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Scintillations in Some Phosphor-Plastic Systems*

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The scintillation properties of anthracene and stilbene dissolved in polystyrene, Lucite, and Paraplex have been investigated. The Lucite and Paraplex solutions were very poor counters, but the polystyrene solutions compared favorably in performance with pure anthracene. A study of the emission spectra indicates that the fluorescence bands of polystyrene overlap the absorption bands of anthracene and stilbene; consequently, it is possible to have an efficient energy transfer from the plastic to the phosphor in these cases and good counting systems result. This is not the case in the systems involving Lucite and Paraplex; consequently, their performance as counters is poor.

I. INTRODUCTION

RECENT publications[1–3] of results on scintillations produced in solutions of phosphors in organic solvents suggest the possibility of obtaining similar results with solid solutions of organic phosphors in plastics. Such a possibility has been under investigation in this laboratory and during the course of this work Schorr and Torney[4] published their preliminary results. In view of the fact that our investigation involved more than one plastic system and that the spectral studies which we have made shed some light on the mechanism of the energy transfer from plastic to the phosphor, it was considered worthwhile to make a report of the results.

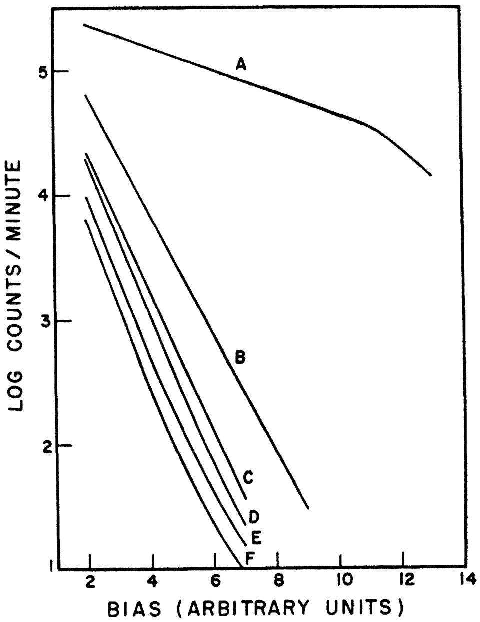

FIG. 1. Discriminator curves for some phosphor-plastic combinations using Co^{60} as a gamma-ray source: (A) single anthracene crystal, (B) 2 percent anthracene-polystyrene, (C) 10 percent stilbene-polystyrene, (D) 2 percent stilbene-polystyrene, (E) polystyrene, (F) background with the source in position but no phosphor present.

The advantages of phosphor-plastic solid solution counters over both the liquid solution and the single crystal counter is obvious; however, it might be mentioned that, since one can form large clear masses of the plastics very simply, it might be expected that such counters could be utilized to count γ-rays and fast neutrons with higher efficiencies than is now possible.

II. EXPERIMENTAL METHOD

The organic phosphors (anthracene and stilbene) used in this work were commercial products which had been recrystallized from appropriate solvents and then further purified by sublimation in high vacuums. When single crystals of these materials were needed, they were made in the usual manner, by slow cooling of the melt. In the preparation of the phosphor-plastic solid solution a weighed amount of the phosphor was dissolved in a weighed amount of the monomer of the plastic. To this solution about 0.5 percent catalyst (50–50 mixture of beyzoyl peroxide and tricresyl phosphate) was added. Then the material was frozen, the air was pumped out, and the glass vessel was sealed and heated overnight at about 125°C. The polymer was then removed from the glass container, cut into disks, and polished. The final dimensions of the disks consisted of a diameter of 1.28 cm and a thickness of 0.40 cm. Solutions of stilbene or anthracene in the three plastics, polystyrene, Paraplex, and Lucite were investigated. Concentrations up to 10 percent of the phosphor in polystyrene gave a clear colorless solid. Attempts to make 25 and 50 percent phosphor-plastics resulted in opaque masses. Overheating tended to produce a yellowish tint in the plastic which affected its performance efficiency.

The phosphor-plastic disks were mounted on a 5819 photo-multiplier tube. The output of this tube was amplified and sent into a pulse-height discriminator[5] using a Schmitt trigger-type circuit followed by a scale-of-1000 counter. Co^{60} was used as a γ-ray source and a

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* This work was performed under the auspices of the AEC.

[1] Ageno, Chizzoto, and Querzoli, Atti. accad. nazl. Lincei **6**, 626 (1949).

[2] Reynold, Harrison, and Salvini, Phys. Rev. **78**, 488 (1950).

[3] H. Kallman, Phys. Rev. **78**, 621 (1950).

