Evidence for the Radioactivity of Slow Mesotrons

FRANCO RASETTI
Department of Physics, Laval University, Quebec, Canada

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A beam of mesotrons is selected by means of a fourfold coincidence system of counters, and is allowed to pass through a block of iron 10 cm thick. The absorption of mesotrons by the iron is recorded by means of a battery of anticoincidence counters. It is found that a certain fraction of the stopped mesotrons is associated with the emission of an ionizing particle from the absorber. A special coincidence recording system, whose resolving time is of the order of one microsecond, enables one to establish that the emission of the particles is delayed with respect to the passage of the mesotron by a few microseconds. The delayed particles are interpreted as the electrons resulting from the β-decay of the mesotron. The present experiment establishes only the order of magnitude of the mean life of the mesotron at rest, but more quantitative measurements are in progress.

RECENT experiments on the absorption of mesotrons[1] by the earth's atmosphere and by condensed materials have brought convincing evidence for the hypothesis of the decay of the mesotron.

Much less satisfactory is the present situation concerning the detection of the disintegration electrons. Williams and Roberts[2] obtained two cloud-chamber photographs which seem to demonstrate the process of β-decay of a mesotron; on the other hand, other assumed mesotron tracks have been seen to end in the chamber without producing any ionizing particle. The evidence from the equilibrium between the electron and mesotron components in the atmosphere is, at best, inconclusive.[3]

The detection of delayed coincidences from the disintegration electrons produced by stopping mesotrons in a block of lead was attempted by Montgomery, Ramsey, Cowie and Montgomery, with a negative result.[4]

I wish to report some results which seem to bring positive evidence for the delayed emission of the disintegration electrons and to afford a rough measurement of the mean life of the mesotron at rest.

The counter set-up is illustrated in Fig. 1 (circles represent the effective cross sections of the counters; counters designated by the same letter are connected in parallel; cross-marked counters are used as anticounters).

Counters A, B, C and D define a beam of mesotrons, which impinges upon the battery of anticounters F. The number of anticoincidences ($ABCD-F$) is about 1.5 percent of the number of coincidences ($ABCD$), when no absorber is present between D and F. A block of iron $10\times2.5\times40$ cm^3, placed as indicated by Fig. 1, brings the number of anticoincidences to about 5 percent, in agreement with the known absorption coefficient of mesotrons at sea level.

A certain fraction of the anticoincidences ($ABCD-F$) is associated with a discharge of one of the counters E. This may be due partly to mesotrons scattered by the iron, partly to disintegration electrons from mesotrons stopped by the absorber. Convincing evidence in favor of the latter process will be obtained if it can be proved that the passage of a particle through E is delayed with respect to the discharge of counters ($ABCD$).

For this purpose, the counters were connected to a system of amplifier units, indicated in Fig. 1 as $AU1$, $AU2$, $AU3$ and h.r.p. (for high resolving power) unit $A4$. Unit 1 is a fivefold coincidence set (resolving time 3.6×10^{-5} sec.) connected to counters ($ABCDE$). The output pulse is passed onto unit 2, and operates recorder $R2$ only if it is associated with an anticoincidence from counters F and G. The output pulse from unit 2 is passed onto unit 3, which is a double coincidence set, and operates recorder $R3$ only

[1] See B. Rossi and D. B. Hall, Phys. Rev. **59**, 223 (1941), also for earlier literature.
[2] E. J. Williams and G. E. Roberts, Nature **145**, 102 (1940).
[3] G. Bernardini, B. N. Cacciapuoti, B. Ferretti, O. Piccioni and G. C. Wick, Phys. Rev. **58**, 1017 (1940).
[4] C. G. Montgomery, W. E. Ramsey, D. H. Cowie and D. D. Montgomery, Phys. Rev. **56**, 635 (1939).

when a simultaneous (within 10^{-4} sec.) pulse is fed to it from the h.r.p. unit 4. The latter is a double coincidence set, connected to counters (DE), and has a resolving time of 1.2×10^{-6} sec.

If the discharge in the E counters is not delayed, recorder $R3$ will record the *same* number of pulses as $R2$, since *every* process ($ABCDE-FG$) is also a double coincidence (DE). But, if the discharge in E is delayed by more than 1.2×10^{-6} sec. and less than 3.6×10^{-5} sec. with respect to the fourfold coincidence ($ABCD$), then it will be recorded by $R2$ and not by $R3$. Thus, the difference in the number of counts $R2-R3$ will give the number of particles emitted from the absorber within the above time limits after the stopping of a mesotron.

Two obvious causes of error must be avoided. First, one must be certain that practically all true systematic coincidences (DE) are recorded by the h.r.p. set. More than twenty separate checks, distributed through the series of experiments, showed that the efficiency of the h.r.p. set for true coincidences was always better than 99.5 percent.

Another source of error might reside in the random coincidences between systematic fourfold coincidences ($ABCD$) and pulses in E, which fall within 3.6×10^{-5} sec. but not within 1.2×10^{-6} sec. Their number ought to be only about one in fifteen days. However, it was considered safer to take readings alternately with and without absorber. In this way, all random coincidences and other possible spurious effects would show in the blank runs.

An easily measurable number of delayed pulses in E was observed with the iron absorber in place, as contrasted with an almost negligible number in the blank runs. Table I summarizes the results.

