Slow Mesons in the Cosmic Radiation

C. G. Montgomery, W. E. Ramsey, D. B. Cowie and D. D. Montgomery
Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania
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The following experiment was performed to measure the disintegration time of cosmic-ray mesons. Mesons falling on a lead plate were detected by a layer of counters above the plate. Some of these mesons presumably stopped within the plate and a short time later emitted a disintegration electron and a neutrino. The electron would, in a certain fraction of the cases, be detected by a second layer of counters placed below the plate. Those events were recorded in which a discharge of one of the upper counters was followed by a discharge in one of the lower counters after a time t_1 and before a time t_2. In the absence of the lead plate, no disintegration electrons were expected. However, a considerable number of counter discharges were recorded which must be interpreted as the result of an intrinsic time delay in the counter between the passage of the ionizing ray, and an appreciable change in potential of the counter wire. The number of disintegration electrons was measured by taking the difference in the counting rates with the lead plate present and absent. For t_1 equal to 1.5 microseconds, and t_2 equal to 20 microseconds, we expected 23 electrons per hour, assuming that the mean life of the mesotron is 2.7 microseconds. A series of observations results in the measured number of 1.4 ± 2.4 per hour, a value much smaller than expected. Possible explanations of this discrepancy are discussed, the most likely one perhaps being that most mesons are absorbed by some nuclear process before they come to rest.

Introduction

It has been observed[1] that the absorption of the cosmic radiation in air depends not only upon the mass of air traversed but also upon the path length of the rays. An explanation of this anomaly was first suggested by Kulenkampff,[2] namely, that the mesons which comprise the hard component of the cosmic radiation are unstable, and decay spontaneously into electrons and neutrinos. The additional absorption resulting from this instability has been calculated by Euler and Heisenberg,[3] and harmony with the observations is realized if the mean life of a meson at rest is 2.7×10^{-6} second. Other observers[1] have determined values from 1.5 to more than 4 microseconds, the value deduced depending upon the assumptions made regarding the height of origin of the mesons and their rest masses.

Notwithstanding the short lifetime, some mesons should come to rest before disintegration, and it should be possible to determine, in a more direct manner, the time until decay. The rest-mass energy of a meson decaying at rest will be divided equally between the electron and the neutrino, and hence the electron will have considerable penetrating power.

Experimental Method

Over a plate of lead two centimeters thick and of 20×30 cm^2 area, was placed a set of twenty-one Geiger-Mueller counters, in parallel, each 1 cm in diameter and 15 cm long, filled with a mixture of 94 percent argon and 6 percent oxygen to a pressure of 9 cm of Hg.[4] The mesons falling upon the lead were detected by discharges of the counters. A certain fraction of these mesons presumably stopped in the lead plate, and a certain time later emitted electrons. Some of the electrons would impinge upon another layer of twenty-one counters below the lead plate. These lower counters were 1 cm in diameter and 20 cm long and filled to a pressure of 18 cm of Hg with the oxygen-argon mixture. The electrical recording circuits were so arranged as to record those cases in which a discharge of a counter in the top tray was followed by a discharge of a counter in the lower tray after a definite time interval t_1 and before a time t_2. Above the whole counter system were placed 12 cm of lead to absorb the soft component rays. The geometrical relations of the counters and the lead are shown to scale in Fig. 1.

[1] E.g., P. Ehrenfest, Jr., and A. Fréon, J. de phys. et rad. **9**, 529 (1938); T. H. Johnson and M. A. Pomerantz, Phys. Rev. **55**, 104 (1939).
[2] H. Kulenkampff, Verh. deut. phys. Ges., Breslau (1938).
[3] H. Euler and W. Heisenberg, Ergeb. exak. Naturwiss. **17**, 1 (1938).
[4] G. L. Locher, Phys. Rev. **55**, 675 (1939).

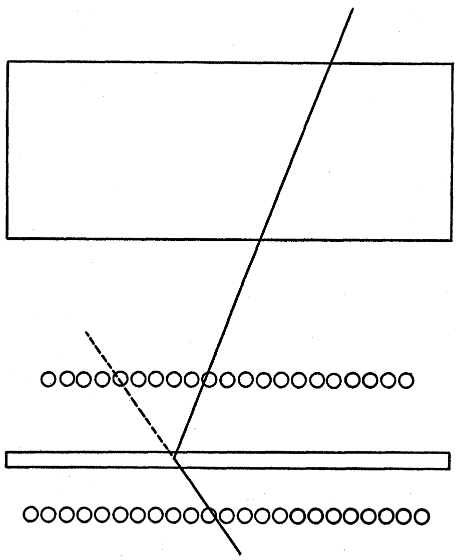

FIG. 1. Schematic diagram of the counter arrangement. A slow meson discharges one of the upper counters, stops in the thin lead plate, and some time later emits a neutrino and an electron which discharges one of the lower counters.

