_2(MBLE), and CaF_2:Mn.



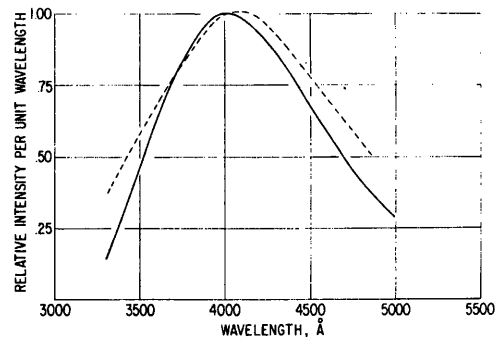
(a) CaF_2:Mn



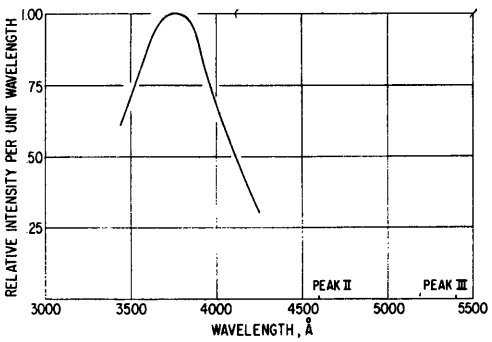
(b) $CaSO_4$:Mn



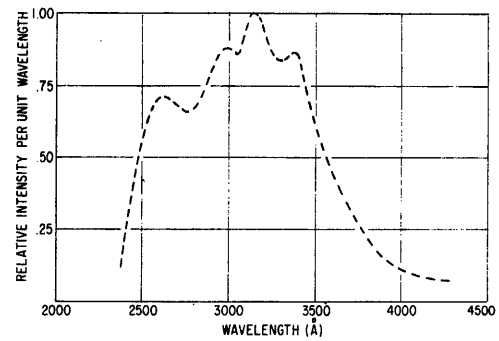
(c) $Li_2B_4O_7$:Mn



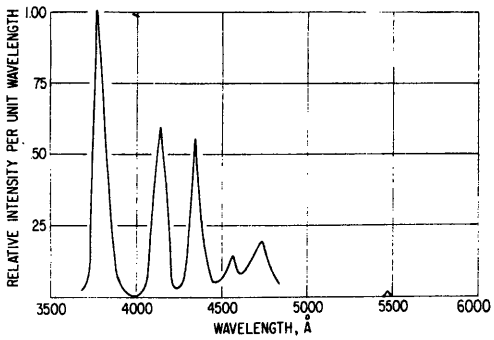
(d) LiF(TLD-100)



(e) CaF_2(MBLE)



(f) CaF_2(MBLE) (approximate spectra)



(g) Terbium-activated lithium aluminosilicate glass

Fig. 8 - The thermoluminescence spectra (solid curves) and radioluminescence spectra (dashed curves) of the materials indicated

