TABLE I. Analysis of the star shown in Fig. 1.[a]

Track	Range (microns)	Ionization (I/I_0)	$p\beta$ (Mev/c)	Identity	E (Mev)
a	23 960 observed	0.90±0.06	430±70	π(?)	332.0
b	19 500 observed	1.29±0.09	98± 9	π	57.5
c	4250 total			p	32.3
d	1100 total			p(?)	15.0
e	340 total			p(?)	7.6
f	202 total			p(?)	5.5
g	4050 total			p(?)	31.4
h	206 total			p(?)	5.5
i	100 total			p(?)	3.6

[a] The particle identity for tracks b and c is certain. That for track a is only slightly uncertain; a very improbable alternative is that it is due to an electron. The others can be protons or alpha particles.

protons, in the scanned part of our stacks. Up to now only one has been found. We think, however, that we should not draw any conclusion about the attenuation cross section from these numbers, since our efficiency of observation is different for different scanning methods and is not easy to estimate.

Intensive scanning in Rome and in Berkeley has produced one star, found in Rome, and shown in Fig. 1. It has outgoing tracks as indicated in Table I. The most reasonable assumption is that track a is a pion. If the black prongs are due to protons, the visible energy release may be computed as follows: kinetic energy of the two pions, 389 Mev; rest energy of the two pions, 280 Mev; kinetic energy of the black tracks, 101 Mev; and binding energy for the black tracks, 56 Mev. The total visible energy is 826 Mev.

The momentum unbalance is 520 Mev/c, and in the most conservative (and very unlikely) assumption that four neutrons escaped, all with the same energy and in the same direction, the minimum invisible energy release would be 65 Mev. A more realistic estimate of the energy represented by neutrons would be 160 Mev. It is possible that a very considerable energy went into neutral pions. Other assumptions on the identity of the heavy tracks give higher total energy releases.

We must conclude that the visible energy release is consistent with that to be expected from the annihilation of an antiproton-proton pair; it would be harder to explain as due to a reaction in which all the energy is supplied by only one particle of protonic mass.

From the magnetic analysis we can say that the particle that generated this star entered the copper absorber preceding the emulsions with a momentum of 1090±20 Mev/c. The observed range is 132 g cm^{-2} of copper plus 9.31 cm of emulsion. From these data we can calculate the ratio M/M_p of the mass of this particle to the proton mass, and we obtain 1.02±0.04, in which the main uncertainty is due to the uncertainty in momentum. We have not considered here the remote possibility of inelastic scattering in the copper absorber, which would lead to a lower mass value. Somewhat less precise values of the mass are obtained from measurements made exclusively in the emulsion. All these mass measurements are reported in Table II.

TABLE II. Mass measurements.

Method	Range interval from the end (mm)	M/m_e	M/M_p
Ionization-scattering	82.0−66.0	1840±250	1.00±0.14
Ionization (mean gap length)-range	74.6−19.0	1810±100	0.99±0.06
Same as above	5−0	1740±130	0.95±0.07
Scattering-range	10−0	1635±280	0.89±0.15
Residual range-momentum (from orbit)	93.14 plus 132 g cm^{-2} copper	1865± 70	1.02±0.04
Weighted average		1824± 51	0.99±0.03

This event is corroborating evidence, but not final proof, for the interpretation given in reference 1 that the new particles observed at the Bevatron are antiprotons. It also gives support to the hypothesis that the star described in reference 5 was indeed due to an antiproton.

A more detailed description of these results is being submitted for publication in *Nuovo Cimento.*

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

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Radiative and Nonradiative Boson Decay into Leptons*

SIDNEY A. BLUDMAN AND MALVIN A. RUDERMAN
Radiation Laboratory and Physics Department, University of California, Berkeley, California
(Received November 28, 1955)

THE decay $K_{\mu 2}\rightarrow\mu+\nu$, which is the most common K-meson decay, is strikingly similar to $\pi\rightarrow\mu+\nu$. A simple phase-space estimate gives a $K-\mu$ lifetime less than one-tenth the $\pi-\mu$ lifetime, while the observed lifetimes are more nearly equal. In this note, we wish to point out that the long $K_{\mu 2}$ lifetime and the absence of K_{e2} are both understandable in terms of the same interaction (axial vector) as has been invoked[1] to explain the absence of $\pi-e$ decay. Since this interaction is one that suppresses the emission of *fast* electrons, it had been expected[2] that radiative decays like $\pi\rightarrow e+\nu+\gamma$ might be relatively important. That this is not so, however, can be shown in a simple way by a generalized equivalence theorem.

Since γ_5 merely inverts neutrino spins, and in the final state neutrino spins are summed over, the decay of a scalar meson by scalar (vector) coupling is identical with the decay of a pseudoscalar meson by pseudoscalar (pseudovector) coupling. The essential feature of derivative coupling is that the matrix element squared is proportional to $1-(v/c)=[m/(M+m)]^2$, where v and m are the electron or muon velocity and mass, and M is the pion or K-meson mass. The transition rate is

$$\tau^{-1}=[g^2(M^2-m^2)^2/2M^3](m/M)^2, \tag{1}$$

where g is the effective boson-lepton coupling constant. The pseudovector interaction for the pion decay was motivated by the small ratio 1.3×10^{-4} that this equation gives for the probability of the pion decaying into $e+\nu$ rather than into $\mu+\nu$.

