

FIG. 2. Transmission of Te crystals as a function of thickness for a few values of λ .

absorption constant (cm^{-1}), and x is the thickness in cm. The resulting values of k are shown in Fig. 3.

The interpretation of these results suggests first of all that the increasing absorption beyond the edge toward shorter λ is due to electrons making the transition from the filled to the conduction band. If we locate the absorption edge which occurs for the larger value of λ at 3.6μ by associating it with the gap width as deter-

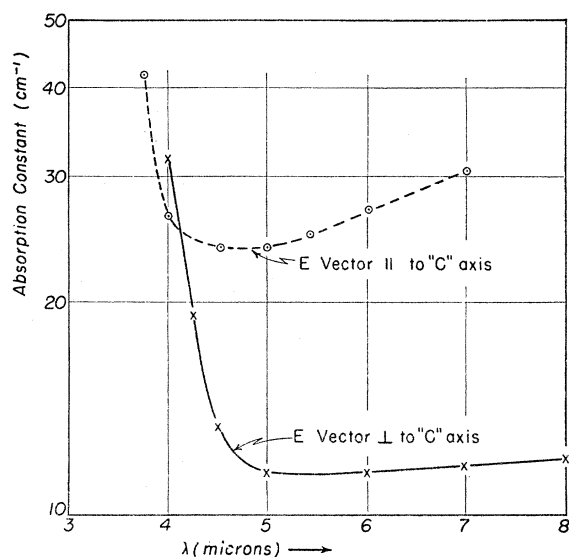


FIG. 3. Experimental values of the absorption constant of Te crystals as determined from the slopes of the lines in Fig. 2.

mined by conductivity measurements, i.e., 0.34 eV ,⁴ the criterion so established places the second edge at 3.3μ . This is an arbitrary method of locating the edge, since the values as determined by absorption and conductivity can be expected to agree only at low temperatures. Secondly, as in germanium and silicon,⁵ the value of k as determined by assuming only free carrier absorption beyond the edge toward longer λ is smaller by a factor of 10^3 than the experimental values. Finally, the index of refraction, n , as computed from the expression

$$R = (n-1)^2 / (n+1)^2,$$

is about 5.3 ± 0.2 at 6μ , which is somewhat larger than the value found by Moss in tellurium films. It was impossible to detect any difference in the values of n for the two directions of polarization by this method. Preliminary measurements on prisms of crystalline tellurium yield values of n of this same magnitude.

* Preliminary reports of this work were presented at the meetings of the American Physical Society on June 15, 1951 and March 21, 1952 [Phys. Rev. **83**, 876 (1951) and **86**, 652 (1952)].

† This work was supported by the ONR.

¹ T. S. Moss, Proc. Phys. Soc. (London) **B65**, 62 (1952).

² We wish to acknowledge the help of Dr. W. Scanlon, Naval Ordnance Laboratory, White Oaks, Maryland, who arranged for the analysis.

³ Elliott, Ambrose, and Temple, J. Opt. Soc. Am. **38**, 212 (1948).

⁴ V. E. Bottom, Science **115**, 570 (1952); T. Fukuroi, Sci. Repts. Research Inst. Tohoku Univ. **A3**, 175 (1951).

⁵ M. Becker and H. Fan, Phys. Rev. **76**, 1530 (1949).

Enhancement of the *F*- and *V*-Bands in Sodium Chloride Containing Calcium

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(Received July 18, 1952)

IT has been observed by Hummel¹ that the introduction of calcium as an impurity in KCl results in a γ -ray induced *F*-band absorption which is much greater than one observes for the "pure" alkali halide. Curves B, C, D, and E in Fig. 1 show this enhancement in x-rayed NaCl single crystals grown by the Kypoulos method, which contain, respectively, 1, 5, 10, and 50×10^{-2} mol percent calcium added to the melt. Approximately one-tenth of the calcium concentration in the melt is present in the crystals. In the same figure is shown the *F*-band absorption for "pure" NaCl, curve A, and for two crystals, curves F and G, which contain additions of divalent cadmium rather than divalent calcium. To insure uniform coloration the crystals were cleaved to less than 0.36 mm in thickness. All crystals were x-rayed using molybdenum radiation at 40 kvp and 20 ma for one hour. After the first half-hour the crystals were rotated through 180° , and the second face was placed nearest the x-ray tube. The absorption measurements were made using a Beckman Model DU Quartz Spectrophotometer. All experimental work was carried out at room temperature.

