A Search for Delayed Photons from Stopped Sea Level Cosmic-Ray Mesons*

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If the meson disintegrates into a photon and an electron, the stopping of a meson and its subsequent decay should give rise to a delayed 50-Mev photon. Delayed coincidences were sought between the stopped meson and the photon, detected by its materialization in a Pb sheet (calculations are presented of the photon detection efficiency for various lead thicknesses and photon energies of 20, 40, and 60 Mev; the electron range-energy curves used in the calculation are also shown). In 477.4 hours, nine apparent delayed photon coincidences were found. The measured inefficiency of the anticoincidence arrangement leads us to expect five spurious delayed photon coincidences in this time, so we conclude that the number of true delayed photon coincidences is small, if not zero. If the hypothesis under test is correct, the expected number of true delayed photon coincidences, computed from the rate of delayed electron coincidences (as measured with the same geometry) and the calculated photon detecting efficiency, is of the order of 100. The negative result of this test argues not only against decay into a photon and an electron, but also shows that if meson decay leads to a neutral meson which then decays into two photons, the mean life against the latter process must be greater than about 10^{-10} sec.

I. INTRODUCTION

WHILE it is well established that the sea level cosmic-ray meson disintegrates spontaneously with a mean life of about 2.2 microseconds,[1] one of the decay products having, very approximately, the mass and charge of an electron,[2] the exact nature of the disintegration process has not yet been determined. One possibility is that the meson disintegrates into a photon and an electron. There is some indirect evidence against it;[3] but in view of the current uncertainties in the physics of elementary particles, it seemed worth while to make a more direct test.[4]

If the meson does disintegrate in this fashion, the photon and the electron have equal and opposite momenta of about 50 Mev/c in the rest system of the meson,[5] which practically coincides with the laboratory system in the case of mesons slowed down in a dense absorber. A 50 Mev photon has a relatively high probability, in passing through an appropriate thickness of material, of being converted into an electron pair of which at least one electron has sufficient range to emerge from the material (see Section III below). We have made use of this property to detect the hypothetical photon. Our apparatus was designed to detect delayed coincidences between the arrival of a meson that gets stopped in a brass plate and the subsequent emission of a high energy photon detected by its materialization in a lead sheet. In order to permit comparison of the time distribution of the delayed photons with the known time distribution of decay electrons,

* This experiment was reported at the New York meeting of the American Physical Society, Jan. 29, 1948 (R. D. Sard and E. J. Althaus, Bull. Am. Phys. Soc. 23, 2, 20 (1948); (Phys. Rev. 73, 1251 (1948)). The present paper gives a more detailed account and includes additional data obtained since Dec. 8, 1947, confirming the result already published.

[1] B. Rossi and N. Nereson, Phys. Rev. 64, 199 (1943); M. Conversi and O. Piccioni, Phys. Rev. 70, 859 (1946); R. Maze, R. Chaminade, and A. Fréon, J. de Phys. et Rad. 7, 202 (1945). These papers give references to earlier work.

[2] E. J. Williams and G. E. Roberts, Nature 145, 102 (1940); R. P. Shutt, S. De Benedetti, and T. H. Johnson, Phys. Rev. 62, 552 (1942). See also the work of Anderson and his collaborators [Phys. Rev. 72, 724 (1947)].

[3] L. Nordheim, Phys. Rev. 59, 554 (1941); G. Bernardini, *Colloque sur les Rayons Cosmiques* (Union Internationale de Physique Pure et Appliquée, Paris, 1947), p. 43 *et seq.* of Document R.C. 48-1.

[4] E. P. Hincks and B. Pontecorvo, Phys. Rev. 73, 257 (1948) have independently performed an experiment very similar to our own, with the same negative result. The two experiments complement each other, as the meson absorbers are different (graphite as against brass), the lead materialization sheets are of different thickness (0.21 as against 0.86 cm), and the circuits are different.

