We are indebted to Dr. R. M. Sinclair for drawing our attention to the positron problem. We wish to record our gratitude to Dr. N. O. Lassen and his co-workers for providing the strong radioactivity essential to this research. Two of us (S. F. and G. M. T.) further deem it a pleasant duty to acknowledge the generous hospitality extended to us by Professor Niels Bohr at his Institute, as well as the support derived from grants of the John Simon Guggenheim Memorial Foundation.

* John Simon Guggenheim Memorial Fellow. Permanent address: Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania.

† Permanent address: A. E. K., Risø, Roskilde, Denmark.

‡ John Simon Guggenheim Memorial Fellow. Permanent address: Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D. C.

[1] Frauenfelder, Bobone, von Goeler, Levine, Lewis, Peacock, Rossi, and DePasquali, Phys. Rev. **106**, 386 (1957); H. de Waard and O. J. Poppema, Physica **23**, 597 (1957); M. E. Vishnevsky *et al.*, Nuclear Phys. **4**, 271 (1957).

[2] Frauenfelder, Hanson, Levine, Rossi, and DePasquali, Phys. Rev. **107**, 643 (1957).

[3] Goldhaber, Grodzins, and Sunyar, Phys. Rev. **106**, 826 (1957).

[4] Deutsch, Gittelmann, Bauer, Grodzins, and Sunyar, Phys. Rev. **107**, 1733 (1957).

[5] We are indebted to A. Bohr for working out for us the separate $M=0$ and $M=1$ annihilation-in-flight cross sections.

[6] L. A. Page, Phys. Rev. **106**, 394 (1957).

[7] Frauenfelder, Hanson, Levine, Rossi, and DePasquali, Phys. Rev. **107**, 910 (1957).

[8] H.C.R. alloy (50% Fe, 50% Ni).

[9] H. W. Kendall and M. Deutsch, Phys. Rev. **101**, 20 (1956).

[10] Let us define the polarization $P$ of the positron beam as $P=(N^+-N^-)/(N^++N^-)$. ($N^+$, $N^-$ represents number of $\beta^+$ spins parallel and antiparallel to the $\beta^+$ momentum, respectively.) Designating the annihilation cross sections for $M=0$ and $M=1$ by $\sigma_0$ and $\sigma_1$, their ratio $\sigma_0/\sigma_1$ by $R$, and the counting rates for polarized *electron* spins parallel and antiparallel to the positron momentum by $C_p$ and $C_a$, respectively, we easily obtain the following expression for our iron-nickel alloy ($Z_{\text{eff}}=27$): $C_a/C_p=1+0.0741nP(R-1)/(R+1)\equiv 1+\delta$, with $n$, the effective number of electron spins aligned parallel to the incident positron beam, equal to $N_B\cos\theta/gs$. $N_B$ is the effective number of Bohr magnetons per atom for the material used (1.7) and $g$ is the electronic gyromagnetic ratio ($s=\frac{1}{2}$, and we assume $g=2$ for want of a more accurate value). If we insert values of $R$ appropriate for our geometry with an approximate acceptance cone of 45 degrees half-angle, we obtain the theoretical values $\delta=1.6\%$ and $\delta=2.4\%$ for completely polarized positrons of 2 Mev and 1.5 Mev, respectively. The larger effects observed at the highest photon energies indicate that the effective acceptance cone is narrower since $R$ increases with decreasing acceptance angle. This is as expected since the energetic positrons producing the higher energy gamma rays have undergone less multiple scattering.

---

# Photoproduction of Pion Pairs in Hydrogen*

MICHEL BLOCH AND MATTHEW SANDS
*California Institute of Technology, Pasadena, California*

(Received August 23, 1957)

NEGATIVE pions from the interaction of $\gamma$ rays with protons are presumed to arise from events in which two or more pions are produced. Pions which emerge from a high-density, hydrogen-gas target in the bremsstrahlung beam of the Caltech synchrotron have been selected for charge and momentum by a wedge-magnet analyzer and detected in a scintillation-counter telescope. Discrimination against electrons was obtained with a Čerenkov counter in anticoincidence.