From Eq. (1), the ratio of $K-e$ to $K-\mu$ decay is

$$\tau_{Ke2}^{-1}/\tau_{K\mu2}^{-1}=2.5\times10^{-5}. \tag{2}$$

When the coupling constant in Eq. (1) is adjusted to the observed lifetime,

$$\tau_{K\mu}=0.70\tau_{\pi\mu}=1.8\times10^{-8}\text{ sec.} \tag{3}$$

No K_{e2} has in fact been reported, and the lifetime in Eq. (3) is in good agreement with the observed value.[3]

The derivative coupling supresses the transition rate so long as $1-(v/c)=1+(\mathbf{p}_\nu/E_\nu)\cdot(\mathbf{p}_e/E_e)\approx0$, a relation which is altered by photon emission. If radiative transitions were to be somewhat enhanced relative to nonradiative decays, K_{e3} and $K_{\mu3}$, which appear to be a few percent of $K_{\mu2}$, might be interpretable (at least in part) as radiative decays. That this is not the case, but rather that the radiative decay is of order $\alpha/\pi=0.2\%$ of the nonradiative decay, follows immediately from an equivalence theorem relating (pseudo)scalar and (pseudo)vector interactions. From $(p_e-eA)\psi_e=m_e\psi_e$ and $p_\nu\psi_\nu=m_\nu\psi_\nu$, it follows, for every order in e, that

$$\begin{aligned}g\langle\psi_{e,\mu}|(i\partial-eA)\phi|\psi_\nu\rangle&=g\langle\psi_{e,\mu}|(p_e-p_\nu-eA)\phi|\psi_\nu\rangle\\&=(m_{e,\mu}\mp m_\nu)g\langle\psi_{e,\mu}|\phi|\psi_\nu\rangle.\end{aligned} \tag{4}$$

The minus sign holds when ϕ is a scalar meson wave function and the plus sign when ϕ is γ_5 times a pseudoscalar wave function. For $e=0$, the matrix element of Eq. (4) is that for the nonradiative decay; if terms are kept linear in e, the matrix elements of Eq. (4) are those of the radiative decay. For both the radiative and the nonradiative decay, with derivative coupling, the matrix element for electron emission is m_e/m_μ times the matrix element for muon emission. The ratio of radiative and nonradiative decay rates of spin-zero mesons is the *same* with derivative and with direct coupling.[4]

In all four cases [$S(S)$,[5] $P(P)$, $S(V)$, $P(A)$], the probability of radiative decay with the emission of muons or electrons of momentum p in the energy interval dE is

$$\begin{aligned}P(E)dE=\frac{\alpha}{\pi}\left(\frac{M^2}{M^2-m^2}\right)\Bigg\{&\frac{4}{M^2+m^2-2ME}\\&\times\left[E\ln\left(\frac{E+p}{E-p}\right)-2p\right]+\frac{M^2+m^2-2ME}{M(M^2-m^2)}\\&\times\ln\left(\frac{M(E+p)-m^2}{M(E-p)-m^2}\right)\Bigg\}dE.\end{aligned}$$

It is interesting to observe that for all four couplings the spectrum obtained is essentially that expected from classical radiation damping.

We would like to thank S. Gasiorowicz, C. J. Goebel, and W. K. B. Watson for helpful discussion.

* This work was supported in part by the U. S. Atomic Energy Commission.

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3 We are grateful to S. Yamaguchi for pointing out that a similar calculation has been done by Ogawa, Okonagi, and Oneda, Progr. Theoret. Phys. **11**, 330 (1954). They calculate, however, a $K_{\mu2}$ lifetime shorter by an order of magnitude.

4 In reference 2, the emission of photons by virtual nucleon pairs was unjustifiably discounted. Their inclusion gives agreement with the above result. Simultaneously with the preparation of this letter, one of us received a preprint from S. B. Treiman and H. W. Wyld [Phys. Rev. (to be published)] who, as part of a more extensive calculation, find this same result for the unimportance of radiative decay with pseudovector coupling. We are grateful to Dr. Treiman and Dr. Wyld for informing us of their results.

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Multiple Pion Production in *n*-*p* Collisions at the Bevatron*

William B. Fowler, George Maenchen, Wilson M. Powell, George Saphir,† and Robert W. Wright

Radiation Laboratory and Department of Physics, University of California, Berkeley, California

(Received November 18, 1955)

MORE than 500 events showing pion production in n-p collisions have been obtained by exposing a hydrogen-filled diffusion cloud chamber[1] to high-energy neutrons from the Bevatron. The neutrons were produced by bombarding an internal Cu target with 6.2-Bev circulating protons. The cloud chamber was placed 75 feet from the target along a line tangent to the proton beam, and was in a pulsed magnetic field of 15 300 gauss. The beam at the chamber was collimated to $\frac{5}{8}$ inch by 2.5 inches. A 19-inch paraffin filter was inserted into the beam 55 feet from the cloud chamber to reduce the number of low-energy neutrons; and a 2-inch Pb filter, followed by a small sweeping electromagnet, was inserted 40 feet from the cloud chamber to remove the γ rays. The energy distribution of the neutrons undoubtedly extended from a few Mev up to 6.2 Bev. However, since no events were recorded with fewer than three outgoing prongs, neutrons below 280 Mev did not contribute.

One event had seven outgoing prongs (Fig. 1). Measurements of momentum and relative ionization of the prongs are given in Table I. A reasonable assumption is that all the prongs are either pions or protons, and there is no evidence to indicate otherwise. Track 1 ionizes slightly more than minimum and is therefore