[5] W. B. Fretter, Phys. Rev. 70, 625 (1946). Anderson and his collaborators have recently obtained two cloud-chamber pictures at 9200 meters altitude [Anderson, Adams, Lloyd and Rau, Phys. Rev. 72, 724 (1947); Adams, Anderson, Lloyd, Rau, and Saxena, Rev. Mod. Phys. 20, 334 (1948)] that can be interpreted most directly as showing the disintegration of a meson with emission of a 25-Mev electron. This result is incompatible with the photon-electron hypothesis if the rest mass of the disintegrating meson is 100 Mev/c^2. In view of the evidence now available for the existence of different types of mesons, it is not certain that the two mesons observed by Anderson *et al.* at high altitudes are of the same kind as those which form the bulk of the hard component of the cosmic radiation at sea-level. The negative result of the present experiment is, however, perfectly consistent with Anderson's suggestion that his mesons do have mass 100 Mev/c^2, disintegrating into an electron and a neutral particle of mass 70 Mev/c^2.

the delayed coincidences were measured in four adjacent time intervals covering in total the range from 1.2 to 8.0 microseconds after arrival of the meson.

II. EXPERIMENTAL ARRANGEMENT

The experiment was carried out in the sub-basement of the Physics Building, at an elevation of about 30 meters above sea level. The floors and roof overhead amounted to approximately one-half meter of reenforced concrete, and there was some earth outside the walls of the sub-basement that was in the solid angle of the meson-selecting telescope. Figure 1 shows the arrangement of Geiger-Mueller tubes and absorbers in the two configurations used.

The G-M tubes were of 2.4 cm inside diameter and 25 cm (A, B, D, E) and 50 cm (C) effective length. They were filled with a 9:1 mixture of argon and ethyl alcohol to a pressure of 10 cm Hg, and were operated at 950 volts, 80–100 volts above threshold. They were grouped in parallel as shown. The walls of the tubes of groups A and B were of 0.8 mm brass; those of the tubes of C, D, and E were of 0.4 mm brass. The individual counter groups were enclosed in boxes made of 1.6 mm aluminum; the boxes for D and E were, however, open over the effective areas so that an electron moving downward from the lead sheet had only to penetrate the 0.8 mm steel plate
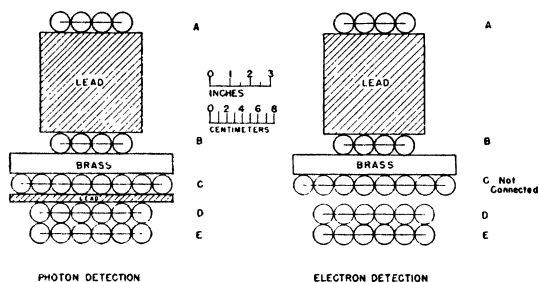

FIG. 1. The two experimental configurations. In both we are interested in mesons that pass through A and B and stop in the brass plate. The photon detection arrangement is designed to detect downgoing photons resulting from the decay of the stopped mesons. C is in anticoincidence with (AB). The lead slab serves to materialize the photons; one or both of the pair of electrons may pass through D and E, giving rise to a delayed coincidence of (DE) with respect to (AB). The electron detection arrangement is designed to detect downgoing decay electrons. There is no high-voltage on C and the lead slab is absent. Delayed coincidences of (DE) with respect to (AB) result from these decay electrons.
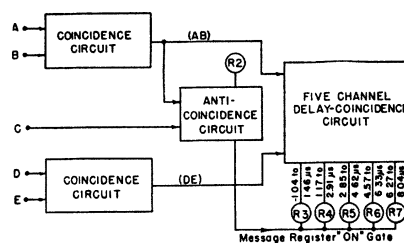

FIG. 2. Block diagram of the circuit.

supporting the lead, and the brass counter walls of D and E, in order to be counted.

Referring to the "photon detection" arrangement, shown in Fig. 1, trays A and B, separated by 12.7 cm Pb, defined a cone of incident mesons, some of which stopped in the 21.6 g/cm^2 brass absorber. Tray C more than covered the incident cone, and was connected in anticoincidence with the coincidences of A and B. To detect photons produced in meson disintegrations, a 9.75 g/cm^2 Pb sheet was placed beneath C. Its function was to produce electrons from high energy photons (mainly by pair production), the electrons being detected by coincidences between D and E. The lead sheet was supported by an 0.8 mm steel plate.

In order to determine how many delayed photon coincidences were to be expected, we took data with the "electron detection" arrangement also shown in Fig. 1. This differed from the photon detection arrangement only in that the lead sheet was removed and the high voltage was not applied to the G-M tubes C. In this case, decay electrons emerging downward from the brass were detected. Since the decay of stopped mesons is isotropic, and the angular divergence in pair-production by a 50-Mev photon is small, the geometrical factors in the photon detection, and electron detection arrangements were essentially the same. If the hypothesis being tested is correct, the ratio of delayed photon coincidences to delayed electron coincidences should be equal to the chance that an incident photon produces in the Pb sheet at least one electron capable of actuating D and E (as shown in Section III, the chance of the decay photon emerging from the brass is very nearly equal to that for the decay electron). An alternative electron detection arrangement was also used, different only in that

C was physically removed. The two arrangements gave essentially identical results.