It is interesting to note that the introduction of Cd^{++} to the lattice, and subsequent x-raying, do not produce the same striking enhancement of the *F*-band as does the incorporation of Ca^{++} . A difference in the behavior of Ca^{++} and Cd^{++} as impurities in NaCl is also observed in the work of Etzel and Maurer² and Bean and Maurer.³ The former investigators found that in the neighborhood of 400°C the crystal shown in Fig. 1, curve F, has about one-third of the positive ion vacancies introduced by the Cd^{++} associated with this ion. At room temperature it is then likely that this association is complete. In contrast to this, Bean and Maurer find that no observable association occurs between the Ca^{++} and the positive ion vacancies.

The following mechanism is suggested to explain the enhancement of the *F*-band in the alkali halides containing ions of rare gas electronic structure as divalent impurities. When a Ca^{++} , for instance, is added to the NaCl lattice, one positive ion vacancy is also added to the lattice, at least to a first approximation. This occurs in order to maintain electrical neutrality within the crystal

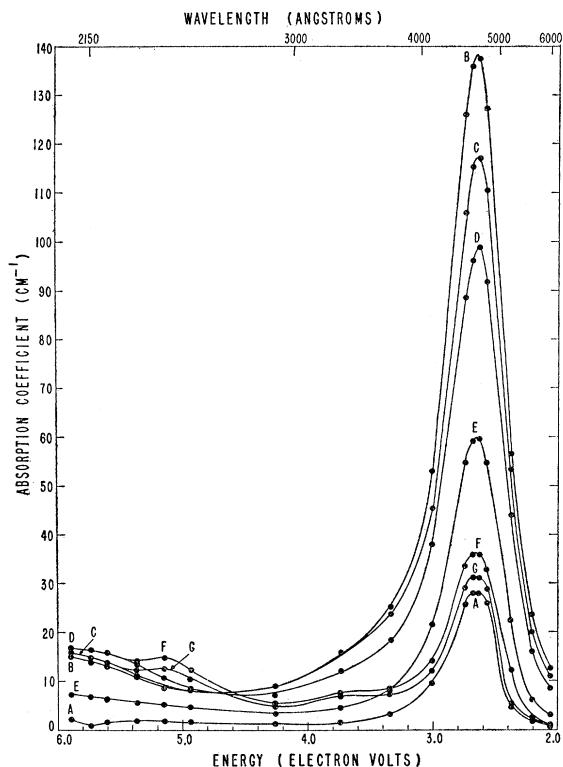


FIG. 1. Spectral absorption of x-rayed NaCl single crystals containing the following nominal mol ratios of impurities to Na in the melt: curve A: None; B: 0.005 Ca/Na; C: 0.001; D: 0.0005; E: 0.0001; F: 0.005 Cd/Na; G: 0.001.

since two Na^+ are replaced by each Ca^{++} . If the crystal is then x-rayed, the probability for the capture of holes by positive ion vacancies to form V -centers is greater than it would be in a "pure" crystal. As a result, the probability for the recombination of holes and electrons is reduced. The probability for the formation of F -centers is thereby increased since more electrons are free to be trapped by negative ion vacancies. If the F -band is enhanced, then an increase in the V -band absorption which occurs in the short wavelength ultraviolet region should also be observed. Figure 1 shows a three- to eightfold increase in the absorption in the neighborhood of 2100 Å for Ca^{++} -bearing crystals over that of "pure" NaCl. Irradiation into this band produces no observable emission, indicating these crystals are not radiophotoluminescent in this region. The same conditions do not exist in crystals containing Cd^{++} since the excess positive ion vacancies are bound to the Cd^{++} at room temperature and are not favorable traps for holes. Therefore, recombination of electrons and holes occurs with nearly the same probability as exists in a "pure" crystal, and the F -band is not significantly enhanced. Unfortunately NaCl containing Cd^{++} has radiophotoluminescent absorption bands at 2400 Å and 3400 Å; thus it is not possible to strengthen the explanation further by showing no enhancement of the V -band in the crystals containing Cd^{++} .