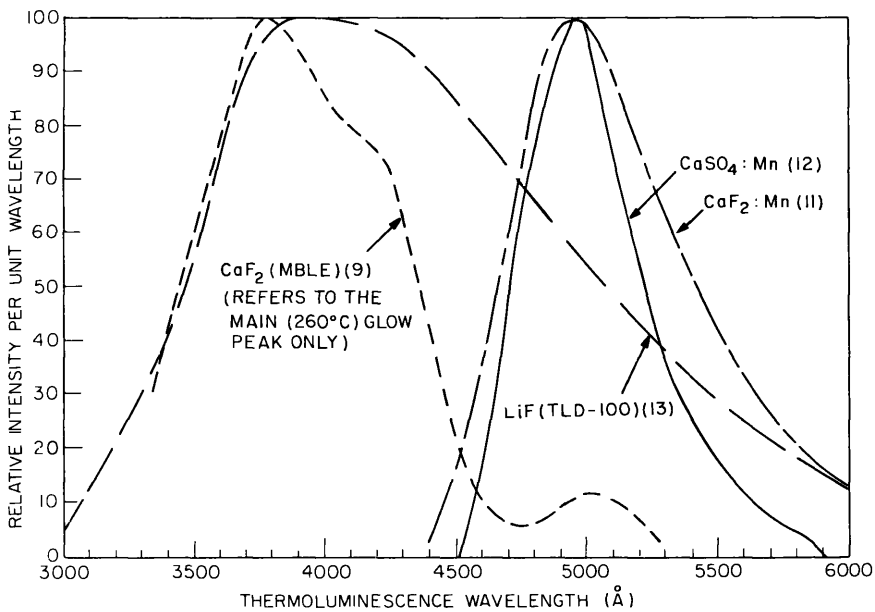


Fig. 9 - Previous measurements of the thermoluminescence spectra

The spectrum for $CaSO_4$:Mn was obtained by Bjärngard (12), who employed a Zeiss Model PMQ II spectrophotometer.* Phosphor samples having identical γ-ray exposures were "glowed out" in front of the spectrophotometer slit with the monochromator set at a different wavelength for each sample. The wavelength dependence of the photomultiplier tube sensitivity was corrected for on the basis of manufacturer's recommendations for the tube type employed. (The same general method was employed by the investigators who obtained the data for LiF(TLD-100) and CaF_2(MBLE), except that other types of spectrophotometers were used.) The present results for the thermoluminescence spectrum of $CaSO_4$:Mn (Fig. 8(b)) are in reasonably good agreement with the Bjärngard spectrum, inasmuch as both maxima occur at 4950Å and the widths at half maximum differ by less than 100Å. Neither of these results is in significant disagreement with three earlier measurements of the same spectrum (14-16).

The thermoluminescence spectrum of LiF(TLD-100) measured by Cameron (13) is given in Fig. 9. The present spectrum of Fig. 8(d) is appreciably narrower (1200Å versus 1600Å at half maximum), but the maxima for both spectra occur near 4000Å.

Schayes et al. (9) have reported the results of spectral measurements of the thermoluminescence of CaF_2(MBLE). The curve in Fig. 9 is a smoothed presentation of the spectrum of the principal glow peak, which occurs at about 260°C. Unlike the methods used for obtaining the $CaSO_4$:Mn and LiF(TLD-100) curves, that employed by Schayes made use of a series of bandpass filters. A comparison of the CaF_2(MBLE) curve of Schayes with the spectrum in Fig. 8(e) reveals reasonable agreement in the position of the major maximum, but the curve of Schayes contains some additional structure not observed in the present measurement.

*This spectrum was originally given in terms of the numbers of photons per wavelength interval versus wavelength but was converted to relative intensity (energy) per wavelength interval versus wavelength for ease of comparison with the other spectra in Ref. 10.

The last curve in Fig. 9 gives the thermoluminescence spectrum of CaF_2:Mn as obtained by Palmer et al. (11), using a Hilger-Watt spectrograph. The agreement between this spectrum and that of Fig. 8(a) is quite good, with both maxima occurring at about 4950Å and the widths at half maximum differing by only 150Å. A second spectral measurement on a sample of CaF_2:Mn which was prepared in a different manner (resulting in a greater activator concentration) is also reported in Ref. 11. In this case, a similar but much broader spectrum (width at half maximum of 1150Å versus 580Å from the present measurement) is observed.

ACKNOWLEDGMENTS

The continuing support and interest of F. H. Attix in all phases of this work is greatly appreciated. In addition, the author is greatly indebted to J. H. Schulman, R. J. Ginther, and R. D. Kirk for their valuable advice about eliminating reciprocity-law failure as a source of spectral distortion and for supplying several of the phosphors as well as loaning the spectrograph; to A. E. Nash for his participation in the work during its early stages; to R. D. Kirk and E. W. Claffy for supplying the data shown in Fig. 7; to R. Schayes for supplying the powdered CaF_2(MBLE) used in obtaining the data for Figs. 8(e) and 8(f); and to F. H. Attix and V. Mejdahl for critically reviewing the manuscript.

REFERENCES

1. Schulman, J.H., Kirk, R.D., and West, E.J., "Use of Lithium Borate for Thermoluminescent Dosimetry," Proc. Int. Conf. on Luminescence Dosimetry, Stanford Univ., June 1965 (in press, U.S. Atomic Energy Commission)

2. Ginther, R.J., "Terbium Activated Thermoluminescent Glass for Dosimetry," Proc. Int. Conf. on Luminescence Dosimetry, Stanford Univ., June 1965 (in press, U.S. Atomic Energy Commission)

3. Sawyer, R.A., "Experimental Spectroscopy," 3rd edition, New York:Dover, 1963

4. Stair, R., Schneider, W.E., and Jackson, J.F., "A New Standard of Spectral Irradiance," Appl. Optics 2:1151 (Nov. 1963)

5. Forsythe, W.E., and Adams, E.Q., "Fluorescent and Other Gaseous Discharge Lamps," New York:Murray Hill, 1948

6. Schulman, J.H., Attix, F.H., West, E.J., and Ginther, R.J., "New Thermoluminescent Dosimeter," Rev. Sci. Instr. 31:1263 (1960)