The coincidences were counted with a circuit identical with that used previously at the Massachusetts Institute of Technology.[6] It was designed by M. L. Sands, and built by the M.I.T. Research Laboratory of Electronics. The anticoincidence unit was of our own design. Figure 2 shows schematically the mode of operation of the circuits. The pulses from *A* and *B* went into a coincidence circuit, giving an output whenever the two input pulses were within 1.3 microseconds of each other. The circuit was designed so that the output pulse occurred at a fixed interval of time (1.3 μsec.) after whichever of the two input pulses was the earlier. The purpose of this was to reduce the effect of spontaneous lags in the G-M tubes, as it is very unlikely that both tubes will have large delays when actuated by the same particle. Trays *D* and *E* fed an identical circuit, producing a pulse 1.3 μsec. after the earlier of *D* and *E* provided that they discharged

FIG. 3. Calculated range-energy curves for electrons.

[6] B. Rossi, M. Sands, and R. D. Sard, Phys. Rev. **72**, 120 (1947).

within 1.3 μsec. of each other. The two output pulses (*AB*) and (*DE*) went to a five channel double-coincidence circuit. The first channel, actuating the electromechanical counter *R3*, measured prompt coincidences in which (*DE*) occurred between 1.0 μsec. before and 1.5 μsec. after (*AB*). The remaining four channels, actuating *R4*, *R5*, *R6*, and *R7* respectively, measured delayed coincidences of (*DE*) with respect to (*AB*) in successive time channels, the first covering delays from 1.2 to 2.9 μsec., the second 2.9 to 4.6 μsec., the third 4.6 to 6.3 μsec., and the fourth 6.3 to 8.0 μsec. The distribution of counts between these four channels indicated whether or not the delayed coincidences were due to the 2.2 μsec. decay process. Our anticoincidence circuit passed (*AB*) whenever tray *C* did not discharge between 1.0 μsec. before and 10.0 μsec. after the time of occurrence of (*AB*). Its output turned on the recorders *R3*, *R4*, *R5*, *R6*, and *R7*. Thus the delay discriminator proper recorded counts if and only if *C* were not discharged. In the photon detection arrangement, this prevented counting of charged particles emerging downward from the brass, as these could not reach *D* and *E* without tripping *C*. It did not do so in the electron detecting arrangement, because there was then no high voltage on *C*.

The M.I.T. unit contained a monitoring circuit, which could be switched to record any one of the following: (*AB*), *A*+*B*, *D*+*E*, (*DE*). *A*+*B* means the sum of the *A* and *B* counts as passed through a mixer insensitive for about 15 μsec. after each pulse that reached it; similarly for *D*+*E*. The monitoring circuit was continually switched between the four positions while data was being taken.

III. THEORY OF THE EXPERIMENT

If the hypothesis under test is correct, an electron and a photon, each of about 50 Mev, fly off in opposite directions from the point at which the stopped meson disintegrates. Our test of the hypothesis was based on the assumption that the formulas of Bethe and Heitler for pair creation by photons and energy loss by electrons are at least approximately correct for energies up to 50 Mev. This assumption can be considered to be well verified experimentally.

