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

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

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

$$\tau_{Ke2}^{-1}/\tau_{K\mu 2}^{-1}=2.5\times10^{-5}. \qquad (2)$$

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

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

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

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

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

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

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

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[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*

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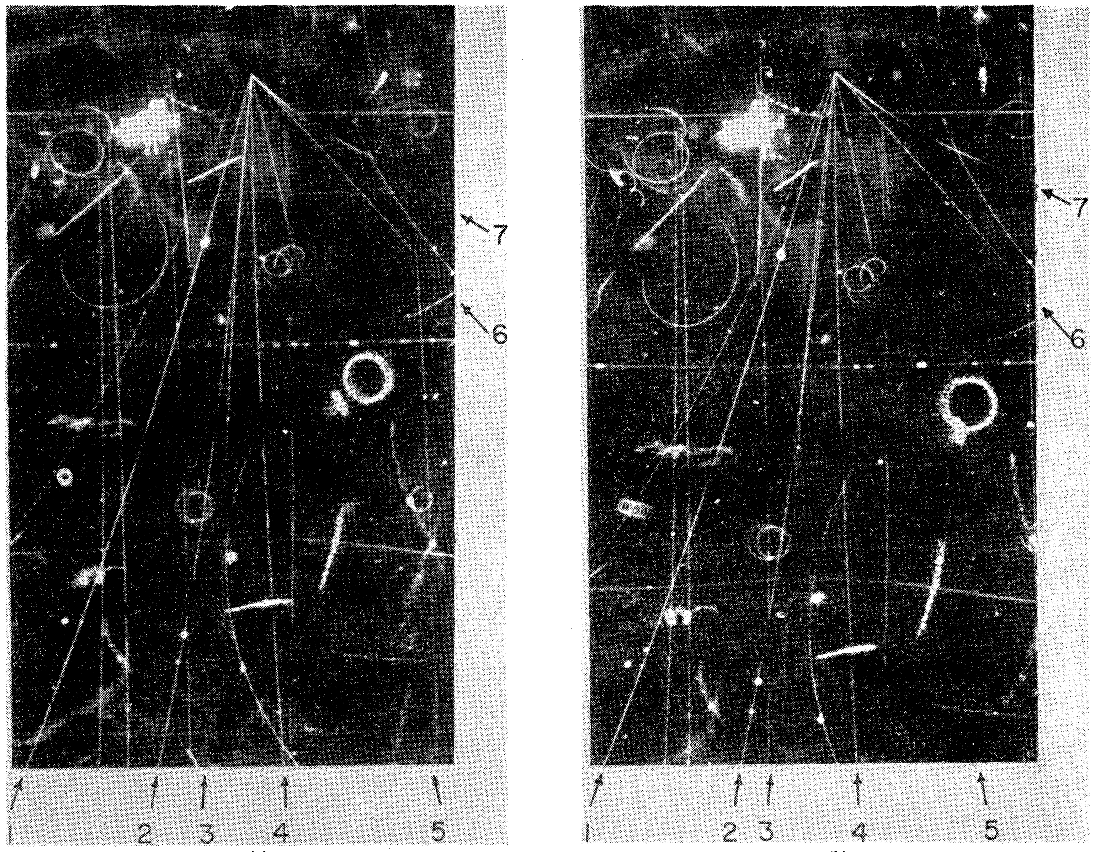
More than 500 events showing pion production in n-p collisions have been obtained by exposing a hydrogen-filled diffusion cloud chamber[1] to high-energy neutrons from the Bevatron. The neutrons were produced by bombarding an internal Cu target with 6.2-Bev circulating protons. The cloud chamber was 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



(a) (b)

FIG. 1. Photograph of seven-prong event interpreted as production of five pions in an n-p collision.

an identified proton. Tracks 2 and 6 are minimum ionization and, therefore, are identified as positive pions. Tracks 3, 4, and 7 are negative and, therefore, are negative pions. Track 5 is unidentified from ionization and momentum. Since the transverse momentum can be balanced within the errors of measurement, there is probably no neutral particle leaving the collision; and since all the particles are identified except Track 5 we know that under these conditions it must be a proton. The reaction is therefore believed to be

$$n+p\rightarrow p+p+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{-},$$

where five pions have been produced in a nucleon-nucleon collision. The kinetic energy of the incoming neutron is approximately 4.7 Bev for this case. We are unable to rule out six-meson production, i.e., $pp++---0$ or $pn+++---$, but both these possible reactions are considered less probable. The total charge of $+1$, the relatively high momentum of all the positive tracks, and the absence of a recoil blob at the origin make it highly unlikely that the event is a rare carbon or oxygen star from the methyl alcohol in the cloud chamber.

Of the remaining events, 48 have five prongs and 473 have three prongs. Table II shows the events classified according to the number of visible prongs and the number of pions produced in the collision. A preliminary analysis of the five-prong events indicates that 16 of these have one or more neutral outgoing particles, indicating the production of four or more pions. Identification of these events is based on (a) ionization and momentum measurements showing that two of the positive particles are pions (six cases), (b)

TABLE I. Data on seven-prong event.

