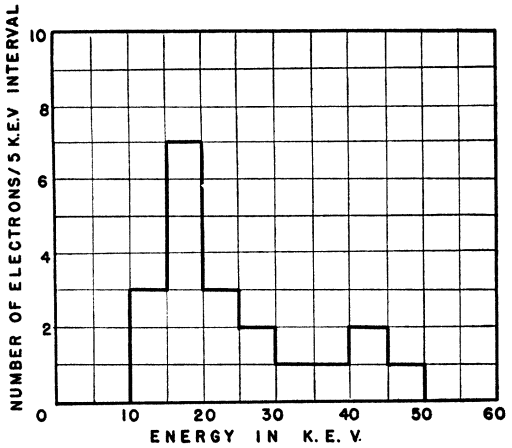

FIG. 2. Spectral energy histogram of 20 low energy electrons from mesons.

The density of random electron tracks in the emulsion has been measured. It is estimated that less than two percent of the mesons ending in the emulsion would appear to have associated electron tracks due to this background.

Assuming that the stopping power of the various constituents of the emulsion, for low energy mesons, is proportional to the atomic number, an estimate can be made of the relative number of mesons ending in gelatine and in silver bromide crystals. Assuming equal numbers of positive and negative μ-mesons,[2] 40 negative mesons are estimated to have stopped in silver bromide crystals, while 12 stopped in gelatine. If the observed electrons are due to the interaction of the meson with the orbital electrons, it seems improbable, from radiation considerations, that electrons of this energy originate from the lighter elements. The present data indicate that a negative meson, which has been captured in the field of a heavy atom, has a probability of 1/2 of having an associated electron in the 10 to 60 kev range; the probability that it have two such electrons is about 1/12.

[1] Cosynes, Dilworth, Occhialini, and Shoenberg, Proc. Phil. Soc. **62**, 801 (1949).
[2] C. Franzinetti, Phil. Mag. **41**, 86 (1950).

Restriction of Prismatic Punching to a Limited Class of Crystals

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June 30, 1950

SMAKULA and Klein[1] have observed that when a small single crystal of thallium bromoiodide is indented, mounds appear on the other surfaces at points lying in ⟨100⟩ directions from the indentation. Seitz[2] has attributed this prismatic punching to the formation of rectangular loops of dislocation, a typical loop lying in two (110) planes and two $(1\bar{1}0)$ planes, with the slip direction [001]. He has discussed the formation of such loops. Whether they arise from internal nuclei, as he suggests, or at the free surface where it meets the indenter, they can geometrically lead to the observed prismatic punching.

Why has this behavior so far been observed only in the thallium halides? It would be geometrically possible for prismatic punching to occur in aluminum, with a loop lying in two (111) planes and two $(\bar{1}11)$ planes, with the slip direction $[0\bar{1}1]$, but it has not been observed. The simplest explanation seems to be that the slip vectors ⟨100⟩ in thallium halides form an orthogonal set. It is not possible to resolve the $[001]a$ slip vector into two other permissible slip vectors, and slip must always be parallel to the axis of the prism. For aluminum the case is different. The slip vector $[0\bar{1}1]a/\sqrt{2}$ in the plane (111) may dissociate into the two permissible slip vectors $[\bar{1}01]a/\sqrt{2}$ and $[1\bar{1}0]a/\sqrt{2}$ in the same slip plane. A similar dissociation is commonly observed in the bubble model. Unless slip occurs equally in these two directions the resultant will not be parallel to the axis of the prism. A complicated system of internal strains is then set up, and propagation of glide down the prism ceases. In a homogeneously stressed single crystal, the tendency to dissociation of the slip vector is not very noticeable, because the crystal is already slipping on that glide system for which the resolved shear stress is greatest. In a polycrystal, branching of the slip bands is commonly observed near the grain boundaries. The condition for prismatic punching is that there should be no linear relation connecting the permissible slip vectors.