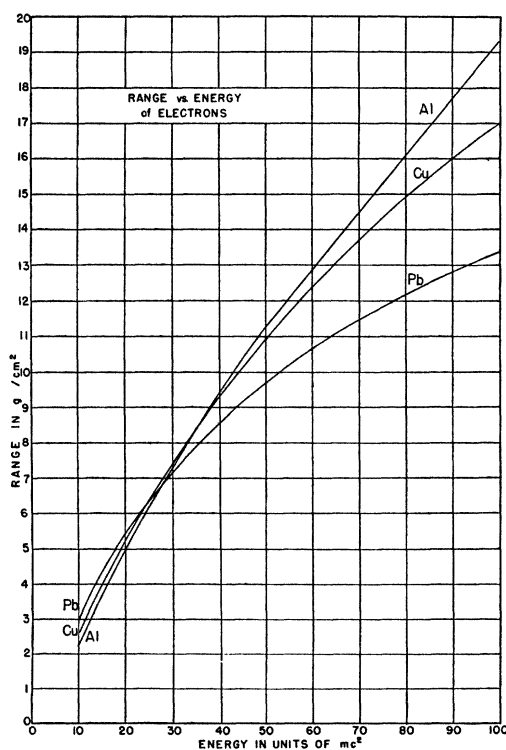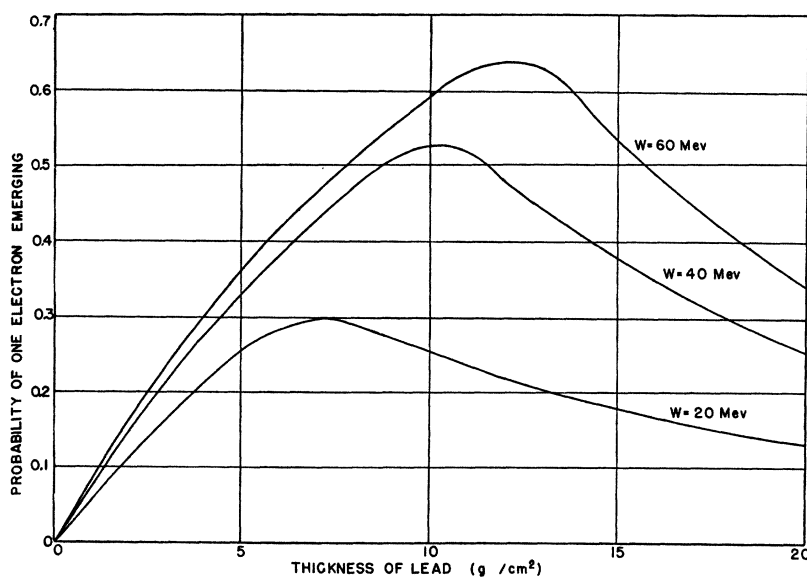It was necessary to know first of all the relation

FIG. 4. Calculated probability that at least one electron (+ or −) emerges downward per vertically incident photon of energy W.

between energy and mean range for electrons. One of us (R.D.S.) has computed it for a number of materials; the results for Al, Cu, and Pb are plotted in Fig. 3. For total energies above 10 mc², the theoretical expressions for the mean radiative loss[7] and the loss by non-radiative collisions[8] were used; the reciprocal of the rate of energy loss so computed was integrated numerically to give the range down to a total energy of 10 mc². As scattering was neglected, the range obtained was actual path length rather than thickness of material. The result for 100 mc² electrons agrees to within one percent with the result of Bethe and Heitler[7] for Cu and of Heitler[9] for Pb. At energy 10 mc², the curves were joined to the theoretical points calculated by Widdowson,[10] diminished by 0.4 g/cm² to bring them into closer agreement with experimental data on β-ray ranges.

The efficiency of the lead slab in making photons detectable depends on the probabilities of pair production for various partitions of the energy in the pair and on the range-energy relation for the electrons. In our calculation we used the Bethe-Heitler formulas[7] for pair creation and

the range-energy curve for Pb of Fig. 3. The major approximations were neglect of electron scattering and neglect of fluctuations in the rate of radiation by electrons. The same range-energy relation was applied to negatrons and positrons, and their angular divergence was taken to be zero.

The results are shown in Fig. 4. For small thicknesses, the calculation is elementary. In effect, one of the pair electrons is bound to emerge so long as the thickness of the Pb is less than the range of an electron of half the photon's energy, $R(W/2)$. The required probability is therefore simply the probability of pair production:

$$1 - \exp(-\sigma_p(W)T),$$

where $\sigma_p(W)$ is the probability of pair production per unit thickness and T is the thickness. At large thicknesses $(T > R(W))$ the dependence on thickness is again simple, as

$$\exp(-\sigma_t(W)(T - R(W))),$$

where $\sigma_t(W)$ is the sum of the probabilities of pair production and Compton scattering. This dependence expresses the fact that only the lower part of the slab is effective. At intermediate thicknesses, $R(W/2) < T < R(W)$, the emergence or not of at least one electron depends on the particular mode of division of energy in the pair, and a numerical integration over the various partitions was carried out. It is in this inter-

[7] H. A. Bethe and W. Heitler, Proc. Roy. Soc. **A146**, 83 (1934). Radiation probabilities for materials other than Pb, Cu, and H₂O were obtained by interpolation in Fig. 3 of this reference.

