High-Energy $\pi-$He Experiments: Charge Symmetry and the Determination of the K-Meson Spin*

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The associated production of K particles and hypernuclei in high-energy $\pi-$He interactions may be studied to verify charge symmetry at small distances, to determine conclusively the spin of the K meson (as long as angular momentum is conserved), and to detect a possible effect due to the nonconservation of angular momentum.

EXPERIMENTS are now being planned to study the $\pi-$He interaction in a helium bubble chamber at Cosmotron energies.[1] In this note we show that the reactions

$$\pi^- + \mathrm{He}^4 \rightarrow {}_\Lambda\mathrm{H}^4 + K^0, \quad (1)$$

$$\pi^+ + \mathrm{He}^4 \rightarrow {}_\Lambda\mathrm{He}^4 + K^+, \quad (2)$$

are worth studying for several reasons.

We first show that there is some reason for believing that the reaction (1) may compete favorably with the reaction

$$\pi^- + \mathrm{He}^4 \rightarrow \mathrm{H}^3 + \Lambda^0 + K^0.$$

It is known that in the reaction

$$\pi^- + p \rightarrow \Lambda^0 + K^0$$

the angular distribution for the K^0 in the center-of-mass system is peaked strongly in the forward direction.[2,3] This can be best explained by means of the "predissociation model" in which the incident pion gives up most of its energy-momentum to the K^+ resulting from the virtual dissociation of the proton into Λ^0 and K^+.[4–8] In the $\pi-$He collision, if the strange particles are produced by a similar mechanism in the He nucleus, the Λ^0 that is left behind has little momentum relative to the three remaining nucleons and hence has large probability for forming a hypernucleus. The probability for hypernucleus formation further depends on the wave function of the $\Lambda-\mathrm{H}^3$ system at small distances.

As is well known, the principle of charge independence is the starting point of the Gell-Mann-Nishijima scheme. Yet to date there has been no direct confirmation of the principle. Moreover, from electron-deuteron scattering we know that, if pions *alone* are responsible for the charge distribution of the nucleon, charge symmetry is clearly violated at distances of the order 0.7×10^{-13} cm provided that conventional electrodynamics still holds.[9,10] Reactions such as

$$K^- + d \rightarrow \Sigma^- + p, \quad K^- + d \rightarrow \Sigma^0 + n,$$

or

$$K^- + \mathrm{He}^4 \rightarrow \Lambda^0 + \mathrm{He}^3 + \pi^-, \quad K^- + \mathrm{He}^4 \rightarrow \Lambda^0 + \mathrm{H}^3 + \pi^0,$$

if they occur with the ratio 2:1, can confirm charge independence at low energies,[11] but they do not supply any information concerning the validity of the principle in high-energy interactions.

If charge symmetry holds in $\pi-$He interactions at Cosmotron energies, the differential cross sections for the reactions (1) and (2) (which are presumably peaked in the beam direction) have to be equal. Thus we have a means of testing whether the manner in which the proton is dissociated into Λ^0+K^+ is identical to that in which the neutron is dissociated into Λ^0+K^0. Similarly, the reactions

$$\pi^- + \mathrm{He}^4 \rightarrow \Sigma^- + \mathrm{H}^3 + K^0, \quad \pi^+ + \mathrm{He}^4 \rightarrow \Sigma^+ + \mathrm{He}^3 + K^+,$$

can be compared to test the charge symmetry of the elementary interactions

$$p \leftrightarrow \Sigma^+ + K^0, \quad n \leftrightarrow \Sigma^- + K^+.$$

If these experiments confirm charge symmetry, the observed charge distribution of the nucleon (N) can be best understood along the lines of Sandri's suggestion[12] provided that the $\bar{K}\bar{Y}N$ coupling ($Y=\Lambda, \Sigma$) is strong enough and that the virtual dissociation of the nucleon takes place primarily in an S-state.[13] The

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[1] We are indebted to Professor E. Harth for informing us of recent works on helium bubble chambers by the Duke group.

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[8] J. J. Sakurai, Nuovo cimento, Ser. X, **5**, 1340 (1957).

[9] J. A. McIntyre, Phys. Rev. **103**, 1464 (1956).

[10] Yennie, Lévy, and Ravenhall, Revs. Modern Phys. **29**, 144 (1957). Other relevant references, including earlier work on the scattering of slow neutrons by atomic electrons, can be found in this review article.

[11] T. D. Lee, Phys. Rev. **99**, 337 (1955).

[12] G. Sandri, Phys. Rev. **101**, 1616 (1956).

[13] If the spin of the K meson is zero and that of the Y hyperon is $\frac{1}{2}$, this latter condition means that the $\bar{K}\bar{Y}N$ interaction is scalar (scalar). Although weak-coupling calculations with such a coupling give attraction for K^+-p scattering, which is contrary to observation, D. Amati and B. Vitale [Nuovo cimento (to be published)] have shown that strong scalar (scalar) coupling can give a repulsion of reasonable magnitude if we use a static model similar to the Lee model. Further, our preliminary investigations show that a scalar (scalar) coupling constant of the order $G_{K\Lambda N}^2/4\pi \approx 2$ is not in contradiction with the known experimental data on the associated photoproduction of K and Λ particles. The chief contribution in that case is likely to arise from the meson-

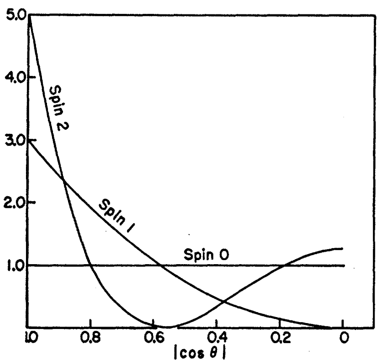

FIG. 1. Angular distributions for θ_1^0 decays of K^0 particles produced in the beam direction by $\pi^- + He^4 \rightarrow {}_\Lambda H^4 + K^0$ in coincidence with those ${}_\Lambda H^4$ hypernuclei which decay into $He^4 + \pi^-$ in the beam direction. θ is the angle between the direction of the θ_1^0 decay products (π^- and π^+) and the beam direction measured in the rest system of the K^0 particle.

