Search for Electromagnetic Interactions Between μ Mesons and Electrons*

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An attempt was made to observe the reaction $\gamma \rightarrow \mu^{\pm}+e^{\mp}$ up to 23 Mev above threshold. It was found that the cross section for this reaction is less than 10^{-31} cm^2 per proton. We have also looked for the decay $\mu^{\pm}\rightarrow e^{\pm}+\gamma$, and we find that its lifetime is longer than 10^{-3} second.

A SEARCH for electromagnetic transitions between electrons and μ mesons was undertaken at the Massachusetts Institute of Technology synchrotron by attempting to observe the reactions (A) $\gamma \rightarrow \mu^{\pm}+e^{\mp}$ and (B) $\mu^{\pm}\rightarrow e^{\pm}+\gamma$.

(A) The reaction $\gamma \rightarrow \mu^{\pm}+e^{\mp}$ might have been observed in previous attempts to detect the direct production of μ mesons. The cross section for the direct production of μ mesons was found by Peterson *et al.*[1] to be less than 2 percent of the cross section for π-meson production. We have undertaken to set a new upper limit for the direct production of μ mesons by photons with energies below the π-meson production threshold. The maximum bremsstrahlung energy was kept 23 Mev above the threshold for $\gamma \rightarrow \mu^{\pm}+e^{\mp}$ (i.e., at 136 Mev).

In these measurements, the apparatus of Osborne and Winston[2] was used (see electron detector of Fig. 1). This apparatus detects μ mesons by observing the delayed emission of their decay electrons after a short (approximately 2 μsec) synchrotron pulse. A sufficiently large polyethylene target was employed so that most of the mesons with energies less than 23 Mev would have stopped and decayed in the target.

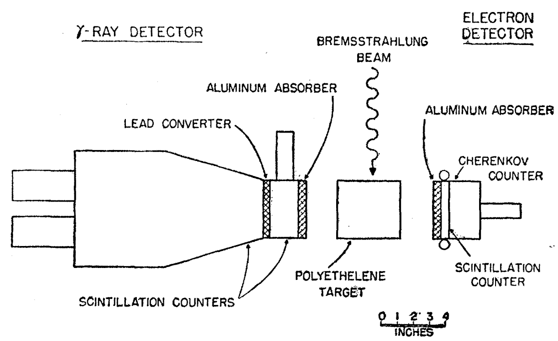
In a 24-hour run below π-meson threshold 2 events were recorded. The computed number of accidental counts for this run was 0.2 count. With this low a counting rate, we cannot rule out the possibility that these two events arose from electronic failures or fluctuations (e.g., fluctuations that permitted the energy of the synchrotron to rise with the accompanying production of π^+ mesons).

π^+ mesons were used to calibrate the apparatus and geometry by raising the maximum energy of the bremsstrahlung beam to 23 Mev above the π-meson threshold. From the number of π^+ mesons observed, it is calculated that the direct production of μ mesons is less than 3×10^{-3} of the cross section for π^+ meson production. From the cross section for π^+ production determined by Janes and Kraushaar,[3] the mean cross section for direct μ-meson production is less than 1×10^{-31} cm^2 in the range from 0 to 23 Mev above threshold. This upper limit is about 1/7 of that previously given by Peterson *et al.*[1]

(B) In regard to the transition $\mu^{\pm}\rightarrow e^{\pm}+\gamma$, previous published experiments have shown that the probability for this transition to occur is less than 5 percent of the probability for all other modes of decay of μ mesons.[4]

A search for the decay $\mu^{+}\rightarrow e^{+}+\gamma$ was made, using the $\pi^{+}\rightarrow \mu^{+}+\nu$ as a source of μ mesons. The apparatus employed is shown in Fig. 1. The γ ray and electron detectors are on opposite sides of the target in which most of the μ mesons decay. The γ-ray detector was biased to exclude γ rays with energies below 25 Mev. The efficiency of the γ-ray detector was checked with 70-Mev γ rays from π^0 mesons and was found to be 36 percent. The electron detector was estimated to be capable of counting 53 percent of the $\mu^{+}\rightarrow e^{+}+2\nu$ electron spectrum.[5] The solid angle was effectively determined by the electron detector.