Since the number of mesotrons absorbed by the iron per hour is approximately known, the observed number of delayed coincidences is found to correspond to about seven percent of the number of absorbed mesotrons. Considering geometrical factors, absorption of the electrons by the iron, and the fact that probably about 40 percent of the mesotrons decay within 1.2 microseconds, the observed percentage of electrons does not appear to be inconsistent with the assumption of one emitted electron per mesotron.

The results would afford a measurement of the mean life τ if one knew that *all* additional coincidences produced by the absorber, falling within 1.2 microseconds, are due to disintegration electrons. Actually, some of them will be due to scattered mesotrons, and the value of τ will represent a lower limit. From the data of Table I, one finds:

$$\exp(-1.2\times10^{-6}/\tau)>42/111;\quad \tau>1.2\times10^{-6}\text{ sec.}$$

Iron was used instead of lead because of the more favorable stopping/scattering ratio. Some measurements were also taken with an Al absorber and gave similar results. Besides the strong scattering of slow mesotrons, the absorp-

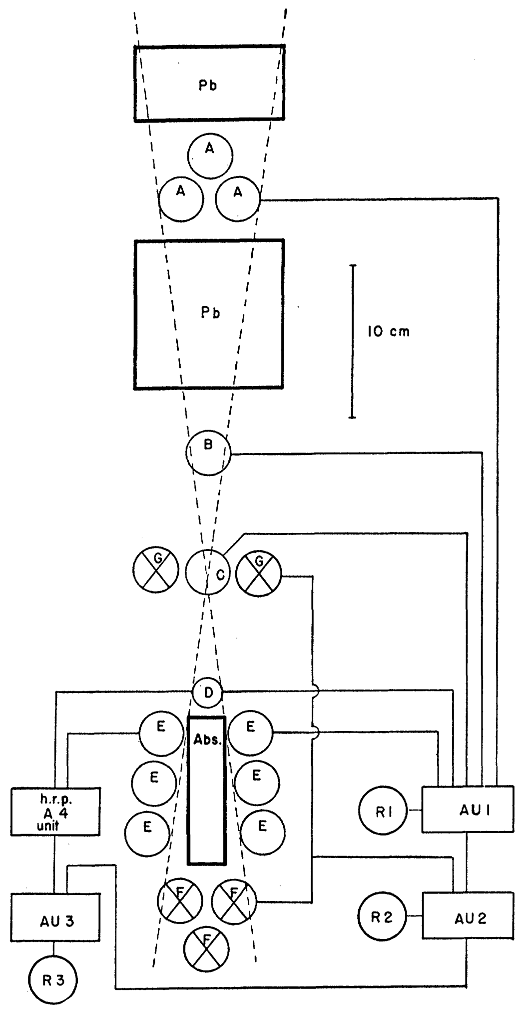

FIG. 1. Arrangement of counters and amplifier units.

TABLE I. *Experimental results.*

Absorber	Number of Hours	Pulses $R2$	Pulses $R3$	$R2-R3$
None	231.6	96	93	3 ± 2
10 cm Fe	231.6	207	162	45 ± 7

tion of disintegration electrons due to radiative losses is another reason against the use of a heavy element, and may possibly explain the failure of Montgomery *et al.* to observe the disintegration electrons.

The experiments are being continued with an improved arrangement that is expected to give a reliable value of the mean life.[5]

[5] *Note added in proof.*—Preliminary results with the new arrangement have been announced in a letter to *The Physical Review* (Phys. Rev. **59**, 613 (1941)). Experiments in progress, however, seem to indicate a mean life shorter than already reported, of the order of 2 microseconds or possibly less.

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The Total Mass of a Particle in General Relativity

C. LANCZOS
Department of Mathematics, Purdue University, Lafayette, Indiana

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Without specifying otherwise the stress-energy distribution inside of a material particle, the assumption is made that the scalar quantity T, known in electromagnetism as the "scalar of Laue," shall vanish, in harmony with the Maxwellian stress tensor, and confirmed also by other considerations. It is shown that under this condition a theoretical explanation can be given of the long established empirical fact that the mass of any particle is necessarily positive. All metrical contributions to the total mass come out as necessarily positive, second-order quantities, with the only exception of an eventual spin, which has a decreasing instead of increasing effect on the mass. The strict proportionality of gravitational and inertial mass can still be established, at least for the spherically symmetric case. The factor of proportionality, however, is numerically different from the value ordinarily assumed.

1. Introduction

ONE of the peculiar mysteries of nature is the fact that all masses are positive. Electric charges can take positive and negative values. The masses of elementary particles show a great diversity in values, but the sign is always positive. The Newtonian force of universal gravity is always a force of attraction and not a force of repulsion. Why is it that we do not encounter negative masses in nature? The present paper attempts to give the theoretical explanation of that long established empirical fact, on the basis of general relativity.

2. Basic Assumptions

In the Newtonian theory of gravity the mass m of a particle appears as a constant of integration. The potential equation is

$$\Delta\phi=0. \tag{2.1}$$

The spherically symmetric solution of that equation is

$$\phi=m/r. \tag{2.2}$$

The constant m is in physical interpretation the mass of the attracting particle.

In general relativity the potential function ϕ is replaced by the much more comprehensive scheme of ten g_{ik} quantities, defined by the line element

$$ds^2=g_{ik}dx_idx_k. \tag{2.3}$$

The field equation (2.1) is replaced by the Einsteinian field equations:

$$R_{ik}=0, \tag{2.4}$$

where R_{ik} is the contracted Riemann-Christoffel tensor. The spherically symmetric solution of the field equations (2.4) is the line element of