Tellurium. From analysis of Bridgman's data on variation of intrinsic conductivity with pressure.[8] The high mobility of electrons and holes in germanium is thus correlated with a small shift in energy gap with dilation.

[1] S. Peckar, J. Phys. USSR, **10**, 431 (1946).
[2] Hubert M. James, Phys. Rev. **76**, 1602 (1949).
[3] A proof, together with a direct calculation of the pertinent matrix element without making use of the effective mass concept, will be given in a forthcoming paper by the authors.
[4] See A. Sommerfeld and H. Bethe, *Handbuch der Physik*, Vol. XXIV, 1; A. H. Wilson, *The Theory of Metals* (Cambridge University Press, London, 1936); Frederick Seitz, Phys. Rev. **73**, 549 (1948).
[5] G. L. Pearson and J. Bardeen, Phys. Rev. **75**, 865 (1949).
[6] P. H. Miller and Julius Taylor, Phys. Rev. **76**, 179 (1949) and personal communication from Professor Miller.
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Color Centers in Calcium Fluoride and Barium Fluoride Crystals

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THE color centers produced photochemically (x-rays, ultraviolet light) or additively (metal vapor, electrons) have been investigated by Pohl[1] and his school mainly in monovalent ionic crystals, such as, alkali halides. The first results on color centers produced by x-rays in calcium fluoride (CaF_2) and barium fluoride crystals (BaF_2) are presented in this note.

Natural and synthetic crystals of calcium fluoride and synthetic crystals of barium fluoride were used. The thickness of the crystals was between 0.5 and 1.0 cm. Hard x-rays (200 kv, 10 ma) were used to produce a uniform coloration throughout the entire crystals. The exposure time varied from 0.5 to 5.0 hours. Immediately after exposure to x-rays, the transmission of the colored crystals was measured with a Beckman spectrophotometer in the spectral region from 2200A to 10,000A. No change in coloration occurred during measurements.

The absorption spectrum of color centers in calcium fluoride crystals is reproduced in Fig. 1. The three absorption bands fall at 5800A, 4000A, and 3350A. A strong increase of absorption toward shorter wave-length indicates a fourth band with a maximum below 2200A.

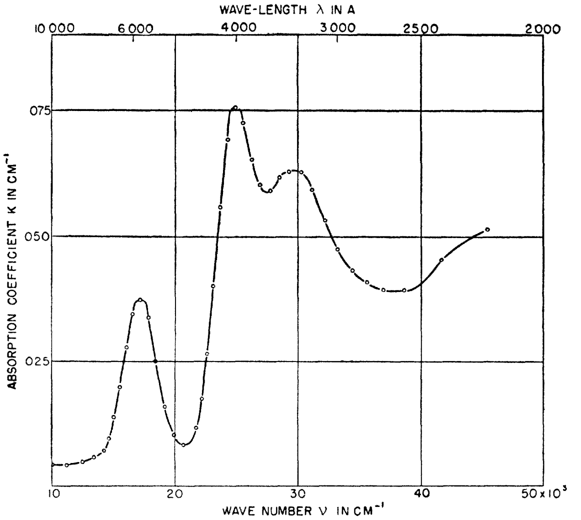

FIG. 1. Absorption spectrum of color centers in calcium fluoride (CaF_2) crystal [$k=(1/d)\log_{10}(I_0/I)$; 200 kv, 10 ma, exposure 5 hours].

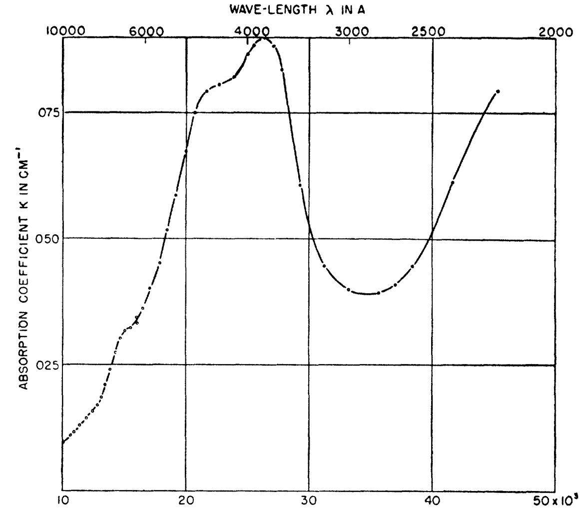

FIG. 2. Absorption spectrum of color centers in barium fluoride (BaF_2) crystal [$k=(1/d)\log_{10}(I_0/I)$; 200 kv, 10 ma, exposure 0.5 hour].