7. Patterson, D.A., and Friedman, H., "Milliroentgen Dosimetry with Thermoluminescence," J. Opt. Soc. Amer. 47:1136 (1957)

8. Schulman, J.H., Attix, F.H., West, E.J., and Ginther, R.J., "Thermoluminescence Methods in Personnel Dosimetry," Proceedings of the Symposium on Personnel Dosimetry Techniques, published by the Organization for Economic Cooperation and Development, Paris, 1963

9. Schayes, R., Lorthioir, M., and Lheureux, M., "La Dosimetrie par Thermoluminescence," Review M.B.L.E. 6:33 (Brussels), Part IV (1963)

10. Attix, F.H., "Present Status of Dosimetry by Radiophotoluminescence and Thermoluminescence Methods," NRL Report 6145 Sept. 1964

11. Palmer, R.C., Blase, E.F., and Poirier, V., "A Coprecipitation Technique for the Preparation of Thermoluminescent, Manganese-Activated Calcium Fluoride (CaF_2:Mn) for use in Radiation Dosimetry," Intern. J. Appl. Radiat. Isotop. 16:737 (Dec. 1965)

12. Bjärngard, B., "The Properties of $CaSO_4$:Mn Thermoluminescent Dosimeters," Aktiebolaget Atomenergi Report AE-109, 1963

13. Cameron, J.R., personal communication to F.H. Attix, 1964

14. Watanabe, K., "Properties of a $CaSO_4$:Mn Phosphor under Vacuum Ultraviolet Excitation," Phys. Rev. 83:785 (1951)

15. Arkhangel'skaya, V.A., Vainberg, B.I., Kodyukov, V.M., and Razumova, T.K., "Luminescence Dosimeter Based on a $CaSO_4$:Mn Phosphor for Gamma Rays, Beta Particles and Neutrons," Atomnaya Energiya 8:559 (1960); also English translation in AEC-tr-4568, Soviet J. Atomic Energy 8:481 (1961)

16. Bettinali, C., Ferraresso, G., and Stampacchia, G., "Termoluminescenza di Carbonati e Solfati di Calcio Naturali e Artificiali – Composizione Spettrale dei Picchi," Atti Accad. Naz. Lincei, Rend. Classe Sci. Fis., Mat. Nat. XXXI:123 (1961)

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

THE EMISSION SPECTRA OF VARIOUS THERMOLUMINESCENT MATERIALS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

An interim report on one phase of the problem.

5. AUTHOR*(S)* *(Last name, first name, initial)*

Gorbics, S. G.

6. REPORT DATE August 5, 1966	7a. TOTAL NO. OF PAGES 13	7b. NO. OF REFS 16

8a. CONTRACT OR GRANT NO. NRL Problem H01-24 b. PROJECT NO. RR 002-06-41-5009 c. SF 011-05-04-6192 NASA S-16444G d. AEC AT(49-7)-1864	9a. ORIGINATOR'S REPORT NUMBER*(S)* NRL Report 6408 9b. OTHER REPORT NO*(S)* *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Dept. of the Navy (Office of Naval Research and Naval Electronics Systems Command), Washington, D. C. 20360. (Also NASA and U.S. AEC.)

13. ABSTRACT

The thermoluminescence emission spectra of various materials have been determined using a quartz-prism spectrograph. The materials studied include: CaF_2:Mn, $CaSO_4$:Mn, $Li_2B_4O_7$:Mn, LiF(TLD-100), CaF_2(MBLE), and a terbium-activated lithium-aluminosilicate thermoluminescent glass. The spectra were measured photographically and corrected by means of an NBS quartz-iodine tungsten-filament standard of spectral irradiance. Precautions were taken to prevent spectral distortions resulting from the variation in sensitivity of the film as a function of wavelength, and from reciprocity-law failure. The present spectra are in general agreement with earlier measurements for CaF_2:Mn, $CaSO_4$:Mn, LiF(TLD-100), and CaF_2(MBLE).

The radioluminescence spectra of CaF_2:Mn and $CaSO_4$:Mn was determined and found to be similar in shape and peak position to the thermoluminescence spectrum but were narrower. The radioluminescence spectrum of LiF(TLD-100), however, was wider than the thermoluminescence spectrum. The radioluminescence spectra of CaF_2(MBLE) extended far into the ultraviolet region.

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Security Classification

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