I am indebted to Professor Seitz for allowing me to see his letter before publication, and to Professor Cottrell for discussion.

[1] A. Smakula and M. W. Klein, J. Opt. Soc. Am. **39**, 445, 890 (1949).
[2] F. Seitz, Phys. Rev. **79**, 723 (1950).

Luminescence of Color Centers in Alkali Halides

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June 23, 1950

WHEN alkali halides are x-rayed various color centers are formed. The one giving the strongest absorption is the F-center which is generally agreed to be an electron trapped at a vacant negative ion site. The next strongest absorption band is due to the M-center which Seitz[1] has suggested as being due to an electron trapped in a complex of two negative ion vacancies and a positive ion vacancy. Because these color centers are simple cases of impurities in solids there has been much investigation on their optical absorption and photo-conductive properties. The investigation reported here was to determine under what conditions these color centers luminesce and the effect of temperature on the luminescence emission. Gurney and Mott[2] have suggested

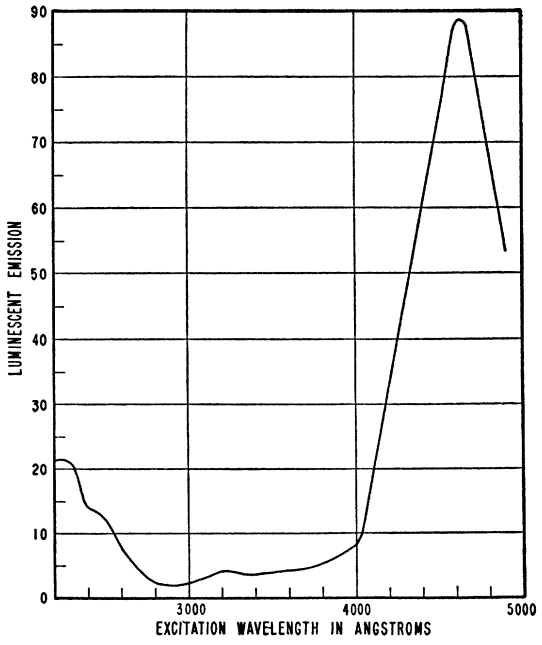

FIG. 1. Excitation spectrum of x-rayed lithium fluoride.

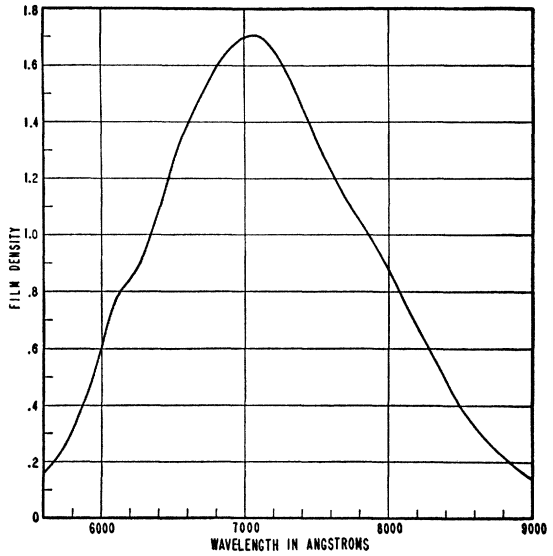

FIG. 2. Densitometer trace of luminescent emission of lithium fluoride due to excitation in the M-absorption band. Emission is at room temperature.

