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 $E\times(16\pi^2/9)\times(me^4/\hbar^3)$ 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.

[1] R. E. Bell and R. L. Graham, Phys. Rev. **90**, 644 (1953).
[2] DeBenedetti, Cowan, Konneker, and Prinakoff, Phys. Rev. **77**, 205 (1950).
[3] L. Madansky and F. Rasetti, Phys. Rev. **79**, 397 (1950).

Some *K*-Particle Mass Measurements*

D. M. Ritson†
Physics Department, University of Rochester, Rochester, New York
(Received July 21, 1953)

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.

The author is very grateful to Dr. P. Barrett of Cornell for providing two examples of K mesons for measurement and to Professor M. F. Kaplon for discussion during the course of the work.

* This research was supported in part by the U. S. Air Force under a contract monitored by the Office of Scientific Research, Air Research and Development Command.
† Now at Massachusetts Institute of Technology, Cambridge, Massachusetts.
[1] Crussard, Leprince-Ringuet, Morellet, Orkin-Lecourtois, and Trembley, Phys. Rev. **90**, 1127 (1953).
[2] P. E. Hodgson, Phil. Mag. **41**, 725 (1950).