Figure 2 shows the diagram of the circuit for selecting the coincidences. A pulse from a counter in the top tray is delayed by the condenser across the plate resistance of the vacuum tube T_1 and is impressed on the grid of T_3 until the counter recovers. A pulse from a counter in the bottom tray is impressed on the grid of T_3, for only a short time, by the network in the plate circuit of T_2. If the bottom counter pulse occurs in the proper time interval, the resultant pulse on the grid of T_3 from the combination of top and bottom counter discharges is sufficient to overcome the bias to such an extent as to allow the delayed coincidence to be recorded. The time of delay could be adjusted by the bias on T_3 and the size of the condenser in the plate circuit of T_1. The three tubes were of the type RCA 6C6. The plate supply and the screen grid potentials were 45 volts, supplied from dry batteries, and the current for the heaters was supplied by a storage battery. The actual recording circuit is not shown in the diagram, since it consisted only of the conventional amplifier, with provision for lengthening the duration of the pulses, operating a watch recorder.

In order to determine the minimum time t_1, by which a lower counter discharge could follow a discharge of an upper counter and be recorded, it was necessary to employ a calibration circuit which would supply two pulses separated by a known time interval. Fig. 3 shows the schematic diagram of the circuit employed. A mercury switch (*Sw*) charges a condenser through a resistance. The switch makes contact in an extremely short time and the rise of potential of the condenser may be calculated with good accuracy. The potential rise of the condenser is impressed on the grids of two type 6C6 tubes, whose plate supply and screen grid potentials are 45 volts. One of these grids is biased to a large negative voltage and the other to a smaller one. Thus one tube begins to conduct before the other and we have two pulses produced, separated by a known time interval. The pulses are directly applied to the grids of T_1 and T_2 of the coincidence selector circuit, and values of t_1 are obtained as a function of the bias on T_3. A calibration curve obtained in this way is shown in Fig. 4. It may be thought of as representing the shape, but not the magnitude, of the voltage pulse which was impressed upon T_3 when a counter in the upper tray discharged.

An evaluation of t_1 in this manner is accurate only as long as the time taken for the vacuum tubes to be turned on or off is small compared to the times measured. Since the voltage range between a completely conducting and a completely nonconducting state of the tubes used under the conditions which obtained here is only about three volts, it is easy to see that the pulses from the calibrating circuit are sufficiently fast. The largest error in the lag determination is the error in the knowledge of the distributed capacity of the circuits, and this may be generously estimated at not more than 5 percent. The counter

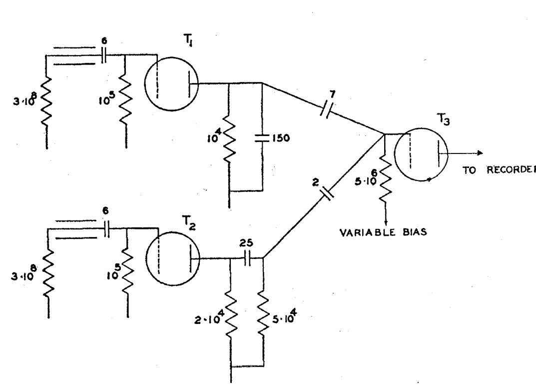

FIG. 2. Circuit for selecting the delayed coincidences.

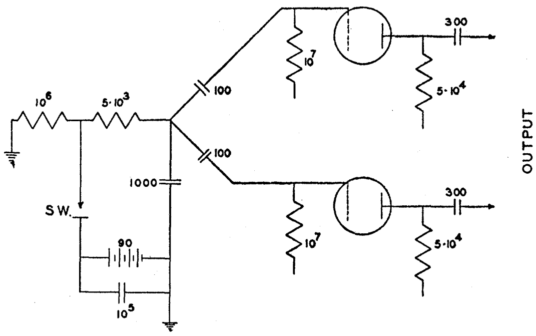

FIG. 3. Calibrating circuit for measuring the sensitive times of the coincidence selector circuit.

discharges must also be sufficiently fast for the calibration to be accurate. That this was the case was determined by two methods. First, if the size of a counter pulse be increased, and the speed remains the same, the time necessary for the counter wire to change in potential by a given amount will be proportionally lowered. By raising the high potential on the counters, the size of the pulse was increased by about 50 percent, but the number of counts recorded remained unchanged. This indicates that the counter breakdown time was small compared to the time of action of the circuit, and no correction need be applied. The second determination was made by one of us (W. E. Ramsey) by directly measuring the breakdown characteristics of the counters employed.[5] It was found that the time necessary for the tubes to be cut off was less than 2×10^{-7} sec., and therefore small enough to be neglected.