The yields of negative pions obtained at a laboratory angle of 60° for several pion laboratory energies $T_-$ and for several bremsstrahlung cutoff energies $k_{\max}$ are given in Fig. 1(a). The yields, $d^2\sigma^*/dT_-d\Omega_-$, are expressed as a cross section per proton, per effective quantum (the energy flux divided by the maximum photon energy), and per unit energy and solid angle of the emitted pions. The yields obtained at a laboratory angle of 120° are given in Fig. 1(b). The photon beam was monitored with a thick ionization chamber whose energy dependence has been calibrated against a "quantameter" constructed according to the design of Wilson.[1] Other instrumental parameters were calibrated by using the yield of positive pions from the single-production resonance with the synchrotron operating at 500 Mev. Background runs with an evacuated target gave corrections of from 5% to 15% of the hydrogen yields. Smaller corrections have been made for counts due to cosmic rays and accidental coincidences. The arrows in the figure indicate the energy thresholds for the production of pion pairs with one pion at the required energy and angle.

The data for a maximum bremsstrahlung energy of 600 Mev agree with the results reported by Friedman and Crowe.[2] The results for 50-Mev pions at 60° show qualitative features similar to those reported from Cornell[3] at 35°.

Owing to the finite thickness of the radiator in the synchrotron, the energy spectrum of the photon beam used for these experiments does not have the ideal

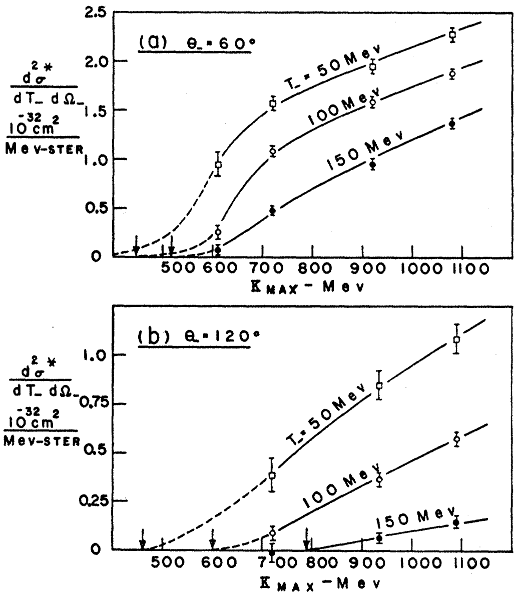

FIG. 1. Yields of negative pions from $\gamma+p$, as a function of the bremsstrahlung cutoff energy $k_{\max}$, for pion kinetic energies $T_-$ and laboratory angles $\theta_-$.

bremsstrahlung $(dk/k)$ energy dependence. The increase of the yield with increasing bremsstrahlung cutoff energy shown in the figure does not, therefore, represent solely the contribution from the photons of the highest energies. A detailed analysis of the differences in the yields will be deferred until the completion of a projected measurement of the energy spectrum of the photon beam.

A preliminary analysis has been performed using a photon spectrum computed for an assumed effective radiator thickness. This analysis yields for the center-of-momentum system, a differential cross section per unit energy and solid angle of the negative pion (and per photon), which varies slowly with the pion energy (falling to zero at the maximum permissible energy). The cross section shows no large dependence on the pion angle from 90° to 150° (c.m.). The integral of this cross section over the negative-pion energy is consistent with a constant value of about $5\times10^{-30}$ cm²/sterad for all photon energies from 600 to 1100 Mev.

---

* Work supported in part by the U. S. Atomic Energy Commission.

[1] R. R. Wilson (to be published).

[2] R. M. Friedman and K. M. Crowe, Phys. Rev. **105**, 1369 (1957).

[3] Woodward, Wilson, and Luckey, Bull. Am. Phys. Soc. Ser. II, **2**, 195 (1957), and report in *Proceedings of the Seventh Annual Rochester Conference on High-Energy Nuclear Physics* (Interscience Publishers, Inc., New York, 1957).

## Detection of Parity Nonconservation in Λ Decay*†

F. S. Crawford, Jr., M. Cresti, M. L. Good, K. Gottstein,‡
E. M. Lyman,§ F. T. Solmitz, M. L. Stevenson,
and H. K. Ticho‖

*Radiation Laboratory, University of California,
Berkeley, California*

(Received October 8, 1957)

The recent discovery of parity nonconservation in $\beta$ decay, $\pi$ decay, and $\mu$ decay has made it extremely important to find out whether parity is also violated in hyperon decay.

