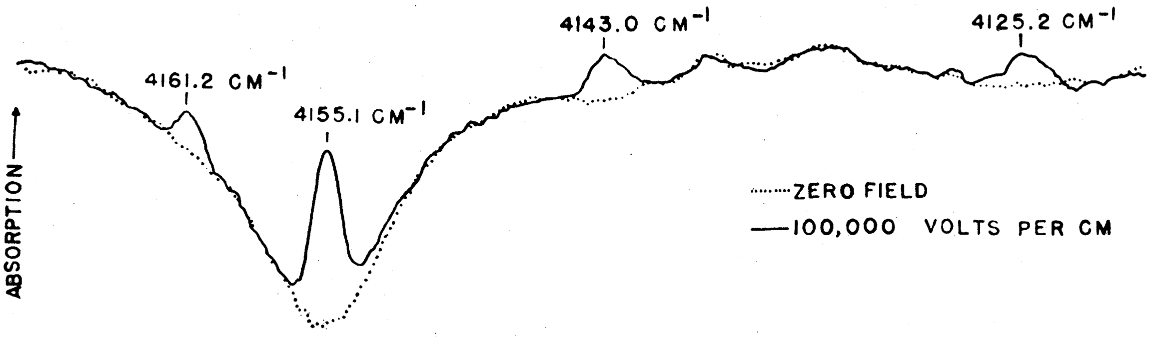

FIG. 1. Field-induced components of the Q-branch of the $1\leftarrow 0$ vibrational transition of H_2.

plate condenser. The two side walls were polished strips of aluminum 85 cm long by 1.75 cm wide; the top and bottom were strips of Plexiglass which separated the metal walls by 1.4 mm. One plate of this condenser was connected to an insulated terminal in the wall of the absorption cell. The other plate was in electrical contact with the wall. Hydrogen pressures up to 2000 lb per square inch were used. The absorption was measured with a Littrow type grating spectrometer using a PbS photoconductive cell as a detector.

The absorption induced by the static electric field is observed superimposed on the pressure-induced absorption,[3] but the two effects are readily distinguished from each other because their half-widths are radically different. The dotted curve of Fig. 1 shows a contour of a portion of the Q branch of the pressure-induced absorption of hydrogen. The sharp maximum of transmission at 4155 cm^{-1} arises from the splitting of the Q branch. The continuous curve of Fig. 1 shows the contour obtained when the potential difference between the plates of the light guide was 14 000 volts, other conditions remaining the same. It is apparent that the application of the electric field has produced four sharp absorption lines. These are components of the Q branch of the fundamental rotation-vibration band. A comparison of the frequencies of these lines with the frequencies of the Q branch components of the Raman spectrum of hydrogen[4] is given in Table I.

TABLE I. Observed transitions.

Transition $\Delta v=1-0$ $\Delta J=0$	Frequency, (cm^{-1}); static field (density =82.9 amagat[a]	Frequency, (cm^{-1}); Raman spectrum (density =5 amagats)
0–0	4161.2	4161.28
1–1	4155.1	4155.48
2–2	4143.0	4143.55
3–3	4125.2	4125.88

[a] The density in amagats is defined as the ratio of the density of the gas under experimental conditions to the density of the gas at one atmosphere pressure and zero °C.

The static field frequencies are slightly smaller; the differences apparently are significant since they increase with J and with density.

In principle the matrix element of the mean value of the polarizability for the 1–0 vibrational transition, α_{01}, and the matrix element of the anisotropy γ_{01} can be evaluated from the integrated absorption coefficients. The integrated absorption coefficients as yet are not sufficiently accurate to warrant an estimate of γ_{01}. However, the coefficient of the 1–1 component of the Q branch has been measured sufficiently well to allow a first determination of α_{01}. It has been established experimentally that the absorption coefficient is proportional to the square of the field strength. Thus a specific absorption coefficient can be defined and for the 1–1 component is 5.53×10^{-29} cm^{-1}, per cm path, per molecule per cm^3, per (esu of potential per cm)^2. The matrix element determined from this value is $\alpha_{01}=1.2(5)\times 10^{-25}$ cm^3.[5] Corrections have been applied for polarization produced in the incident light flux by the quartz prism of the monochromator and for the small effect of the matrix element of the anisotropy. The result is intermediate to the value obtained from the ratio of Raman to Rayleigh scattering, 1.05×10^{-25} cm^3,[6] and the theoretical value, 1.393×10^{-25} cm^3.[7] By using polarized light and a more efficient grating, more accurate determinations of α_{01} and γ_{01} should be possible.

