trons arising from a collision are detected individually in two Geiger-Müller counters connected in coincidence.

Figure 1 (a) shows a plan view of the scattering chamber used. A uniform magnetic field is vertical. Beta-rays from the source, S,

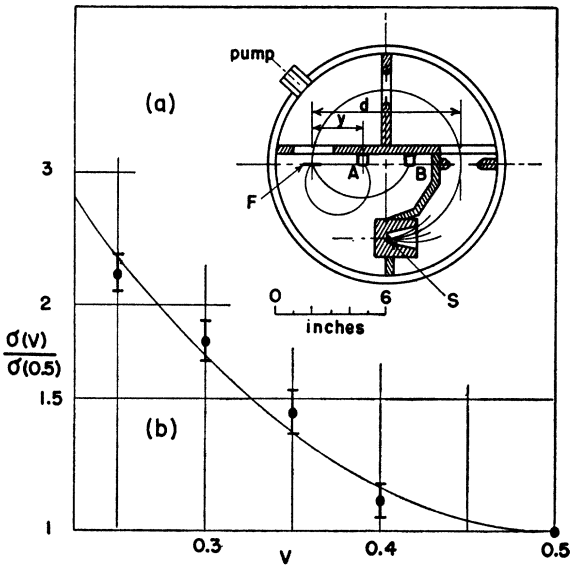

FIG. 1. (a) Plan view of scattering chamber. Shown are beta-emitter, S, scattering foil, F, two movable Geiger-Müller counters, A and B. Fractional energy transfer is given by y/d. (b) Relative differential cross section against fractional energy transfer, v, at fixed incident energy, $E=3.5\ mc^2$. A beryllium scatterer, 4.5 mg/cm², was used. The curve is taken from the Møller formula.

travel in a horizontal plane and strike a scattering foil, F. The two Geiger-Müller counters, A and B, with axes vertical, are movable from left to right in the figure. One counter is situated somewhat above the scattering foil, the other below. Momentum considerations show that to each horizontal setting of counter A, for example, there corresponds a definite horizontal setting of counter B in order for elastic collisions to be recorded. Experimentally, the scattering events appear to be practically elastic, in the sense that an inelasticity of the order of one percent in all events could have been detected. In the interest of obtaining reasonably large solid angles, the counters can be made quite long, because all elastically scattered electrons of given fractional energy transfer are focused in a vertical line at each counter. Fractional energy transfer, v, is related to counter setting by $v=y/d$, where y is the horizontal distance from scattering foil to the nearest counter, and d is the diameter of the circular path of the incident particles.

Using 10 millicuries of $Sr^{90}-Y^{90}$ as beta-emitter, and scattering foils of 0.5 mg/cm² collodion and 4.5 mg/cm² beryllium, results were obtained as follows. Figure 1 (b) shows the variation of measured differential cross section, $\sigma(v)$, with v, at a fixed incident kinetic energy, $E=3.5\ mc^2$ with a total spread of $0.4\ mc^2$. Standard statistical errors are attached. The resolution in v has a width at half-maximum of 0.04. The curve shown has been computed from the formula of Møller[1] for elastic electron-electron scattering. Similar results, not reproduced here, were found at $E=2.3\ mc^2$.

Figure 2 shows the results for absolute differential cross section at $v=0.5$, as a function of incident kinetic energy in units of mc^2. The spread in incident energy for each experimental point is that corresponding to a 12 percent incident momentum spread. The errors shown are statistical only. The experimental error is estimated to be 10 percent standard deviation. Curve A is a plot of Møller's formula. To indicate the effect of the "spin terms" in the Møller expression,[2] a plot is made with these terms arbitrarily suppressed (curve B).

The formula of Møller appears to be verified within the 10 percent experimental error. The result here is not at variance with the results of previous cloud-chamber experiments,[3,4] although for a given incident energy there is essentially no overlap in terms of fractional energy transfer investigated.

It may be of interest to note that an alternative conclusion could be drawn concerning the identity of negative beta-particles

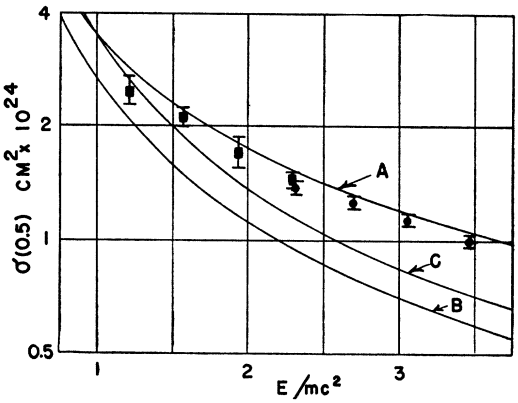

FIG. 2. Absolute differential cross section against incident kinetic energy. Observed cross section, in 10^{-24} cm² per unit fractional energy transfer, is shown as squares for 0.5-mg/cm² collodion scatterer and circles for 4.5-mg/cm² beryllium scatterer. Curve A is the Møller formula, curve B is the Møller formula less the spin terms, and curve C is the Bhabba formula less the virtual annihilation terms.

