

From Eqs. (1) and (3) it is seen that by using measurements of both the initial drop and the decay constant of Fig. 2(a), it should be possible to reconstruct the variation of conductivity, and hence current density, with electric field. In Fig. 3 the variation of current density (obtained as just described) and drift mobility determined by pulse measurements is compared with the Hall mobility and current density determined as a function of E by dc measurements. The j - E curve obtained from the pulse data was normalized to the dc data at one point. It is this excellent agreement of the pulse measurements with the dc data that justifies the fundamental assumption that, even for the large pulses involved in these experiments, the distribution function follows changes in applied electric field in a time short compared to the time constant, τ , for change in carrier density. It is the value of τ obtained from pulsing to a value of E_B in the linear conductivity range that was used, with Eq. (2), to obtain the values of B_T plotted in Fig. 1. The additional assumption that

$$A_I \ll B_T N_A / (N_D - N_A)$$

in the linear range was made. A nominal value for N_A of $\sim 5 \times 10^{12}/\text{cm}^3$ was obtained from comparison of the measured Hall mobility and conductivity with results from similar data on other samples.² This value should be correct to within 30%. The experimental values of τ , and their rms spread, are also shown in Fig. 1.

To compare Hall and drift mobilities requires a knowledge of the absolute value of drift mobility for at least one value of electric field. This can be obtained in the linear conduction range from a measurement of the Hall constant at large (effectively infinite) magnetic fields. Such measurements are currently in progress. It should then be possible to determine the ratio of Hall to drift mobility as a function of electric field for a wide range of lattice temperature.

It is felt, partly because of the relatively large value of the cross section τ , and partly because of additional (as yet unpublished) data on the dependence of B_T on the "electron temperature," that the mechanism of capture is similar to that discussed by Lax³ in connection with "giant traps."³ Recombination on this model involves capture in an excited state as the result of an appropriate, but improbable, energy-losing collision followed either by a cascade of transitions to the ground state, or by an immediate ejection of the electron (by absorption of a phonon) into the conduction band with no net contribution to the recombination rate. Because the event which brings the electron into orbit is unlikely, the calculated cross section is much smaller than the "geometrical" area of the orbits that make the major contribution to the total cross section but large compared with that of the ground state.

The experimental cross section is in qualitative

agreement with the theory of Lax for the temperature range of Fig. 1.⁴ The "saturation" of τ at the lower temperatures is to be associated with a cutoff for orbits larger than the spacing between recombination sites.

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¹ S. H. Koenig, Phys. Rev. **110**, 986 (1958), preceding Letter.

² S. H. Koenig and G. R. Gunther-Mohr, J. Phys. Chem. Solids **2**, 268 (1957).

³ M. Lax, Bull. Am. Phys. Soc. Ser. II, **1**, 128 (1956).

⁴ M. Lax (private communication).

Luminescence from X-Ray Colored KBr Crystals during Plastic Deformation*

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In a previous report¹ the effect of strain, strain rate, and irradiation time on the luminescence induced by plastic deformation of various alkali halides containing F centers was discussed. However, it was not possible at that time to determine the spectral distribution accurately.

The spectral distribution of this luminescence from 2000 to 9000 Å has now been determined in the case of potassium bromide. The emission spectrum, shown in Fig. 1, is a broad, bell-shaped curve with its maximum at 4000 Å and showing a long-wavelength tail.

The experimental details are as follows: single crystals, about $5 \times 5 \times 10$ mm, were cleaved from large pieces supplied by the Harshaw Chemical Company. The crystals were heated overnight at 100°C below

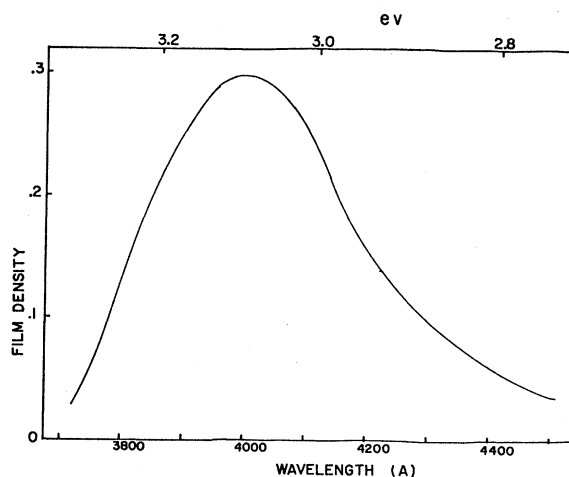


FIG. 1. Luminescence spectrum from x-ray colored KBr (50 crystals). Kodak 103-F Plate.

the melting point, quenched quickly in air to room temperature, and then irradiated for one hour at 40 kv and 20 ma with a Machlett AEG50 x-ray tube with a tungsten target and beryllium window. The crystals were then uniaxially compressed in the dark at 8.1 mm/min. The resulting light emission was analyzed by using a Hilger E517 quartz spectrograph. Fifty crystals were used in obtaining the spectrum in Fig. 1. Although no sensitivity *vs* wavelength calibration was made on the plates, the position of the maximum was found to be the same on three quite different emulsions, namely Kodak 103-F, 103-O, and 1-N Plates.