[8] B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 240 (1941); formula (1.12) with $I = 11.5Z$ ev.

[9] W. Heitler, *Quantum Theory of Radiation*, first edition (Oxford University Press, London, 1936), p. 223.

[10] E. E. Widdowson, Proc. Phys. Soc. **51**, 19 (1939).

TABLE I. Calibration of the circuits.

(AB) Coincidence circuit: either A or B within 1.30 μsec. before or after the other.
(DE) Coincidence circuit: either D or E within 1.28 μsec. before or after the other.
Note: In the remainder of this Table we mean by the time of occurrence of (AB) or (DE) the time of occurrence of the earlier of the two pulses A and B or D and E.
$(AB-C)$ Anticoincidence circuit: C from 1.0 μsec. before to 10.0 μsec. after (AB).

	$(AB:DE)$ coincidences	Width
Prompt channel	(DE) from 1.04 μsec. before to 1.46 μsec. after (AB)	2.50 μsec.
First delay channel	(DE) from 1.17 μsec. after to 2.91 μsec. after (AB)	1.74 μsec.
Second delay channel	(DE) from 2.85 μsec. after to 4.62 μsec. after (AB)	1.77 μsec.
Third delay channel	(DE) from 4.57 μsec. after to 6.33 μsec. after (AB)	1.76 μsec.
Fourth delay channel	(DE) from 6.27 μsec. after to 8.04 μsec. after (AB)	1.77 μsec.

mediate region that the maximum detection efficiency is found.

For photon energies of 40 and 60 Mev, the Compton effect was ignored. At 20 Mev, where it amounts to 12 percent of the total cross section, the photon attenuation through the Compton effect was taken into account, but the contribution of the Compton electrons to the photon-detection efficiency was neglected. This underestimation is no doubt more than compensated by our neglect of scattering.

For the 9.75 g/cm² thickness used in the experiment, the calculated probability is 52 percent for a 40 Mev photon and 58 percent for a 60 Mev photon. Interpolation gives 56 percent for a 50 Mev photon. It is to be noted that for a photon energy as low as 20 Mev, the calculated probability is as high as 26 percent; of course, the neglect of scattering makes our calculation less reliable the lower the energy.

It was also necessary to know the relative probabilities of a decay electron and a decay photon emerging from the brass meson stopper. We calculated each probability only for 50 Mev energy, but for various thicknesses of brass. The chance of an isotropically emitted photon's emerging unconverted and unscattered from the bottom of the brass plate involves only σ_t and μ, the meson absorption coefficient. The chance of an isotropically emitted electron's emerging involves μ and the mean range, for which the value for Cu of Fig. 3 was used. Both integrals could be evaluated in closed form. At no thickness do the two probabilities differ by more than 25 percent; at the thickness of 21.6 g/cm² used in the experiment, the photon probability is 1.04 times the electron probability. The ratio of the two is essentially independent of μ; the error in-

volved in assuming the brass slab infinite should also be practically cancelled out in the ratio.

Taking our numerical results literally, we conclude that if the photon-electron hypothesis is correct, the delayed coincidence rate with the photon detection arrangement ought to be 1.04 ×0.56=58 percent of the delayed coincidence rate with the electron detection arrangement. This number is, as already remarked, somewhat of an overestimate, but it is difficult to believe that it is wrong as to order of magnitude.

IV. RESULTS

The apparatus was used between the end of August 1947 and March 1, 1948. Data obtained during periods of known or suspected malfunctioning of the equipment were discarded, leaving data from about 1475 hours in the period October 2, 1947 to March 1, 1948. All the G-M tubes were checked at least once every two weeks. Complete calibrations of the circuits were made three times, near the beginning, middle, and the end of the October to March period. In these calibrations we employed artificial pulses having the same general shape as the G-M tube pulses and adjusted in amplitude to match the G-M tube tray being simulated; their relative times of occurrence were continuously adjustable by means of helical wire-wound potentiometers.[11] The dials of the potentiometers were calibrated in 0.4 μsec. steps by means of marker pips derived, like the artificial pulses, from a 2.5 Mc crystal-controlled oscillator; one scale division on the dial corresponded to 0.01 μsec. The calibrations never differed by more than a few hundredths of a microsecond. The average of the first and third

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[11] 'Helipots,' obtained from The Helipot Corporation, South Pasadena, California.