with atomic electrons.[5,6] In Fig. 2, a third formula, curve C, represents Bhabha's elastic positron-electron scattering formula[7] with the parts arising from virtual annihilation deleted. This pseudo-formula is not far from the Mott formula for coulomb scattering of fast electrons,[8] the latter being of order 10 percent smaller for these energies. The preference shown for the Møller formula would, then, imply that beta-particles are the same as electrons as far as scattering by electrons is concerned.

A detailed account of the experiment is to be published. I am indebted to Professor W. M. Woodward for suggesting the problem and for his active interest and counsel throughout the experiment.

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[1] C. Møller, Ann. Physik **14**, 568 (1932).
[2] Mott and Massey, *The Theory of Atomic Collisions* (Clarendon Press, Oxford, 1950), second edition, p. 369.
[3] F. C. Champion, Proc. Roy. Soc. (London) **A137**, 688 (1932).
[4] Groetzinger, Leder, Ribe, and Berger, Phys. Rev. **79**, 454 (1950).
[5] H. R. Crane, Revs. Modern Phys. **20**, 278 (1948).
[6] M. Goldhaber and G. Scharff-Goldhaber, Phys. Rev. **73**, 1472 (1948).
[7] H. J. Bhabha, Proc. Roy. Soc. (London) **A154**, 195 (1936).
[8] N. F. Mott, Proc. Roy. Soc. (London) **A124**, 425 (1929).

The Positron Activity of K^{40}

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THE nucleus K^{40} can decay to A^{40} by three processes: (a) orbital electron capture to an excited state of A^{40} with subsequent gamma-emission, (b) electron capture to the ground state of A^{40}, and (c) positron emission. Fireman[1] has calculated the ratio of process (b) to process (c) for various mass differences $K^{40}-A^{40}$. Nier and Roberts'[2] determination of the $Ca^{40}-A^{40}$ mass difference gives a mass difference for $K^{40}-A^{40}$ of $(3.35\pm0.15)\ mc^2$. With this value of the mass difference, Fireman's calculations give the ratio of process (b) to process (c) equal to (0.01, +0.02, −0.005). On the other hand, Sawyer and Wiedenbeck[3] have found the total

electron capture rate [process (a) plus process (b)] to be (13.5±4) percent of the β^- decay rate, and determined the gamma-ray rate to be (12.7±1) percent of the β^- decay. If the gamma-ray is process (a), then there remains a maximum of 5 percent of process (b). If the upper limit of Fireman's ratio is used, there must be less than one positron to 10^3 electrons.[4]

The coincidences of annihilation quanta were looked for with two scintillation counters. The angular correlation was partially determined by noting the coincidence rate per gram of potassium as a function of the diameter of the source. The experimental arrangement is shown in Fig. 1.

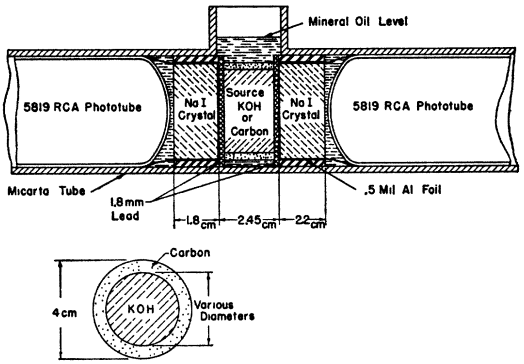

FIG. 1. Experimental arrangement. Typical ring and disk source.

Figure 2 shows the measured counting rates for various source diameters. It is to be noted that the observed potassium coincidence rate (curve I) has a slope opposite to that for the positron detection efficiency (curve II), and, therefore, gives no evidence that the observed coincidence rate from potassium comes from positrons. Furthermore, the potassium curve suggests that the observed coincidence rate arises from the back scattering of the 1.5-Mev gamma-rays. The Compton back scattering of the 1.5-Mev gamma-rays from one NaI crystal to the other would give the observed positive slope of curve I.