Further experiments are planned with Ca^{++} and Cd^{++} in NaCl and in other alkali halides. If the observed differences in the behavior of these ions in NaCl appear in other alkali halides, arguments⁴ based on the *a priori* similarity of these ions may require modification.

The writer wishes to express his appreciation to Mr. R. D. Kirk for growing the single crystals used in this work.

¹ H. Hummel, thesis, Göttingen University (1950) (unpublished).

² H. W. Etzel and R. J. Maurer, *J. Chem. Phys.* **18**, 1003 (1950).

³ C. Bean and R. J. Maurer, ONR Technical Report No. 4 (1952) (unpublished).

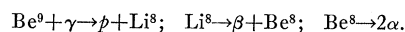
⁴ F. Seitz, *Phys. Rev.* **83**, 1344 (1951).

Threshold for (γ, p) Reaction in Be^9

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(Received July 18, 1952)

ALTHOUGH the (γ, n) reaction in Be^9 is well known, only one paper¹ has established the existence of the $\text{Be}^9(\gamma, p)\text{Li}^8$ in beryllium. They identified a Li^8 beta-activity and made a rough estimate of 18 ± 1 Mev for the (γ, p) threshold.

The radioactive chain for $\text{Be}^9(\gamma, p)\text{Li}^8$ is:



The 0.88-sec half-life beta-particles from Li^8 have a maximum energy of 13 Mev. The final α -particles have about 1.5 Mev each.

Possible alternative reactions from Be^9 in a betatron beam are: $\text{Be}^9(\gamma, n)2\alpha$, $\text{Be}^9(n, \alpha)\text{He}^6$, and $\text{Be}^9(\gamma, d)\text{Li}^7$. He^6 from the (n, α) reaction has a 0.86-sec beta-activity with a 3.5-Mev maximum energy. In spite of a low (~ 2.6 Mev)² threshold, the (n, α) probability is far below the (γ, p) because the neutron flux is far lower than the γ -intensity. There was no evidence of beta-activity below 16.9 Mev.

A large ($1\frac{1}{2}$ in. \times 1 in.) NaI crystal was mounted in contact with a 5819 photomultiplier as shown in Fig. 1. The gate was off during the complete acceleration cycle of the betatron so that spurious γ -counts from the beam and the injection gun were avoided. The discriminator was set for the best ratio between background and true counts. The background remained high even during the dead time of the γ -beam, probably because iron, aluminum, and copper are all beta-active under γ -radiation of this energy.

Threshold determinations from seven sets of data for the (γ, p) reaction give 16.93 ± 0.15 Mev. An accurate mass difference calculation gives a theoretical value of 16.872 ± 0.008 Mev.³ Graphical extrapolation of the seven curves agreed with calculations of the $N = k(E - E_0)^m$ type.

As a check against confusion of other beta-activities, the half-life was measured at 0.89 sec, and the beta-particles penetrated 0.39 in. of aluminum, indicating an energy above 6 Mev.

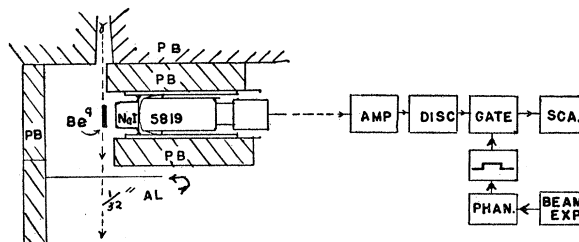


FIG. 1. Experimental arrangement.

A very rough estimate of the absolute cross section for (γ, p) indicates $\sim 3 \times 10^{-28}$ cm² at 19 Mev. Further work is in progress to make an accurate determination of σ between 17 and 21 Mev.

* This work was done under the AEC.

¹ Ogle, Brown, and Conklin, *Phys. Rev.* **71**, 378 (1947).

² 2.6 Mev is the sum of the (γ, n) and (n, α) thresholds.

³ D. M. Van Patter, Office of Naval Research Technical Report ONR-57 (1952) (unpublished).

Neutron Total Cross Section for Lead Between 37 and 156 Mev

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IN the course of an investigation into the variation of neutron total cross sections with energy for a number of elements, a dip has been found in the lead cross section at about 60 Mev. The neutrons used in this experiment were produced by proton bom-