In Fig. 2 is given the absorption spectrum of color centers in barium fluoride crystal. As for calcium fluoride, three absorption bands are seen at 6700A, 4800A, and 3800A. A fourth band below 2200A is also apparent. As compared with calcium fluoride the bands are shifted to longer wave-lengths and they overlap to a greater extent.

The formation of absorption bands with increase of exposure time is shown in Fig. 3. All three bands show saturation with increase in exposure similar to the saturation of the coloration of alkali halides.[2]

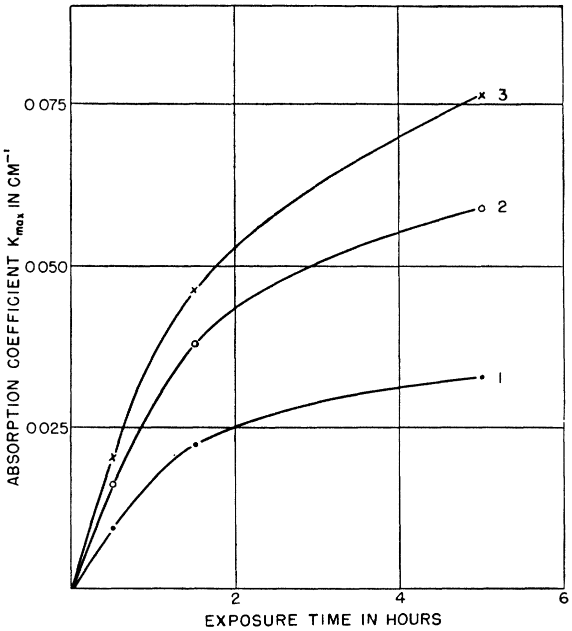

FIG. 3. Change of the absorption band intensity of calcium fluoride with increase of exposure time to x-rays (200 kv, 10 ma). 1. Absorption band at 5800A, 2. Absorption band at 3350A. 3. Absorption band at 4000A.

In additively colored natural calcium fluoride crystals Mollwo[3] found two bands, one at 5250A and the other at 3700A. The additive color centers can be produced at high temperatures only. The absorption bands were obtained only if the crystals are cooled down to room temperature very rapidly. When they were cooled slowly no absorption bands were found. By proper cooling the shape and position of the band in the visible could be changed (probably resulted in the formation of colloids).

As compared with alkali halides, the absorption spectra of colored calcium and barium fluorides show some similar and some different properties. These similar properties can be noted: saturation of coloration with exposure time; half-widths of absorption bands; and bleaching by heat or light.

The differences are as follows: Only two bands appear in alkali halides after a small exposure to x-rays, as was the case here; one is the strong band, called the *F*-band after Pohl;[1] and the other a weak band, called the *M*-band after Seitz[4] (the *M*-bands were discovered by Ottmer[5] and later investigated by Molnar[6]). In calcium fluoride and in barium fluoride, at least four bands can be seen. In alkali halides the *F*-band can be transformed into the *M*-band by exposure to the light absorbed by the former. In calcium fluoride and barium fluoride, the transformation of one band to another one seems to be impossible, at least at room temperature. The relationship, $vd^2=\text{constant}$ ($v=$ frequency of the *F*-band, $d=$ lattice constant) which has been found by Mollwo[7] for *F*-bands of alkali halides is not valid for any of the bands of calcium fluoride and barium fluoride.

From preliminary experiments on bleaching by heat and light one can assume that the absorption bands of the color centers in calcium fluoride and barium fluoride are independent. Although the nature of color centers may be generally the same as in alkali halides, electrons trapped in lattice defects, further investigations are necessary for their quantitative explanation.

Grateful acknowledgment is given Mrs. R. K. Wilkinson for transmission measurements.