Since the application of stress to x-ray colored crystals can result in bleaching,²⁻⁴ a reasonable explanation for the observed luminescence may be that trapped electrons are freed by the motion of dislocations during compression^{5,6} and then are annihilated by recombining with holes present in the crystal, resulting in the emission of light. If such is the case, then the nature of the luminescence would be primarily dependent on the halogen involved, in that the recombination is analogous to the electron affinity process. It is hoped that an investigation of a series of alkali halides now in progress will elucidate the mechanism.

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¹ F. I. Metz *et al.*, *J. Phys. Chem.* **61**, 86 (1957).

² A. Smekal, *Z. Ver. deut. Ing.* **72**, 667 (1928).

³ H. J. Schröder, *Z. Physik* **76**, 608 (1932).

⁴ I. S. Jacobs, *Phys. Rev.* **93**, 993 (1954).

⁵ F. Seitz, *Phys. Rev.* **80**, 239 (1950).

⁶ W. W. Tyler, *Phys. Rev.* **86**, 80 (1952).

Evidence for Interstitials in Low-Temperature X-Ray Irradiated LiF†

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BY a modification of the photoelastic technique of Primak, Delbecq, and Yuster,¹ the volume expansion and annealing of x-ray irradiated LiF has been studied at low temperatures. One half of a thin rectangular plate is irradiated in a direction normal to the plane of the plate in such a manner as to produce electronic ionization throughout it, while the other half is shielded from the radiation. The constraint placed upon the irradiated portion of the crystal by the unirradiated portion at the boundary hampers the expansion of the irradiated part and so introduces strain into both halves of the crystal. The crystal then becomes birefringent and the strain pattern can be analyzed by the use of polarized light. In the elastic range the volume expansion is directly proportional to the angular rotation of the plane of polarization, and

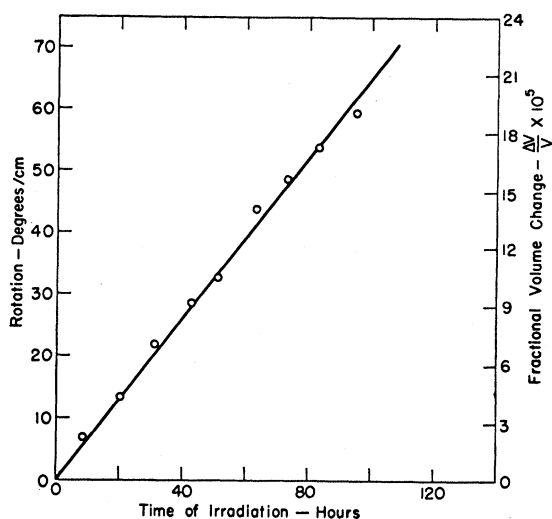


Fig. 1. Rotation of the plane of polarization and volume expansion as functions of time of x-ray irradiation at 94°K. (Crystal LiF No. 18.)

can be calculated if the elastic and photoelastic constants are also known.^{1,2}

In Fig. 1 the volume expansion is given as a function of time of x-ray irradiation at 94°K. The crystal is seen to expand linearly in the range of $\Delta V/V$ from roughly 10^{-5} to 10^{-4} . The *F* band was also found to increase linearly over a shorter range of exposure, i.e., up to 5.5 hours of irradiation. The optical absorption of the *F* band cannot be easily measured by conventional apparatus at higher exposures. However, the time rate of expansion obtained from the *F*-center growth curve by assuming a volume expansion equal to the volume of one negative-ion vacancy per *F* center is roughly that obtained from the volume expansion curve of Fig. 1, thus indicating that *F* centers are produced at a constant rate throughout the whole irradiation period. In contrast to this behavior, a band at 3400 Å saturates after only a short irradiation. In Fig. 2 the annealing of the volume expansion (as given by the rotation per cm of the plane of polarization), the *F* band, and the 3400-Å band are given as the crystal is warmed from 94°K. All three quantities are seen to anneal appreciably in roughly the same temperature interval.

The annealing of the volume expansion between 110° and 160°K cannot be due to diffusion of single positive- or negative-ion vacancies since the activation energies are much too high. The probability for single jumps of vacancies or interstitials may be high enough, however, to account for this annealing, for instance in terms of close pair vacancy-interstitial recombination. Diffusion of vacancy pairs, interstitials, or crowdions are other possibilities to be considered. The data of Fig. 2 indicate that while $\Delta V/V$ anneals by roughly a factor of $\frac{3}{4}$, the *F* band anneals by only $\frac{1}{3}$. In addition, measurements of the growth of the *F* band at 94°K after the crystal has been irradiated at 94°K, warmed to 160°K, and