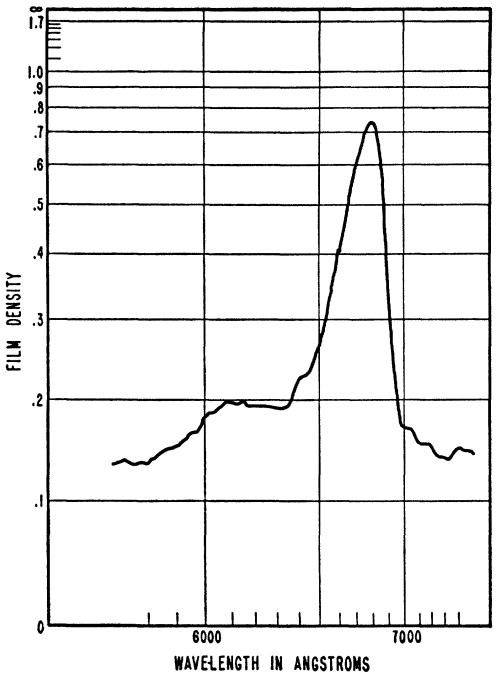

FIG. 3. Densitometer trace of luminescent emission of lithium fluoride caused by excitation in the M-absorption band. Emission is at 4°K.

that absorption in the F-band raises an electron from the ground state to an excited level and that at ordinary temperatures thermal motion raises this excited electron to the conduction band. At low temperatures the excited electron should be bound to the center and return to the ground state either with luminescent emission or by a dissipation process. Mott and Gurney[3] give arguments for believing that of these two processes luminescent emission is to be expected.

Both lithium fluoride and sodium chloride were investigated. For lithium fluoride the F-center absorption band is at 2500A and the M-band, which Molnar found to be luminescent at room temperature,[4] peaks at[5] 4600A. In order to avoid bleaching the F-band in sodium chloride, additively colored material[6] with a permanent F-band was used. The absorption peak of this band at low temperatures is at 4600A.

The luminescent output of x-rayed lithium fluoride at c.p. grade has been measured at room temperature as a function of the wave-length of the exciting light. The output, corrected to equal energy of excitation, is plotted in Fig. 1. There appear to be excitation peaks at 2200A, 2500A, 3100A, and 4600A. Only the 4600A peak gave an emission sufficiently intense so that its spectral distribution could be measured. However, information on the spectral emission of the other peaks was obtained by measuring the excitation spectrum with a variety of filters placed between the luminescent powder and the recording photo-tube. These measurements showed that the relative heights of the 2500A, 3100A, and 4600A peaks are reasonably constant, indicating that they all give the same emission. Excitation at 2200A gives an emission of shorter wave-length.

The large peak in excitation at 4600A coinciding with the M-band absorption indicates that this luminescence is due to M-centers. However, the excitation peak at 2500A is probably not due to F-centers since the excitation peak is quite small while the F-band absorption is always much larger than the M-band. Similarity of the emission due to excitation at 2500A and 4600A suggests that the 2500A excitation is due to some secondary effect such as the formation of M-centers by irradiation in the F-band. Molnar[4] has found this effect in other alkali halides, but if it occurs in lithium fluoride the effect is so small that absorption measurements did not detect it. Neither the 2200A excitation peak nor the 3100A peak correspond to absorption peaks found in our x-rayed material. The fact that in single crystals of lithium fluoride grown by Harshaw and Optovac excitation at 2200A produced an emission even before x-raying indicates that this band may be due to impurities.

At room temperature, then, apparently the only luminescent color center is the M-center. Its emission has been given by Molnar as a band centering at 6500A. Figure 2 gives a densitometer trace of this room temperature emission taken with I-L film upon excitation with the mercury 4358A line. The peak appears at 7050A because this film is sensitive further into the red than was that used by Molnar.

The low temperature emission of the M-centers was obtained by immersing the lithium fluoride in liquid nitrogen and liquid helium at atmospheric pressure. Figure 3 gives a densitometer trace of the M-center emission at liquid helium temperature. A second emission peak appears on the short wave-length side. The large apparent shift of the peak compared with Fig. 2 is caused by the use of film sensitive only to 7000A.

It is evident from Fig. 3 that the M-center emission does not become a line emission as absolute zero is approached. A similar inherent range of emission wave-lengths at liquid helium temperatures has been found for manganese activated zinc silicate, silver activated zinc sulfide, and for zinc tungstate. Further experiments are planned to decide between various possible explanations of this effect.