[4] M. G. Schorr and F. L. Torney, Phys. Rev. **80**, 474 (1950).

[5] Higinbotham, Gallagher, and Sands, Rev. Sci. Instr. **18**, 706 (1947).

discriminator bias curve was obtained for each phosphor-plastic system. These curves were compared with the curve for a single anthracene crystal of approximately the same geometry.

The spectrograms of the fluorescence in the various materials studied here were made with a small Hilger quartz spectrograph using Eastman 103–0 plates. Cu x-rays were used as a source of excitation. The material to be studied was fastened directly over the slit of the spectrograph. The slit width was 0.1 mm. The wavelengths were determined by comparison with a standard mercury spectrum.

III. DISCUSSION OF RESULTS

The results obtained for counting Co^{60} γ-rays are given in the discriminator curves of Fig. 1. The background without the source was practically negligible so is not included; however, the background with the source in place but with the phosphor removed is included, since it was appreciable. It is presumably due to the effect of the γ-rays on the tube envelope and components. It will be noted that the slope for the pure anthracene is considerably smaller than the slopes of any of the phosphor plastics, indicating a rather different distribution of pulse sizes; however, at the lower bias settings the performance of the 2 percent anthracene-polystyrene is comparable to that of the pure anthracene. The anthracene-plastic is superior to the stilbene-plastic, as might be expected. One reason for this is that the emission spectra and the spectral response of the 5819 are more evenly matched in the anthracene case.

The effect of concentration on the counting rate has not been studied exhaustively; but stilbene has been studied at three different concentrations, and the indications are that the counting rate begins to flatten out when the concentration is greater than a few percent. For example, in the bias curves in Fig. 1 it will be noticed that 10 percent stilbene is only slightly better than 2 percent stilbene. This fact appears to be compatible with the work of Schorr and Torney.[4]

The counting results obtained with the Lucite and the Paraplex solutions are not indicated, because their curves would hardly be distinguishable from the background curve. The counts for Paraplex and Lucite were only 150 and 200 counts/min, respectively, higher than the indicated background curve at the bias setting of 3.

The spectral data are summarized by the densitometer tracings in Fig. 2 and by Table I. These data indicate a 240A shift of the strong anthracene peak toward the blue and a considerably smaller shift of the corresponding stilbene peak. In view of the fact that polymerization in polystyrene takes place through the ethylemic linkage and the unsaturated benzene rings are left intact, the stilbene dissolved in polystyrene finds itself in an environment which is not too different from its crystal habitat so the effect of the solvent in shifting the stilbene peak might be expected to be small.

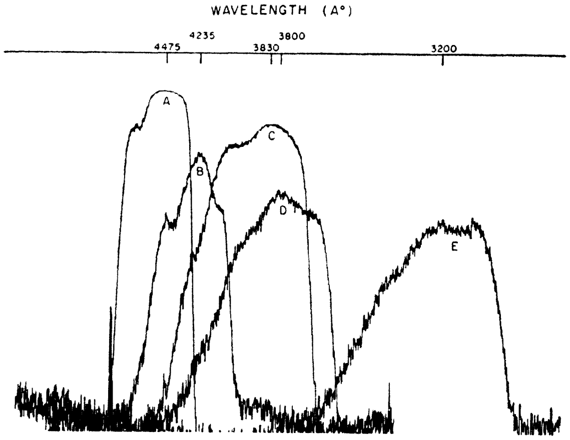

FIG. 2. Densitometer tracings of the emission spectrograms obtained for the following phosphor plastic combinations: (A) anthracene crystal, (B) 2 percent anthracene-polystyrene, (C) stilbene crystal, (D) 2 percent stilbene-polystyrene, (E) polystyrene. X-rays were used as a source of excitation.

This is not the case for anthracene, however, and consequently a larger solvent effect is observed. The emission spectra of polystyrene is of more interest and of greater significance as far as the subject of this investigation is concerned. It has been pointed out by several investigators[6, 7] that scintillations in unsaturated organic crystals are intimately connected with the presence of conjugated double bonds; consequently, one would expect styrene to scintillate because of the presence of the benzene rings. Furthermore, since the wavelength[8] of the scintillations is determined by the extent over which the π electrons can migrate in the molecule, polystyrene would be expected to have an emission spectra in the region further shifted to the ultraviolet than anthracene, since the π electrons in polystyrene can migrate only over the extent of the benzene ring.

TABLE I. Wavelengths of emission bands of various phosphor-plastic systems excited by copper x-rays.

