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.

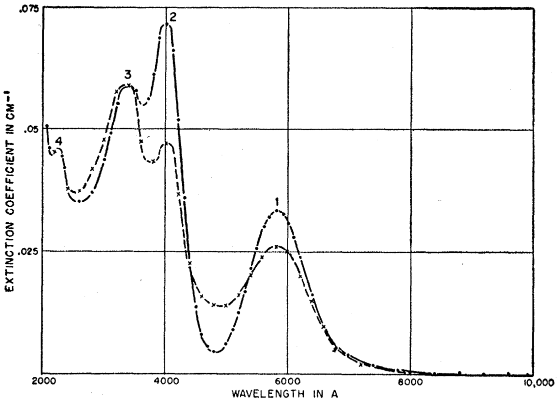

FIG. 2. Bleaching of colored CaF_2 crystal by light absorbed by bands 1 and 2 simultaneously; —·— before bleaching, – – ×– – after bleaching.

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.

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Thermalization of Positrons in Metals

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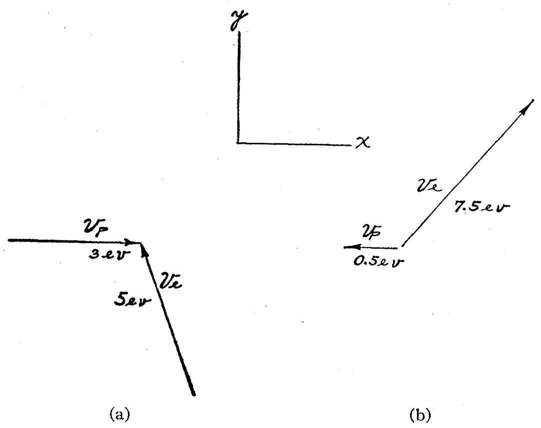
BELL and Graham,[1] in a very thorough investigation of the time distribution of positron annihilation in solids, find a lifetime for positrons in metals of $1.5 \pm 0.3 \times 10^{-10}$ sec, independent of the particular metal used; and a complex decay with two time components for not very crystalline 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 $E_F = (h^2/2m)(3N/8\pi)^{2/3}$, 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 $<(2mE)^{1/2}$ 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



(a) (b)

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.

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

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 loss is then given by the collision rate times the energy lost per collision and is $(\sqrt{2}\pi e^4 N/6m^{\frac{1}{2}})EE_F^{-\frac{3}{2}}$. For a metal with $N=5\times10^{22}$/cc, $E_F\sim8\times10^{-12}$ ergs and a positron of low energy loses energy at a rate of $E\times3\times10^{15}$ sec^{-1}. The loss rate can be written $E\times(16\pi^2/9)\times(me^4/h^3)$ and is thus independent of the electron density so long as the Fermi energy is much greater than the positron energy. The collision cross section, above, is rather unrealistically large because of shielding by the free electrons. It appears unreasonable to imagine it reduced more than a factor of 100, though, still leaving the slowing-down time $\sim10^{-13}$ sec. In a semiconductor, in particular, one could easily detect 10^{16} electrons/cc by their efficacy in thermalizing positrons.

How then can one explain the negative results of Madansky and Rasetti[3] in not finding thermal positrons diffusing from the surface of condensed material? It seems probable that the emergence of thermal positrons is not observed because thermal (or epithermal) positronium comes out instead, being energetically favored over thermal positrons by $E_B-\varphi e$, where E_B is the binding energy of positronium (=6.8 ev) and φ is the work function of the metal. More probably the competition is not with thermal positrons but with positrons of energy eV, where V is the "inner potential" ($\equiv\varphi+E_F$), and the energy difference favoring positronium is closer to $E_B-\varphi+V=E_B+E_F$. Even in the singlet state thermal positronium travels $(1.25\times10^{-10})\times10^7=1.3\times10^{-3}$ cm before decaying, so it could be observed by a collimated system as annihilation radiation emitted from vacuum close to the surface. Triplet positronium would be observable to a distance of several centimeters.