The absolute positron detection efficiency was determined by a calculation of the probability for an observation of one of two annihilation quanta in one crystal, and then multiplying this by the observed ratio of the double coincidence rate to the total rate in one crystal for a pure positron source (C^{11}) in the identical geometry. The calculation was checked by using the same solid angles and the corresponding absorption coefficients to find the detection efficiency of the 1.5-Mev gamma-rays of potassium. The gamma-ray activity of potassium, determined by the calculated efficiency and the observed total counting rate, was within 5 percent of the value obtained by Sawyer and Wiedenbeck.[3]

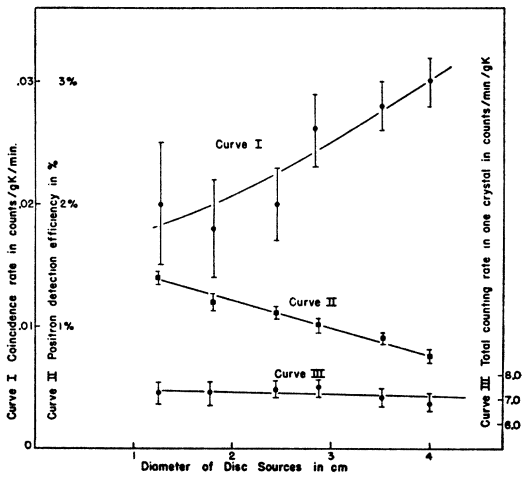

FIG. 2. Counting rates as functions of the source diameter.

A calculation of the positrons created in pair production by the 1.5-Mev gamma-rays and the corresponding detection efficiency gives a background of 0.007 counts per min per gram of potassium. If the minimum counting rate observed is 0.02, the difference gives the rate possibly arising from positrons from the decay process. This results in an upper limit of less than one positron in 1700 electrons.

The lifetime of the excited state of A^{40} was found to be less than one second. The gamma-ray rate of one kilogram of KOH at 20°C, and when boiling violently at 370°, showed no difference within ±5 percent, indicating that the A^{40} driven off had already decayed to the ground state. Theory[5] indicates a quadrupole transition with a lifetime of the order of 10^{-12} sec.

The pure positron sources were carbon disks irradiated in the gamma-ray beam of the Cornell synchrotron. The reaction $C^{12}(\gamma,n)C^{11}$ gave ample activity of the pure positron emitter C^{11}.

I am indebted to Professor P. Morrison for suggesting the experiment and to him and Dr. R. R. Wilson for invaluable discussions during its course.

[1] E. L. Fireman, Phys. Rev. **75**, 1447 (1949).
[2] T. R. Roberts and A. O. Nier, Phys. Rev. **79**, 198(A) (1940). A. O. Nier and T. R. Roberts, Phys. Rev. **81**, 507 (1951).
[3] G. A. Sawyer and M. L. Wiedenbeck, Phys. Rev. **79**, 490 (1950).
[4] P. R. Bell and J. M. Cassidy, Phys. Rev. **79**, 173 (1950). Using a sintillation spectrometer Bell and Cassidy have determined an upper limit to this ratio of 2×10^{-5}, but this figure cannot be reproduced plausibly from the data presented.
[5] P. Morrison, Phys. Rev., to be published.

The Dielectric Properties of $BaTiO_3$ at Low Temperatures*

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BLUNT and Love,[1] using ceramics, measured the dielectric behavior of $BaTiO_3$ at low temperatures. They found a pronounced peak in the dielectric loss at about 70°K, whereas the dielectric constant showed no anomaly down to liquid helium temperatures. Hulm,[2] on the other hand, measured multidomain single crystals and observed a strong increase in the coercive field strength in the region from about 20°K downwards. The increase was so strong that he was unable to polarize the crystals completely and, thus, could not measure the behavior of the electric spontaneous polarization at these very low temperatures.

Since these results were not conclusive, we have measured the dielectric constant and loss of our "single-domain crystals"[3,4] at audiofrequencies, and the hysteresis loop at 60 cps from room temperature down to 4.2°K. The crystal holder, consisting of two spring-loaded silver contacts, was enclosed in a brass chamber serving as a constant volume gas thermometer. The chamber was filled with helium gas and connected to a mercury manometer by a steel capillary.

The results were as follows. The dielectric constant in the direction corresponding to the c axis at room temperature[3] decreases approximately linearly below the last transition near 180°K and reaches a value of about 120 at 4.2°K. We could find no anomaly in the dielectric loss, in contrast to Blunt and Love's measurements; the loss stays about constant and remains small. The coercive field strength, as derived from the hysteresis loops, starts to increase strongly with falling temperature below 90°K. However, our good crystals could be saturated even at helium temperature (Fig. 1) and thus allow measurement of the spontaneous