It is also necessary to determine the maximum time, t_2, for which a pulse from a lower counter could be delayed after an upper counter discharge, and still be recorded. Although this could have been determined in a manner similar to the determination of t_1, it was found more convenient to calculate t_2 from the number of accidental coincidences observed. The counter trays were placed side by side and the number of coincidences determined as a function of the individual counting rates of the trays. If this accidental rate is denoted by A, and the counting rates of the two trays by n_1 and n_2, then t_2 is given by A/n_1n_2. The small correction for showers and horizontal rays was shown to be negligible. The requisite accuracy in t_2 is small, since t_2 is much longer than the mean life of a meson.

Observations to detect delayed coincidences were made with the 2-cm plate of lead alternately present and absent. At the beginning and end of such a series, the calibration curve was determined to ensure that the circuit was operating properly and that the time lag did not change during the run. Actually a change of 5 to 10 percent took place during a twelve-hour observation period, because of the alterations of battery potentials. It was determined that this change varied linearly with time and the arithmetic mean value of the initial and final time lags was taken to apply to the whole run.

RESULTS

When observations were made with no lead present between the counters, it was found that, contrary to expectation, a considerable number of discharges were recorded, even for time lags up to five microseconds. By changing the number of counters and the relative position of the two trays, it was found that the counting rate with a lag in the circuit was proportional to the number of truly coincident discharges. It seems possible to explain the observations in only one way, namely: some of the counter discharges do not take place immediately after the passage of an ionizing ray through the counter, but the dis-

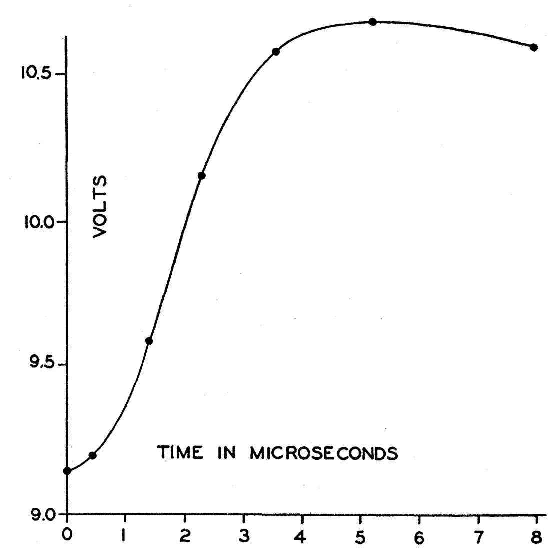

FIG. 4. Calibration curve of the selector circuit.

[5] A description of the method of measurement and the characteristics of several counters is in preparation for publication.

charge is delayed.[6] The circuit used measures the number of discharges in which the difference in time lag between the bottom counter and the top counter is more than the time, t_1, if t_2 is made long compared to t_1. Since, however, the percentage of the total number of rays which produce lagged discharges is small, the difference "bottom lag" minus "top lag" is equal to the bottom lag alone. Fig. 5 shows the observations which have been made. The results for the counters filled with 9 cm of gas were obtained by interchanging the upper and lower trays. The existence of this time lag sets a lower limit to the resolving power which is practical to use for coincidence work. For example, in a twofold coincidence unit employing counters such as the 9-cm ones used here, more than 10 percent of the coincidences would be lost, if the resolving time were made as small as two microseconds. Fortunately, this is small enough not to be serious in any experiments performed up to the present. This limit to practical resolving power is, of course, independent of the limit imposed by the finite breakdown time of some counters. A tentative explanation of this time lag may be the following: In a certain fraction of the cases,

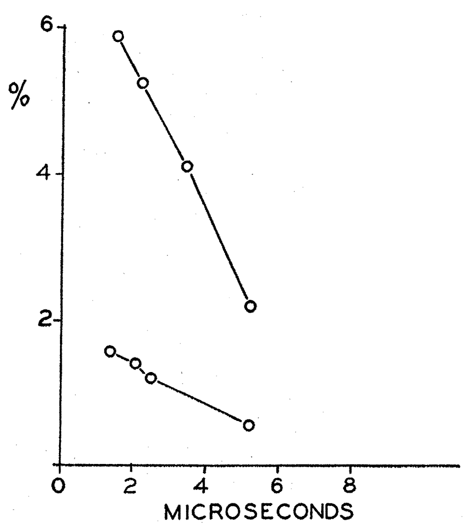

FIG. 5. The percentage of discharges of the counters (ordinate) which are delayed more than a certain time (abscissa) after the passage of the ray through the counter. Upper curve, 9 cm Hg pressure; lower curve, 18 cm Hg pressure.