These results definitely establish the field-induced absorption predicted by Condon. The effect has several interesting and potentially important applications.

[1] E. U. Condon, Phys. Rev. **41**, 759 (1932).
[2] Welsh, Crawford, and Locke, Phys. Rev. **76**, 580 (1949).
[3] Crawford, Welsh, MacDonald, and Locke, Phys. Rev. **80**, 469 (1950); Chisholm, MacDonald, Crawford, and Welsh, Phys. Rev. **88**, 957 (1952).
[4] C. Cumming, Ph.D. thesis, University of Toronto (unpublished).
[5] The calculation will be given in a subsequent publication.
[6] Stansbury, Crawford, and Welsh, Can. J. Phys. (to be published).
[7] Ishiguro, Arai, Mizushima, and Kotani, Proc. Phys. Soc. (London) **A65**, 178 (1952).

Bleaching of CaF_2 Crystals Colored by X-Rays*

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SYNTHETIC and natural CaF_2 crystals colored by x-rays exhibit absorption bands: 5800, 4000, 3350, and 2250A.[1] The increase of absorption below 2100A indicates at least one more band. The same absorption is produced by weak, additive coloration.[2] A theoretical explanation of the nature of these bands is still lacking.

A study of thermal and light bleaching of colored alkali halides contributed much to the understanding of color centers in those

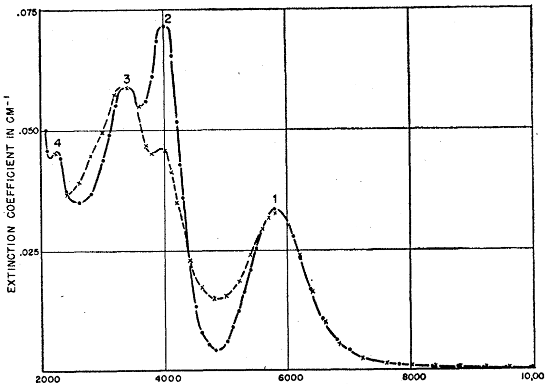

FIG. 1. Bleaching of colored CaF_2 crystal by light absorbed by band 2; —·— before bleaching, - -X- - after bleaching.

crystals. According to Barile,[3] colored CaF_2 can be bleached thermally but not by light at room temperature. It will be shown in the present note that colored CaF_2 can be bleached by light at room temperature also. However, the bleaching process seems to be quite different from that in alkali halides.

All experiments were carried out on synthetic crystals (Harshaw Chemical Company). For bleaching, a Hg lamp with proper Corning glass filters was used. Figure 1 (—·— curve) shows the absorption of CaF_2 colored by x-rays with bands marked 1 to 4, respectively. The bands are very stable at room temperature; after 3 weeks no bleaching could be detected. An exposure to light absorbed only by band 1 does not bleach this band after one hour exposure. If, however, the light absorbed by band 2 is used, a strong decrease of band 2 was observed after 5 minutes exposure (Fig. 1). The other bands remained unaffected. Simultaneously with the destruction of band 2, a new band appears with a peak at 4850A (Fig. 1). Band 2 can be restored either by heat or by light absorbed by band 1. In this case the new band at 4850A disappears, but band 1 remains unaffected. Figure 2 shows the bleaching of bands 1 and 2 and formation of a new band at 4850A if light is used which is absorbed by band 1 and 2 simultaneously. Both bands can be restored either thermally or by irradiation in band 1.

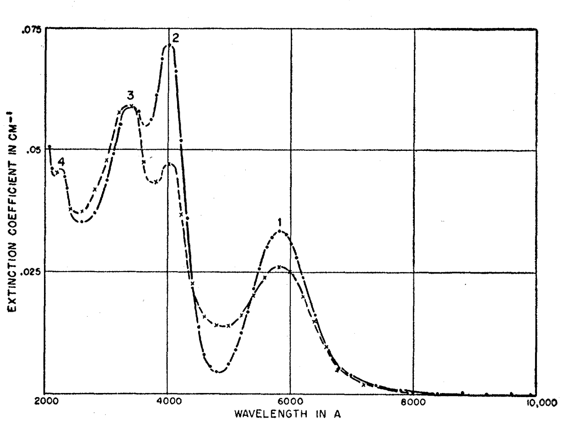

FIG. 2. Bleaching of colored CaF_2 crystal by light absorbed by bands 1 and 2 simultaneously; —·— before bleaching, – – × – – after bleaching.