TABLE II. Raw data on electron and photon delayed coincidences.

	Counts in					Duration	Rate
	First delay channel	Second delay channel	Third delay channel	Fourth delay channel	Sum of delay channels	Hours	Counts per hour
Photons $(AB:DE)-C$	5	2	2	0	9	477.4	0.019±0.006
Electrons $(AB:DE)$							
C in place	112	43	28	16	199	341.5	0.58±0.04
C removed	87	57	30	12	186	330.1	0.56±0.04
Combined	199	100	58	28	385	671.6	0.57±0.03

calibrations, which we considered the most reliable, were used in analyzing the data. The numbers are given in Table I. The regions of uncertainty at the channel edges never exceeded 0.03 μsec.; the numbers given are the half-way points between the fully off and fully on settings.

Table II gives the accepted delayed coincidence data. As already remarked, two alternative arrangements were used for decay electron detection. In one, C was disconnected; in the other, physically removed. It is thought that the former is perhaps slightly better suited for comparison with the photon detection arrangement, but since the two gave the same rates within statistical uncertainties the results were combined. The uncertainties assigned to the rates are estimated standard deviations.

Certain corrections had to be made to the raw data. The data needed in making these corrections are given in Table III. For the photon detection configuration, the most important correction was that for the inefficiency of the anticoincidence arrangement. This inefficiency appeared to be due mainly to the non-zero thickness of the counter walls; for vertically incident particles the walls filled 3 percent of the area of C. Our data gave us a measured value of the inefficiency. In effect, decay products made a negligible contribution ($<5\times10^{-4}$) to the prompt coincidence rates, so that the ratio of the prompt coincidences $(AB:DE)-C$ obtained with the photon arrangement to the prompt coincidences $(AB:DE)$ obtained with the Pb in place but no high voltage on C was the anticoincidence inefficiency. From the first two rows of Table III we found this ratio to be 2.66±0.02 percent. This is perhaps a slight underestimate, as it refers mainly

to the central portion of C; a rough check, involving comparison of $(AB)-C$ with (AB) and (ABC) gave a value of about 3 percent. Because of the inefficiency, mesons could occasionally slip through tray C without discharging it, stop in the lead sheet, and produce decay electrons actuating D and E. Also, a few decay electrons from the brass could slip through C, penetrate the lead sheet, and actuate D and E. Both these effects are comprised in the delayed coincidence rate obtained with the Pb in place but C not sensitive, given in the third row. Multiplying this rate by 2.7 percent we obtained 0.010±0.001 per hour as the expected spurious delayed photon rate. For the 477.4 hours of delayed photon recording, the expected number of spurious delayed coincidences is therefore five. Actually, nine counts were obtained; the chance is not too small ($\sim$4 percent) that all nine were of spurious origin. It is seen that the number of delayed photons detected is essentially zero.

We had also to consider the effect of accidental delayed coincidences. As the anticoincidence "gate" extended beyond the end of the last delay channel, the expected accidental rate was $[(AB)-C][(DE)-C]\tau$, where τ is the channel width. Using the rates of the fourth and fifth rows of Table III and the value 7.04 μsec. for the sum of the delay channel widths, we obtained for the expected accidental rate $(1.167\pm0.008)\times10^{-4}$ per hour, or 0.0557±0.0004 in 477.4 hours. This correction could therefore be neglected.

For the delayed electron coincidences, the only correction applied was for accidentals. These occurred when one event triggered A and B but neither D nor E, and a subsequent unrelated event triggered D and E.[6] The expected acci-

TABLE III. Data used for corrections.

	Number of counts		Duration	Rate
1. Prompt $(AB:DE) - C$ (Photon arrangement)		17,762	28,644 min.	0.620 ± 0.005 per min.
2. Prompt $(AB:DE)$ (Pb in, no H.V. on C)		334,669	14,368 min.	23.29 ± 0.04 per min.
3. Delayed $(AB:DE)$ (Pb in, no H.V. on C)	first channel second channel third channel fourth channel sum	50 20 10 7 — 87	239.6 hr.	0.36 ± 0.04 per hr.
4. $(AB) - C$ (Photon arrangement)		43,549	28,644 min.	1.520 ± 0.007 per min.
5. $(DE) - C$ (Photon arrangement with D and E leads con- nected to circuit inputs normally used for A and B.)		28,868	2,646 min.	10.91 ± 0.06 per min.
6. $(AB:D$ or $E)$ (Electron arrangements using $D+E$ instead of (DE))		74,176	2,533 min.	29.28 ± 0.11 per min.
7. (AB) (Electron arrangements using $D+E$ instead of (DE))		50,240	1,172 min.	42.87 ± 0.19 per min.
8. (AB) (Electron arrangements)		781,824	18,375 min.	42.55 ± 0.05 per min.
9. (DE) (Electron arrangements)		2,983,456	16,639 min.	179.3 ± 0.1 per min