[6] P. Auger, in a personal communication, informs us that similar time lags have been found in his laboratory.

a cosmic ray traversing the counter will produce only one ion pair. If the electron collides with an oxygen molecule or other electro-negative impurity before it has time to initiate the discharge, there is a high probability that it will be captured and not released again until a short time later. Further experiments with different types of counters are at present under way.

The existence of intrinsic time lags in counters complicates the observation of the decay of mesons, but does not destroy the possibility. We must measure the difference in counting rates with the 2-cm lead plate present and absent. This difference represents the number of decay electrons from the lead. The observed difference must be corrected by a small amount (8 percent) because the absorption in the lead reduces the number of lagged counts. Observations were taken with several values of the times t_1 and t_2, but the most complete results were obtained for $t_1=1.5$ microseconds and $t_2=20$ microseconds. The number of mesons passing through the two sets of counters was about 7800 per hour. Since the absorption coefficient is about 0.01 cm^{-1} of lead, we should expect 156 per hour to be stopped in the 2-cm plate. The solid angle of the lower tray was such that only $\frac{1}{4}$, or 39 per hour, of the electrons from the decay of the mesons would be detected. If we assume a mean life of 2.7 microseconds, all but 23 per hour should have decayed before 1.5 microseconds, and practically all of them before 20 microseconds. This expected number is admittedly a rough estimate, but our lack of knowledge of the correct decay time makes it hardly worth while to make a more accurate calculation. When the lead plate was present, a series of runs which agreed well with one another gave 129 counts per hour. With the lead absent 140 counts per hour were observed. With the corrections applied, we observed 1.4 ± 2.4 decay electrons per hour, or no measurable effect, instead of the expected 23 per hour. The probable error is thus only about one-tenth of the expected value. The observations at other time lags also showed no effect.

DISCUSSION

The failure to observe the decay of mesons in the expected numbers may be explained in three ways. First, mesons may be stable and not decay at all. If this be the case, some other explanation must be offered for the anomalous absorption of cosmic radiation in air. Second, the absorption experiments do not determine the mean life directly, but only the ratio of the mean life to the rest mass of the meson. Now if the mass of the cosmic-ray mesons is smaller than the mass of the mesons that have been observed in cloud chambers at the ends of their ranges, we could explain the absorption experiments by a lifetime which would be too small to have been observed in these experiments, but long enough to explain the absorption anomaly. If we could not have detected an effect twice as large as our probable error, then the lifetime could be as long as 0.7 microsecond. With this value, the cosmic-ray absorption experiments would then necessitate an upper limit to the meson mass of about 50 electron masses. This mass seems decidedly too small to give the correct range of nuclear forces, but it is possible that the mesons responsible for nuclear forces and cosmic-ray mesons are not identical. The recent work of Maier-Leibnitz[7] may be regarded as supporting this hypothesis in some degree, since she finds that the mesons that end their ranges in the cloud chamber occur too frequently to come from the stopping of cosmic rays, but seem to be produced as secondaries, presumably from nuclei. The mass determinations which result in values around 200 electron masses are presumably made with these nuclear mesons, and not with cosmic-ray mesons.

The third, and seemingly most likely, explanation is that mesons of low energy are strongly absorbed by atomic nuclei and do not come to rest. The rest-mass energy of the meson would be converted to some other form, possibly going into a shower. We can estimate the order of magnitude of the cross section for this absorption. The momentum distributions of cosmic-ray mesons observed in cloud chambers seem to indicate no large absorption except for small momenta, where there is a maximum in the distribution curve. The maximum varies from $pc=2\times 10^8$ electron volts[8] where p is the momentum, up to almost 8×10^8 ev.[9] The maximum seems to be an instrumental one caused by the deflection of low energy rays away from the counters which control the expansion. However, an excess absorption of mesons would not be detected in this energy region, and we may assume that the mean range for absorption is less than the ranges of particles of this momentum. If we take 10^8 ev as the meson rest mass, the ranges of mesons of $pc=2$ or 8 times 10^8 ev are 5.7 and 52 cm of lead, respectively. If this is, say, twice the mean range of the particles for absorption, we would calculate a cross section of 5×10^{-26} cm^2 or 5×10^{-27} cm^2 per nuclear particle. Heitler[10] has estimated the cross section for meson absorption resulting in the emission of a gamma-ray and obtained 9×10^{-28} cm^2. Although this value seems definitely too low, the uncertainty of the present state of the theory may not allow the difference to be regarded as significant.

[7] H. Maier-Leibnitz, Zeits. f. Physik **112**, 569 (1939).

[8] P. M. S. Blackett, Proc. Roy. Soc. **A159**, 1 (1937).

[9] J. C. Street, J. Frank. Inst. **227**, 765 (1939).

[10] W. Heitler, Proc. Roy. Soc. **A166**, 529 (1938).