The following tentative explanation of the absorption bands is proposed. Since the bands can be formed either by x-rays or by additive coloration, they correspond to trapped electrons. Since band 1 cannot be bleached by light it may be ascribed to an excitation to a level several tenths of an electron volt below the conduction band. Band 2 may correspond to a transition to the conduction band or very close to it. This band and its transformation into a band at 4850A resembles very much the *F* and *M* bands in alkali halides. The peculiar bleaching intercombination between band 1 and 2 requires a further experimental study before it will be possible to give an explanation.

* Sponsored by the U. S. Office of Naval Research, the U. S. Army Signal Corps, and the U. S. Air Force.

[1] A. Smakula, Phys. Rev. **77**, 408 (1950).

[2] F. Lüty, Z. Physik **134**, 596 (1953).

[3] S. Barile, J. Chem. Phys. **20**, 297 (1952).

Thermalization of Positrons in Metals

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BELL and Graham,[1] in a very thorough investigation of the time distribution of positron annihilation in solids, find a lifetime for positrons in metals of $1.5 \pm 0.3 \times 10^{-10}$ sec, independent of the particular metal used; and a complex decay with two time components for not very crystalline material. Their discussion quotes DeBenedetti *et al.*[2] who calculated a thermalization time for positrons in metals of 3×10^{-10} sec, and they presume the positrons to decay before thermalization.

It is the purpose of this note to point out that the thermalization time of positrons in a metal is $\sim 10^{-14}$ sec and that the calculation of Appendix I[2] refers to monatomic insulators rather than to metals. Appendix I[2] computes the thermalization time in a metal by considering only the excitation of lattice vibrations after a positron has reached an energy so low that it can no longer cause interband electronic transitions. In a metal, however, it can still transfer energy to the degenerate electrons (here considered in the free electron approximation) by ordinary Coulomb scattering. Indeed, the positron of 0.1-volt energy loses energy to an electron of energy 5 volts almost as fast as to an electron at rest.

This situation arises in the following manner:

Consider a metal of conduction electron density N, Fermi energy $E_F = (h^2/2m)(3N/8\pi)^{\frac{2}{3}}$, and a positron of energy $E \ll E_F$. We shall work at the absolute zero of temperature, although the results obtained are not sensitive to temperature. It is clear that the positron cannot gain kinetic energy in a collision with an electron, for the electron would then have a decreased energy for which all states are filled. These collisions are forbidden by the Pauli principle. But if there is a collision such that the positron loses energy to an electron of energy within $\frac{1}{2}E$ of E_F, this collision is not restricted by the Pauli principle since all states above E_F are empty. Such a collision between free particles cannot occur in one dimension, since the electrons either give energy to the positrons or are moving away from them so that no collisions take place. But in two dimensions the collision is possible. Figure 1 shows a possible collision between an electron of 5-volt energy and a positron of 3-volt energy in which the positron transfers 2.5 ev. to the electron Energy and momentum are, of course, conserved. Indeed, the process can be conceived as a relatively small angle scattering of the electron by the positron. About one-fourth of the free electron-positron scatterings resulting in a momentum transfer $<(2mE)^{\frac{1}{2}}$ lead to a loss of energy by the positron. The average energy lost in such a scattering may be taken as $\frac{1}{2}E$ and the cross section is then $\sim \pi e^4/EE_F$. The number of collisions per second by electrons of energy between E_F and $E_F - \frac{1}{2}E$ is

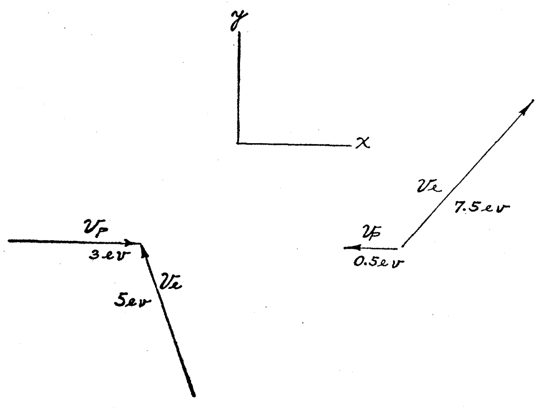

FIG. 1. The collision of a positron of energy 3 ev with an electron of energy 5 ev results in the transfer of 2.5 ev to the electron. (a) Velocities before collision. (b) Velocities after collision.

$$(N)\left(\frac{2E}{6E_F}\right)\left(\frac{2E_F}{m}\right)^{\frac{1}{2}}\left(\frac{\pi e^4}{EE_F}\right),$$

the first two factors being the number of conduction electrons per cc between E_F and $E_F - \frac{1}{2}E$, the third the velocity of these electrons, and the fourth the cross section. The rate of positron energy