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Gamma-Rays of K^{40}

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The gamma-ray emitted by K^{40} has been reported as 1.55 Mev by absorption in lead, and no evidence for softer gamma-rays was found.[1,2]. The scintillation spectrometer has been used to investigate the K^{40} gamma-radiation and to search for annihilation radiation associated with possible positron emission.

The gamma-rays produce Compton electrons in an anthracene crystal and the spectrum of these Compton electrons is measured by determining the pulse distribution from an RCA C-7132 photomultiplier to which the anthracene crystal is cemented.

Figure 1 shows the arrangement of the sample (which was 1300 g of normal KCl) and the anthracene crystal and photo-multiplier. The beta-rays were absorbed by the $\frac{1}{8}$-inch aluminum wall surrounding the crystal. The entire assembly was shielded by 2 inches of lead.

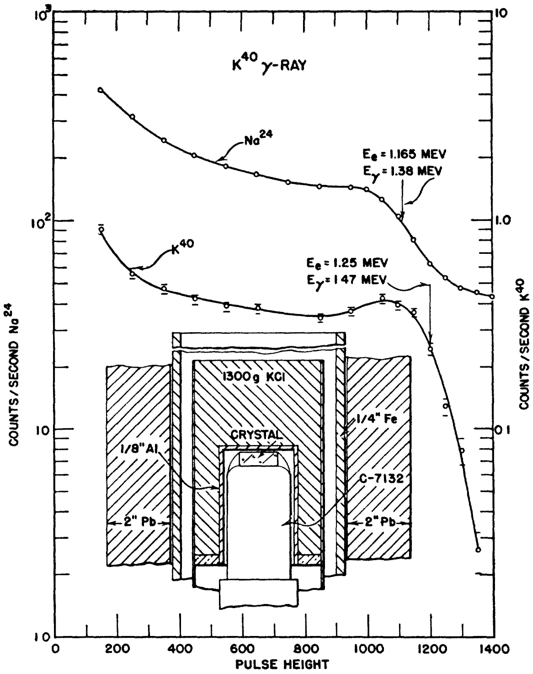

FIG. 1. Arrangement of apparatus and distribution of pulses.

The gamma-ray was compared with the low energy gamma-ray from Na^{24}(1.38 Mev),[3] the gamma-ray of Zn^{65}(1.12 Mev)[4] and the conversion line of Cs^{137}(0.632 Mev).[5] The Na^{24} sample was placed on top of the KCl container leaving the KCl in place. The distribution of pulses from the K^{40} and part of the distribution produced by Na^{24} are also shown in Fig. 1. The background counting rate was quite negligible.

The maximum energy of the Compton electrons was determined in two ways: (1) the maximum slope of the break and (2) the half-counting rate point (in the case of Na^{24} the counts due to the upper gamma-ray were subtracted).

The results of several determinations are given in Table I. A search was then made for annihilation radiation. Figure 2 shows

TABLE I. Energy of Compton electrons.

Comparison radiation	Energy from Maximum slope	Half-counting rate
Na^{24}	1.47 Mev	1.49 Mev
Na^{24}	1.39 Mev	1.42 Mev
Cs^{137}	1.47 Mev	1.48 Mev
Zn^{65}	1.47 Mev	1.46 Mev
average	1.45 ±0.04 Mev	1.46 ±0.04 Mev

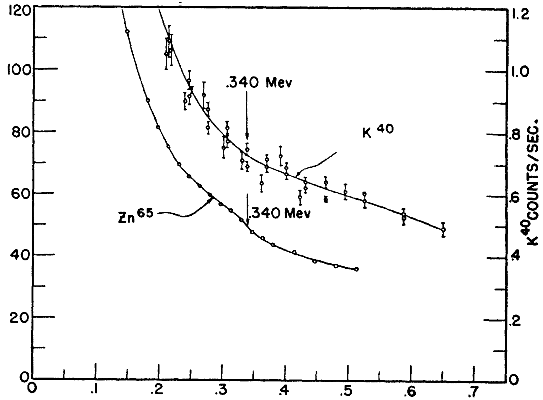

FIG. 2. Gamma-ray spectra.