X-rayed lithium fluoride was also irradiated in its F-band (2500A) at liquid helium temperature. No luminescence was observed in the range of 4000A to 7000A. The ratio of emitted wave-lengths to exciting wave-length observable ranged from 2.8 to 1.6. To check the possibility that the F-center luminescence was close to the exciting wave-length, sodium chloride was irradiated in its F-band (4600A). No emission was detected at liquid helium temperatures with film sensitive out to 7000A. The ratio of emitted wave-length to exciting wave-length observable ranged from 1.5 to 1. Failure to find F-center luminescence in LiF at room temperature in a ratio of emitted wave-lengths to exciting wave-length ranging from 2.8 to 1 and the failure to find this luminescence at low temperatures either for LiF in the range of ratios from 2.8 to 1.6 or for NaCl in the range 1.5 to 1 forces one either to postulate that the luminescence occurred outside the

range of observation, possibly in the infra-red with a ratio of 3 or more, or that the excited F-center returns to its ground state by a radiationless transition.

[1] F. Seitz, Rev. Mod. Phys. **18**, 384 (1946).
[2] R. W. Gurney and N. F. Mott, Proc. Phys. Soc. London **A49**, 32 (1937).
[3] N. F. Mott and R. W. Gurney, *Electronic Processes in Ionic Crystals* (Oxford University Press, London, 1940), p. 136, 222.
[4] J. P. Molnar, thesis, Physics Department, M.I.T. (1948), unpublished.
[5] Professor Pringsheim in a private communication has suggested that the 4600A band in lithium fluoride is not a true M-band in that it is formed at room temperatures by the rapid decay of a 6200A band produced by x-raying. Other differences are the difficulty in bleaching the 4600A band and the absence of an increase in the M-band on irradiation in the F-band.
[6] We wish to thank Mr. C. P. Glover of this laboratory for supplying this material.

Beta-Decay of Ag^{111} and Spin-Orbit Coupling in Cd^{111}

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June 27, 1950

THE radiation of Ag^{111} has been studied by several investigators.[1] The maximum energy of the beta-rays has been determined to be 1.06±0.03 Mev.[2] No gamma-rays have been observed.

When Pd is irradiated with slow neutrons, Pd^{111} (26 min.) is formed among other isotopes. Pd^{111} gives rise to Ag^{111} (180 hr.). In this way it is possible to obtain Ag^{111} quite free from Ag^{106} (197 hr.). The half-life of a sample was followed during ~1000 hr. and was found to be 180±3 hr.

The gamma-radiation has been studied in a lens spectrometer and a 0.007-mm lead converter was used. The photo-electron spectrum is shown in Fig. 1. Two different gamma-lines can be distinguished. The first photo-line corresponds to the K photo-line of a gamma-ray of 243±2 kev. The L photo-line belonging to this gamma-ray is to some extent masked by the K photo-line of a second gamma-ray of 340±2 kev. Also, the L photo-line belonging to this second gamma-ray gives the energy 340 kev. Estimates based on the curves by Evans and Evans[3] give the intensity ratio 8:1 between the gamma-rays of energy 340 and 243 kev.

The beta-spectrum has been measured in a lens spectrometer. From the Fermi analysis it is evident that the beta-spectrum is complex. The upper limit of the main component is 1.04 Mev. As will be discussed below, the beta-spectrum probably has three components, but since the intensity of the third one is only ~1 percent it cannot be resolved in the Fermi analysis.

A gamma-gamma-coincidence measurement has been carried out. No real effect was observed. The beta-gamma-coincidence measurement gave coincidences, but to such a small extent that none of the gamma-rays could follow the main component of the beta-spectrum.