"radius" of predissociation given by Peaslee[7] is roughly 0.5×10^{-13} cm, which is not unreasonable in order that Sandri's argument should work.

According to Lomon, his most recent analysis of the τ-meson decay shows that the best fit is obtained when the spin of the K particle is two.[14] Although there is evidence favoring spin zero, there has not been conclusive evidence against the spin-two hypothesis. The angular-correlation effect in the reaction (1) followed by the familiar decays:

$$ {}_\Lambda H^4 \rightarrow He^4 + \pi^-, \quad K^0 \rightarrow \theta_1^0 \rightarrow \pi^+ + \pi^-, $$

gives a conclusive answer that may settle the question of the spin of the K meson.

The method we propose in order to determine the spin of the K meson is essentially that of Adair.[15] We select those events in which the hypernucleus and the K meson are produced in the beam direction and in which, at the same time, the hypernucleus decays into He^4 and π^- in the beam direction. Then the angular distribution of the θ_1^0 decay is *uniquely* given by $(2S+1)|P_S(\cos\theta)|^2$ provided that angular momentum is conserved. S here stands for the spin of the K particle, and θ is the angle between the direction of the decay products (π^+ and π^-) and the beam direction measured in the rest system of the K particle. In deriving this result it is essential that the spins of He^4 and π are both zero so that the spin functions of ${}_\Lambda H^4$ and K simply yield Legendre polynomials of the same orders as the spins. As seen from Fig. 1, we can clearly distinguish spin zero from spin two.

Some of the cases worth considering are listed below. (I) If the angular distribution of the θ_1^0 decay is given by $(5/4)(3\cos^2\theta - 1)^2$, the spin of the K meson is two as Lomon's analysis indicates. The nonoccurrence of $K^+ \rightarrow \pi^+ + \gamma$,[16] the lack of angular correlation between the production plane and the momenta specifying the decay system, the frequency of K pairs produced in proton-anti-proton annihilation,[17] etc., have to be explained. (II) If the angular distribution is isotropic, there are two possibilities: (a) it is not justifiable to take only a few leading terms in the Dalitz-Fabri expansion because of a peculiar angular-momentum selection rule operative in the τ decay,† or (b) angular momentum is not conserved in the decay of the τ meson. (III) If the distribution is given by $3\cos^2\theta$, it is almost certain that angular momentum is not conserved either in the θ decay or in the τ decay, since Orear's model-independent analysis (based on the energy dependence of low-energy odd pions in the τ decay) is clearly against spin 1.[18] The above view may be further supported if the decay mode $\theta_1^0 \rightarrow 2\pi^0$, for which there is some indirect evidence,[19] is conclusively established. (IV) If the angular distribution is not given by $(2S+1)|P_S(\cos\theta)|^2$ for any integer S (for instance, if the distribution is given by $\sin^n\theta$ or by a linear combination of two or more spherical harmonics), we have unambiguous evidence for the nonconservation of angular momentum.

If angular momentum is not conserved in decay interactions of strange particles, the spins of those particles have to be determined from their strong interactions alone. The reactions proposed by Lee,[11]

$$ K^- + d \rightarrow p + \Sigma^-, \quad p + \Sigma^- \rightarrow K^- + d, $$

which may take place in a hydrogen-deuterium bubble chamber, can be used to determine the quantity $(2S_\Sigma+1)/(2S_K+1)$ where S_Σ and S_K stand for the spins of Σ and K, respectively. The energy dependence of the reaction

$$ K^- + d \rightarrow K^0 + p + p $$

may shed light on the spin of the K meson, as pointed out by Case, Karplus, and Yang.[20]

The present investigation is stimulated by Dr. Lomon's τ-meson analysis, the results of which he has kindly informed us prior to publication. Thanks are also due Professor H. A. Bethe and Dr. T. Kinoshita for illuminating discussions.

Note added in proof.—A week after the present paper was written, it became apparent to the author that charge independence is likely to be violated in hyperon production. There remains the important question whether charge symmetry still holds in high-energy interactions.

current interaction (Marshak's "photoelectric" term). It is important to note that, if K is scalar and the spin of ${}_\Lambda H_4$(${}_\Lambda He^4$) is zero, the reactions (1) and (2) are strictly forbidden.

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[17] J. Sandweiss and M. Goldhaber, Bull. Am. Phys. Soc. Ser. II, 1, 385 (1956).

† It was pointed out by Lomon that the inclusion of higher angular momentum states does not make the [0, −] fit any better.

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[19] B. J. Moyer, *Proceedings of the Sixth Annual Rochester Conference on High-Energy Physics* (Interscience Publishers, Inc., New York, 1956).

[20] Case, Karplus, and Yang, Phys. Rev. **101**, 358 (1956).