Two events were recorded in the $\gamma+e$ coincidence circuits in a long run in which 10 000 electron events were observed ($\mu^{+}\rightarrow e^{+}+2\nu$ decay). As we cannot be certain that these two events were real, we can only set an upper limit on the process $\mu^{+}\rightarrow e^{+}+\gamma$. From the



GAMMA-RAY AND DELAYED ELECTRON COINCIDENCE COUNTER

FIG. 1. Top view of apparatus used in search for electromagnetic transitions. The electron detector consists of a scintillation counter in front of a Čerenkov counter. The γ-ray detector consists of a thin anticoincidence scintillation counter, a $\frac{1}{4}$-in. lead converter, and a large scintillation counter. The electron detector was used alone in the search for direct production of μ mesons. The electron and γ-ray detectors were used in coincidence for the process $\mu^{+}\rightarrow e^{+}+\gamma$.

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above data we estimate that $\mu^+ \rightarrow e^+ + \gamma$ occurs less than 6×10^{-4} as frequently as the process $\mu^+ \rightarrow e^+ + 2\nu$. This means that the decay $\mu^+ \rightarrow e^+ + \gamma$ has a lifetime longer than 10^{-3} second. This value of the lifetime is about 100 times longer than the lower limits previously given in the literature.[4,6]

It might be mentioned that if the same strength of interaction were responsible for both reactions (A) and (B) that the result obtained on reaction (B) is more significant than the result on reaction (A) by many orders of magnitude in setting a limit on the strength of the interaction.

[6] Since these measurements were performed, we have been informed by J. Steinberger that he and S. Lokanathan have found that the lifetime for the decay $\mu \rightarrow e + \gamma$ is appreciably longer than the value we obtained. S. Lokanathan and J. Steinberger, Abstract for the Chicago, Illinois meeting of the American Physical Society, November, 1954 [Bull. Am. Phys. Soc. 29, No. 7, 25 (1954)].

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Biquadratic Spinor Identities

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The representation-independent biquadratic identities which Pauli has proved to hold between a Dirac wave function and its adjoint are shown to be generalizable in several ways. To obtain these generalizations it is first shown how the symmetrical Kronecker product of two spinor representations of the orthogonal group in n dimensions decomposes. Then a method is given to express the tensors formed in a particular way from two covariant and two contravariant spinors in terms of those formed in any other way. These results are applied to write explicitly all biquadratic scalar and pseudoscalar identities in 2ν dimensions and all scalar identities in $2\nu+1$ dimensions. The way to obtain more general tensor identities is indicated.

BIQUADRATIC SPINOR IDENTITIES

SOON after the discovery of the Dirac equation it was noted by Fock and Darwin[1] that there are some quadratic identities which hold between the scalars obtained from the five covariants which can be formed with a Dirac wave function and its adjoint. The proof consisted of writing down these scalars with a particular choice of the matrices and comparing terms. Additional identities involving the pseudoscalars, vectors, and pseudovectors which can be formed from the square of a wave function and the square of its adjoint were given by Uhlenbeck and Laporte.[2] Again a special representation was used.

In 1936 Pauli[3] gave a representation-independent proof of the scalar and pseudoscalar identities. A proof from a different point of view was given by Harish-Chandra,[4] who also proved some of the other identities given in reference 2. In addition Harish-Chandra obtained some relations which hold between tensors formed with two arbitrary wave functions and their adjoints. To a certain extent these relations are similar to results of Fierz.[5] Fierz was interested in expressing the scalars occurring in beta decay interaction terms formed from one arrangement of wave functions in terms of those with another arrangement.

In the following a systematic method is described which gives directly all identities of the desired type. It is hoped that the general mathematical structure of these relations will become particularly clear. The origin of the identities can be stated, group theoretically, quite succinctly. Certain of the irreducible representations of the orthogonal group which occur in the direct product of the spinor representation with itself do not occur in the symmetrized product.

The theory of spinors in n dimensions has been shown by Brauer and Weyl[6] to be extremely similar to the Dirac (four-dimensional) case. Since the essence of the argument to be used is independent of the number of dimensions and since it is desired to shed light on the mathematical basis, we show how to obtain directly all the biquadratic identities existing between n-dimensional spinors. As an essential step, the decomposition of the symmetrical Kronecker square of the spin representation of the orthogonal group is obtained.

Briefly, the method is the following. First we show that certain of the covariants formed with two covariant (or with two contravariant) spinors vanish when the spinors are identical. Second, the work of Fierz is generalized. The biquadratic covariants, formed with two covariant and two contravariant spinors by combining the first and second sets separately into tensors and then combining the two sets of resulting tensors, are expressed in terms of the covariants obtained by first combining a covariant with a contravariant spinor in the more usual manner. Using these two groups of results the desired identities are obtained. It will be

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