A distintegration scheme consistent with all experimental results is presented in Fig. 2. A search was made for the internal conversion line and the L photo-line corresponding to a possible gamma-ray of 340 to 243 kev with negative result. The intensity ratio between the components has been determined by means of calibrated beta- and gamma-ray counters. The calculation has been made under the assumption that the intensity ratio between the gamma-lines is 8:1.

It is known that Cd^{111m}, which can be produced for instance by a (n,n) reaction, decays to the ground level by the successive emission of two quanta of 148 and 247 kev, respectively.[4,5] The last gamma-ray is the same as the one observed[6] in the K-capture decay of In^{111}. Although there is a small discrepancy in energy, it seems probable that this excited level in the Cd^{111} nucleus is common for Ag^{111}, Cd^{111m}, and In^{111} disintegrations.

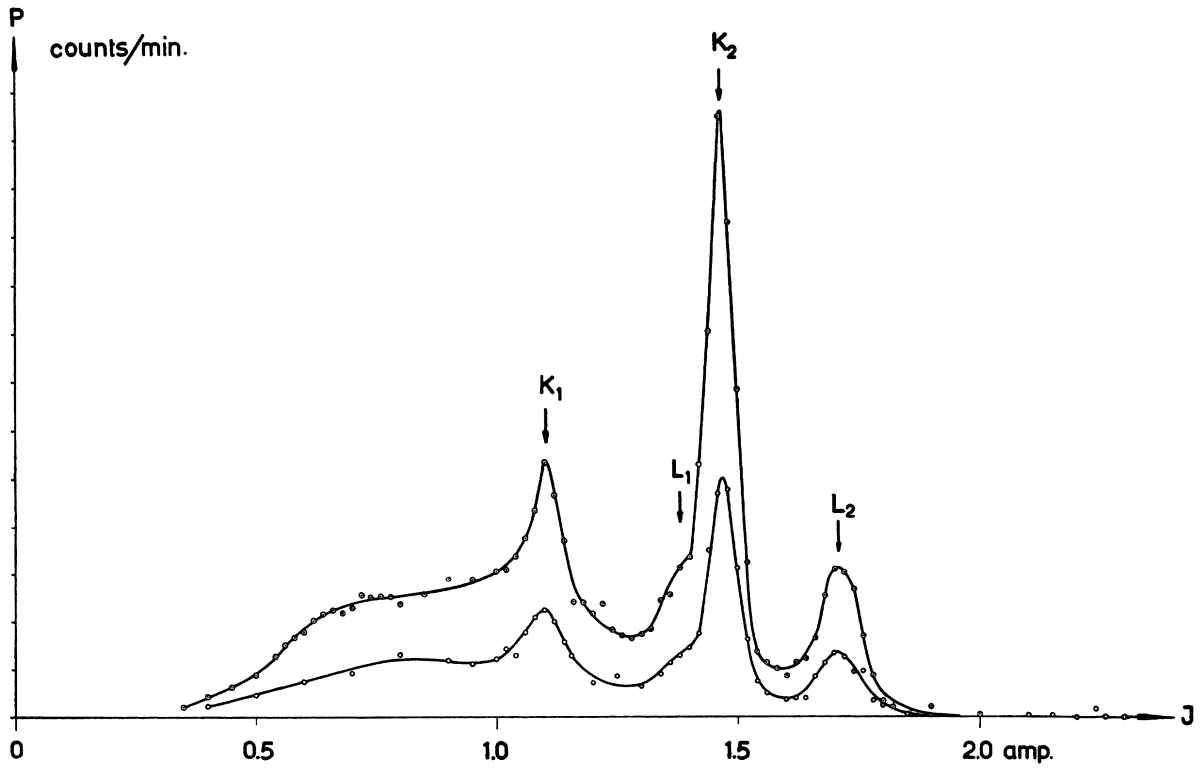

FIG. 1. Photo-electron spectrum of Ag^{111}. The lower curve taken 216 hr. later than the top curve. The half-lives for the three lines K_1, K_2, and L_2 are correct within statistical errors.