In order to study hyperon production and decay we have exposed a 10-inch hydrogen bubble chamber to a beam of 1.12 Bev/$c$ $\pi^-$ mesons. Hyperons are produced according to the reactions

$$\pi^- + p \rightarrow \Lambda + K^0, \tag{1}$$

$$\pi^- + p \rightarrow \Sigma^- + K^+, \tag{2}$$

$$\pi^- + p \rightarrow \Sigma^0 + K^0. \tag{3}$$

We have established the following facts about the decay $\Lambda \rightarrow p + \pi^-$: (1) The degree of nonconservation of parity is very large. (2) Charge conjugation invariance is also violated.

We have found no statistically significant evidence of parity nonconservation in a sample of 122 $\Sigma^-$ decays. This may be the result of lack of polarization or lack of parity violation in $\Sigma^-$ decay, or both. (The findings of emulsion workers suggest that parity nonconservation in $\Sigma^-$ decay may be small.[1])

Lee *et al.*[2] have given a phenomenological discussion of hyperon production and decay, assuming that the $K^0$ spin is zero and the $\Lambda$ spin is $\frac{1}{2}$. We follow their notation and write

$\mathbf{p}_{\text{in}}$ = c.m. momentum of the incoming $\pi^-$.
$\mathbf{p}_\Lambda$ = c.m. momentum of the $\Lambda$ produced.
$\theta$ = hyperon production angle (between $\mathbf{p}_{\text{in}}$ and $\mathbf{p}_\Lambda$).
$R$ = projection of the c.m. momentum of the decay in the direction of $\mathbf{p}_{\text{in}}\times\mathbf{p}_\Lambda$.
$\xi$ = $R$/(maximum value of $R$).
$P(\theta)$ = the polarization of the $\Lambda$ produced at the angle $\theta$ = the expectation value of the spin of the $\Lambda$ in the direction of $\mathbf{p}_{\text{in}}\times\mathbf{p}_\Lambda$, in units of $\frac{1}{2}\hbar$.
$I(\theta)$ = the c.m. differential production cross section.

The decay distribution function for $\xi$ is given by

$$W(\theta,\xi)d\Omega d\xi = I(\theta)d\Omega[1+\alpha P(\theta)\xi]d\xi/2, \tag{4}$$

where the asymmetry coefficient $\alpha$ must lie between $-1$ and 1. The existence of a nonvanishing $\alpha$ constitutes an unambiguous proof of parity nonconservation in $\Lambda$ decay.

Integration of Eq. (4) over all production angles $\theta$ yields

$$\bar{W}(\xi)d\xi = [\textstyle\int I(\theta)d\Omega](1+\alpha\bar{P}\xi)d\xi/2. \tag{5}$$

If we designate by $N_{\text{up}}$ the number of decays having $\xi>0$, then integration of Eq. (5) over $\xi$ yields

$$\alpha\bar{P} = \frac{N_{\text{up}} - N_{\text{down}}}{\frac{1}{2}(N_{\text{up}}+N_{\text{down}})}. \tag{6}$$

Our photographs for $\Lambda\rightarrow p+\pi^-$ fall into two categories: (1) 76 double $V^0$ events, where both the $\Lambda$ and $K^0$ decays are observed. (2) 277 single $V^0$ events, where only the $\Lambda$ decay is observed. (In both categories the disappearance of the incident $\pi^-$ is of course observed.)

We have analyzed 76 double $V^0$ events corresponding to reaction (1). In addition we have performed a preliminary analysis on the 277 single $V^0$ events, which include $\Lambda$'s from reaction (1) and secondary $\Lambda$'s from reaction (3). No attempt has yet been made to separate out those single $V^0$'s which are secondary $\Lambda$'s from $\Sigma^0$ decay.[3] In this preliminary analysis a single $V^0$ event is called a $\Lambda$ decay (i.e., rather than a $K^0$ decay) provided that (*a*) the laboratory angle between the momentum of the positive decay fragment and that of the neutral parent is $<25°$, and (*b*) the negative decay fragment makes a larger laboratory angle than does the positive fragment, with respect to the momentum of the neutral parent.[4]

Our total sample of 76+277=353 $\Lambda$ decays yields

$$N_{\text{up}} = 48+167 = 215, \quad N_{\text{down}} = 28+110 = 138, \tag{7}$$