Track	Sign	Measured momentum (Bev/c)	Ionization density (relative)	Momentum used for momentum balance (Bev/c)	Particle identification
1	+	0.85 ±0.05	∼1.5	0.90	proton
2	+	0.67 ±0.04	minimum	0.71	π^+
3	−	0.74 +0.10 −0.09	minimum	0.83	π^-
4	−	1.19 ±0.06	minimum	1.19	π^-
5	+	3.0 +0.3[a] −1.5	minimum	1.56	proton
6	+	0.63 +0.15 −0.10	minimum	0.53	π^+
7	−	0.065±0.003	∼3	0.065	π^-

[a] The total energy of the outgoing particles is limited by the energy of the original protons in the Bevatron. The upper limit here is obtained in this way rather than from direct measurement.

TABLE II. Relative frequencies of multiplicities of pion production in n-p collisions.

Observed type of event	3-prong			5-prong			7-prong		
Identified No. of pions	1	1 or more	2 or more	3	3 or more	4 or more	5	5 or more	6 or more
No. of events	...	473	...	3	29	16	1	0	0

lack of transverse momentum balance within the errors of measurement (seven cases), or both (a) and (b) (three cases). Production of three pions is indicated in three of the five-prong events that show transverse momentum balance. Because it is easier to establish the absence than the presence of momentum balance, 3:16 can only be considered within statistics as a lower limit to the ratio of three-pion to four-or-more-pion production in the five-prong events. The group of five-prong events listed as "3 or more" pion production consists of those events for which the presence or absence of one or more neutral outgoing particles has not been established. The grouping of the three-prong events into the "one or more" pion-production classification reflects the lack of analysis of this group.

In a similar experiment using neutrons from 2.2-Bev protons at the Brookhaven Cosmotron, no five-prong events were found among 185 three-prong events.[2] The mean available energy in the center-of-mass system in the Brookhaven experiment was determined to be 720 Mev, whereas in this experiment the available center-of-mass energies extend up to 2 Bev.

Similar evidence for high multiplicities has been found in π^--p collisions[3] and p-p collisions. Negative pions with an average kinetic energy of 4.5 Bev yielded three cases of four-or-more meson production in 145 interactions; 5.3-Bev protons gave two cases of four-or-more meson production in 39 interactions.

The cloud-chamber pictures were scanned by Alfred S. Fischler, Mrs. Marjorie E. Isitt, Arthur A. Kemalyan, and Joseph H. Wenzel. They were all scanned at least three times.

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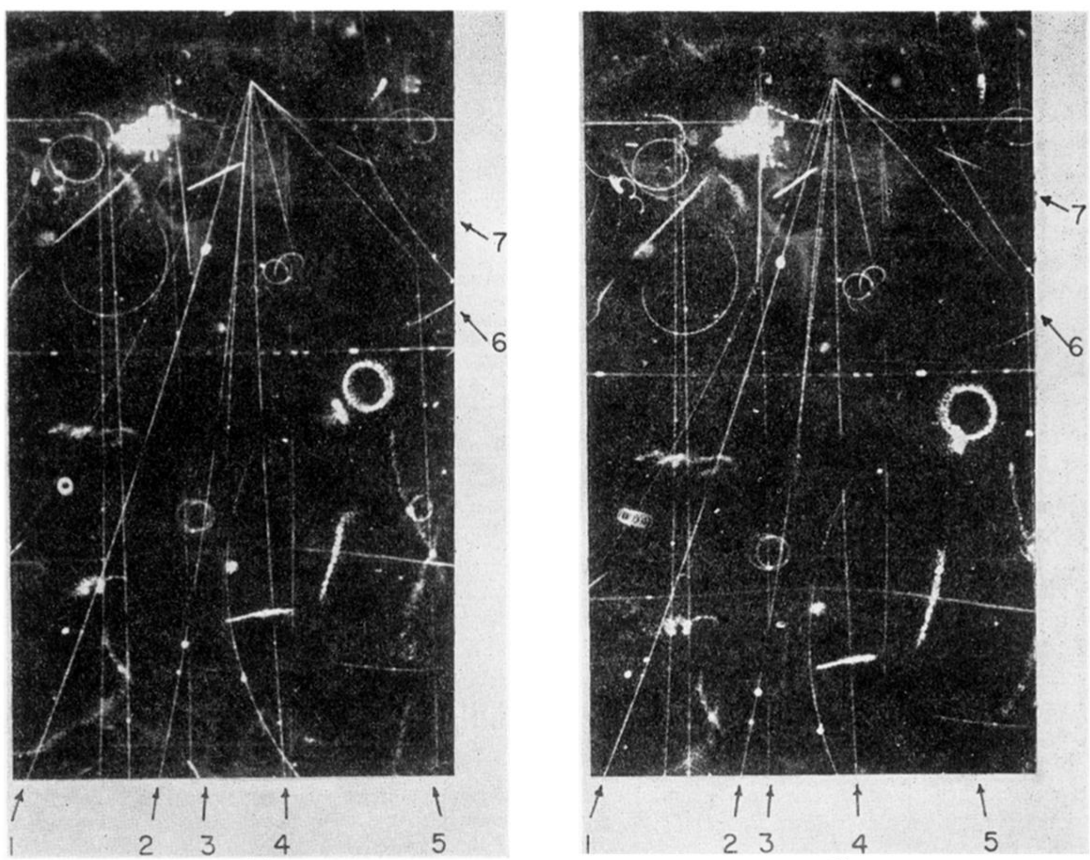

(a) (b)

FIG. 1. Photograph of seven-prong event interpreted as production of five pions in an *n-p* collision.