The results of Bell and Graham with metals are explained, then, as immediate thermalization followed by capture (accelerated by the Auger effect involving the conduction electrons) to form positronium. Exchange collisions with electrons on the Fermi surface convert any triplet state to singlet, and so the decay is very rapid. If this were all that occurred, however, the lifetime would be lengthened by a factor four since the system would spend three-fourths of its time in the nondecaying triplet state, there being no effective energy difference between them. There is still, therefore, a slight puzzle with metals. The results with nonmetals indicate that some positrons are preserved either free or as triplet positronium, decaying probably not by conversion to singlet (in an insulator), but by annihilation with an electron of appropriate spin from a neighboring molecule.

While it is still not certain what processes are effective, it appears that positrons are thermalized in metals in times $\sim10^{-15}$ sec, and that the Auger effect is important in the formation of positronium. It is suggested that work be done on the annihilation of positrons in semiconductors of varying conductivity and that one should look for thermal positronium emerging from the surface of materials in which positrons are stopping.

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Some *K*-Particle Mass Measurements*

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In a recent publication, Crussard *et al.*[1] have reported mass values for six *K* mesons absorbed in photographic emulsions of $950m_e\pm40m_e$. Reported below are measurements made on three *K* particles with a new technique of measuring gap density as a function of residual range in electron sensitive photographic emulsion. The term "gap density" was first defined by Hodgson[2] to be the fractional length of a track unoccupied by grains. To determine mass values, it is assumed that singly charged particles of the same velocity, but differing mass, will produce tracks in photographic emulsions of identical gap density. Then if the ranges at which the velocities are equal are known, the ratio of the masses equals the ratio of the ranges.

To provide a simple precise method of measurement a motor drive was attached to the stage of a Bausch-Lomb scattering microscope (these microscopes permit tracks to be rotated parallel to the stage movements) in such a way that a track was driven past a hairline at the rate of 100μ in 4 minutes. The observer was provided with two counters driven by a common pulser. One counter ran continuously; the other, when the observer pressed a button. The observer pressed a button whenever the hairline was over a portion of track unoccupied by grains. The ratio of the readings of the two counters gave the gap density.

To make a mass measurement on a given particle, one or more reference protons were selected (protons being differentiated from deuterons on the basis of scattering range measurements) running at similar depth in the emulsion to the track being measured. The variation of gap density d with range R was roughly determined and found to be proportional to $R^{0.52\pm0.05}$. The gap density of the K particle was measured for 200μ and then the gap density of the reference protons at the same depth and approximately twice the range (chosen to make the gas density almost identical) was measured for 200μ.

Suppose the gap density of the K particle was d_K and range R_K, and of the proton was d_p and R_p, then using the previously determined variation of d with R, the mass of the K particle m_K relative to the mass of the proton m_p is

$$m_K/m_p=(R_K/R_p)(d_p/d_K)^2.$$

It is possible for the absolute value of d to drift with time by the order of 10 percent, but the ratio, d_p/d_K is repeatable to better than 4 percent. The procedure outlined above was repeated over the whole range of the K particle above 1000μ. Comparison of gap densities on the ranges below 1000μ is affected by differences in the scattering of K particles and protons. If care is taken to randomize the procedure, the accuracy obtainable on a given track should be limited only by the length of track available, and, of course, by the degree of fading on the plates which have been used. The method outlined above seems to be of similar precision with the photoelectric method, of greater simplicity, and less affected by local changes in optical quality occasioned by surface scratches or other factors.

Three K particles were observed in balloon flight exposures; K_1, observed in a stack of stripped emulsions, was 4.5 mm long and came from a star consisting of 14 evaporation prongs and two minimum tracks (probable energy on the order of 5 Bev). K_2 and K_3 (3 mm long) were loaned to us by Dr. P. Barrett of Cornell for measurement using the above method. The origins of these two particles were not observed. In all three cases, the secondary particles were too short to be identified but had ionizations of the order of $I_{\min}$. The mass values determined were

$$K_1=970\pm100m_e \text{ (standard deviation)},$$
$$K_2=1020\pm100m_e \text{ (standard deviation)},$$
$$K_3=870\pm100m_e \text{ (standard deviation)}.$$

The results are quite consistent with the assumption of a single mass value $950\pm60m_e$ and add additional weight to the conclusions reached by Crussard *et al.*[1] that the masses of the majority of K particles observed in emulsions in balloon flights are about $950m_e$ and are within the accuracy of the experiments indistinguishable from the mass of the τ meson.

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