Material	Wavelength (A)
Anthracene crystal	4475 (strong) 4740
Two percent anthracene-polystyrene	4480 4235 (strong) 4090
Stilbene crystal	4035 3830 (strong)
Two percent stilbene-polystyrene	4000 (weak) 3800 (strong) 3640
Polystyrene	3350 (weak) 3200 3110

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[6] Gittings, Taschek, Ronzio, Jones, and Masilum, Phys. Rev. **75**, 205 (1949).

[7] W. S. Koski and C. O. Thomas, Phys. Rev. **76**, 308 (1949).

[8] W. S. Koski and C. O. Thomas, Phys. Rev. **79**, 217 (1950).

This is not the situation in Lucite, since on the polymerization of methyl metacrylate no conjugated double bonds remain; and consequently, it would not be expected to fluoresce in the spectral region investigated here. We have not been able to ascertain the composition of the Paraplex P-43 used in this work; but presumably it does not have an appreciable amount of conjugation after polymerization, since there is no evidence of fluorescence on x-ray excitation. Anthracene in solution has been reported[9] to have a series of intense overlapping absorption bands in the 3500A and 2500A regions. Consequently, the polystyrene fluorescence is absorbed by the anthracene in the phosphor-plastic; and the anthracene in turn gives off its characteristic radiation when it falls from the excited state to a lower state. This interpretation is supported by the fact that even in long exposures where the anthracene emission is strongly overexposed there was no visible evidence of the polystyrene fluorescence on the plate, indicating that a large fraction of it had been absorbed by the solute molecules. A similar situation exists in the case of stilbene. In the case of Lucite and Paraplex the fluorescence is very weak, so there is very little energy transfer from the plastic to the phosphor; and as a result, such solid solutions make very poor counters.

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[9] Radulecu and Ostrogovich, Ber. 64, 2233 (1931).

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Plasma Oscillations in a Static Magnetic Field*

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A theory of the small-amplitude oscillations of an ionized gas in a static magnetic field is developed, including the effects of temperature motions. The Boltzmann equation is solved for this problem, and exact expressions are obtained for the distribution function and dispersion relation. A general feature of the dispersion relation is the existence of gaps in the spectrum at frequencies which are approximately multiples of $\omega_c = eH/mc$. The magnitude of the gap depends on the temperature of the gas, being proportional to it for long wavelengths. This leads to the prediction of selective reflection of waves impinging on a plasma with frequency in the forbidden range.

For $ck \gg \omega_p$, ω_c the waves split into approximately longitudinal plasma waves and transverse waves. Detailed analysis is made of the plasma waves for ω_c small and ω_c large. At long wavelengths the frequency is $\omega^2 \simeq \omega_p^2 + \omega_c^2 + \beta(\kappa T/m)k^2$, where β depends on ω_p and ω_c. For waves near the Debye length the waves are heavily damped.

Two simplified treatments of plasma oscillations based on transport equations are compared with the above treatment. Expressions of the form $\omega^2 \simeq \omega_p^2 + \omega_c^2 + \beta(\kappa T/m)k^2$ are obtained where the factor β is independent of ω_c and ω_p. In addition, the transport treatments fail to predict the heavy damping near the Debye length and the existence of gaps in the frequency spectrum.

I. INTRODUCTION

THE small amplitude vibrations of a plasma oscillating in a static magnetic field are discussed in this paper. For the case in which the thermal velocities of the particles are negligible, or for the limiting case of zero wavelength, the customary[1] theory of the propagation of electromagnetic waves in the ionosphere provides a satisfactory treatment of the vibrations, including the longitudinal plasma oscillations. The customary theory is not adequate to take into account the effects of random thermal motions and to treat these it is necessary to make use of the general methods of kinetic theory. In this type of problem, one is generally interested, from the practical point of view, in the dispersion relation giving the frequency of the possible waves as a function of the wavelength and also in the polarization properties of the waves. From the theoretical viewpoint it is also of great interest to know the velocity distribution of the particles if it is possible to compute it exactly, since this allows one to see what part the individual particles play in sustaining the oscillation. Plasmas are of particular interest in this connection, since they display organized properties depending on the cooperative action of all members of the assembly, but are systems still so simple that one can follow mathematically the detailed motion of the individual members of the assembly to a great extent. A detailed physical picture of the mechanism of ordinary plasma oscillations has been given,[2-4] and in the present

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[1] H. Lassen, Ann. Physik 1, 415 (1947); H. R. Mimno, Revs. Modern Phys. 9, 1 (1937).

[2] D. Bohm and E. P. Gross, Phys. Rev. 75, 1851 (1949).

[3] D. Bohm and E. P. Gross, Phys. Rev. 75, 1864 (1949).

[4] D. Bohm and E. P. Gross, Phys. Rev. 79, 992 (1950).