dental rate was, therefore, $\{(AB) - (AB:D$ or $E)\}(DE)\tau$, where $(AB:D$ or $E)$ was the prompt coincidence rate between (AB) and D or E, measured by throwing a switch so as to feed the $(AB:DE)$ coincidence circuit with $D+E$ rather than (DE). The expression in curly brackets is the rate at which A and B but neither D nor E were triggered; the data of lines 6 and 7 of Table III give the value 13.59 ± 0.22 per min., or a fraction 0.317 ± 0.004 of the (AB) rate. Applying this factor to the (AB) rate of row 8, multiplying by the (DE) rate of row 9, and finally multiplying by the sum of the delay channel widths (7.04 μsec.), we obtain 0.0170 ± 0.0002 per hour for the accidental delayed coincidence rate. This gives an expectation of 11.4 accidental delayed coincidences in 671.6 hours, or about 3 per delay channel. Row 1 of Table IV gives the (combined) results of the last row of Table II, with 3 counts subtracted in each channel. The corrected decay electron rate is seen to be 0.55 ± 0.03 per hour. For an over-all photon detecting efficiency of 58 percent, there should have been 152 delayed photon coincidences in 477.4 hours. Only an overestimate of the photon detecting efficiency by a factor of the order of 40 could bring our result into agreement with the photon-decay hypothesis. Another way of describing the result is to say that less than 5 percent or so of the mesons decaying in the brass could give rise to a high energy photon.

The second line of Table IV shows the expected distribution of 373 counts, calculated for a meson mean life of 2.2 μsec. The observed distribution (first line) is seen to agree with it within the statistical uncertainty. This agreement is an added indication that the observed delayed electron coincidences are not of spurious origin.

TABLE IV. Delayed electron coincidences.

	Counts in					Duration	Rate
	First delay channel	Second delay channel	Third delay channel	Fourth delay channel	Sum of delay channels	Hours	Counts per hour
Corrected data on delayed coincidences caused by electrons	196	97	55	25	373	671.6	0.55 ± 0.03
Expected decay electron distribution for 2.2 μsec. mean life	211	97	44	21	373		

V. CONCLUSIONS

Our results indicate that the bulk of the sea level cosmic-ray mesons which disintegrate after stopping in brass do not have a photon of energy above about 15 Mev as a disintegration product. This seems to be clear-cut evidence against the hypothesis that the μ-meson splits into an electron and a photon. It is also evidence against the suggestion[12] that the μ-meson disintegrates into an electron and a neutral meson, the latter immediately ($\sim 10^{-15}$ sec.) disintegrating into two photons of about 35 Mev. One can conclude[13] from our result that the neutral meson's mean life against this process would have to be greater than about 10^{-10} sec.; in fact, ascribing to the neutral meson a mass of 70 Mev/c^2 and a kinetic energy of 4 Mev,[14] the lower limit on the lifetime is about 3×10^{-10} sec.

Since very few negative mesons disintegrate in brass,[15] our results refer primarily to positive μ mesons. The independent experiment of Hincks and Pontecorvo,[4] in which graphite was used as the meson stopper, leads to the same negative result, for mesons of both signs.

Piccioni[16] has recently reported an experiment designed to detect photons resulting from meson capture. His experimental arrangement was such as to detect decay photons as well. Here also, a negative result was obtained.

VI. ACKNOWLEDGMENTS

[12] For example, R. E. Marshak, Bull. Am. Phys. Soc. 22, 6, 14 (1947) (Phys. Rev. 73, 1226 (1948)).

[13] The same conclusion has been drawn by E. P. Hincks and B. Pontecorvo, Phys. Rev. 73, 1122 (1948).

[14] C. D. Anderson et al., reference 5.

[15] G. E. Valley, Phys. Rev. 72, 772 (1947).

[16] O. Piccioni, Bull. Am. Phys. Soc. 23, 3, 42 (1948).