acceleration is possible with the nonstatistical analysis. The ions that would be accelerated are those which, because they are on the high-energy tail of the Boltzmann distribution or because of shock phenomena, succeed in getting enough initial energy and a long enough mean free path that their motion can be regarded as to some extent independent of the gas motion. It is necessary that the motion be affected more by the magnetic field than by other ions. Analysis of such a model might show that partially ionized heavy atoms are favored because of the large radii of their helices or their longer mean free paths, and this would explain the apparent excess of heavy ions in cosmic rays.

It is a pleasure to acknowledge the helpful discussions on this subject with my colleagues over the past year. Mr. T. W. Layton has been very helpful and Professor R. F. Christy, Professor J. L. Greenstein, and Professor Guido Münch have made valuable suggestions and supplied background information.

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Experiments with Slow K Mesons in Deuterium and Hydrogen*

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It is pointed out that the following useful information can be obtained from experiments on K mesons in deuterium and hydrogen: (a) an indication of the K-particle spin; (b) a test of isotopic spin conservation in reactions involving strange particles; (c) a measurement of the Σ^0 mass.

MUCH of our present knowledge of the intrinsic properties of π mesons has come from experiments involving the interaction of slow π mesons with deuterium and hydrogen. As a natural extension we have considered the possibilities of similar experiments with K mesons.[1] In addition to the obviously interesting experiment of elastic scattering on hydrogen, useful information can be obtained from various inelastic reactions.

First, we shall see that information on the K-particle spin can be obtained from the charge-exchange scattering,

$$K^+ + d \rightarrow K^0 + p + p, \qquad (1)$$

which is expected to take place if (K^0, K^+) form an isotopic spin doublet. At energies of 30 Mev or less, the momentum dependence of the cross section is certainly sensitive to the angular momentum of the states involved. If the dependence[2] is k^4/η, where $\hbar k$ and $\hbar\eta$ are respectively the maximum momentum of K^0 and the momentum of K^+ in the center-of-mass system, the reaction must involve S states primarily. We can then conclude that the K-particle spin is not zero. If, on the other hand, the variation is as $k^6\eta$ (which involves two P states and is the next simplest possibility), no conclusion follows directly. In that case, however, one can conclude that the K-particle spin is zero if the elastic scattering,

$$K^+ + p \rightarrow K^+ p, \qquad (2)$$

is observed to take place primarily in S states at low energy.

Let us now consider K^--capture experiments. We shall see that these can yield a test of the hypothesis of the conservation of isotopic spin. Three categories of consequences of this conservation law may be listed: (a) the existence of isotopic spin multiplets of particles with charges differing from each other by unity and with comparable masses; (b) the conservation of the z-component of isotopic spin in any fast reaction; (c) the conservation of the magnitude of the isotopic spin in any fast reaction. The first two of these have been widely discussed, and in particular have been used in conjunction with the conservation of charge to produce

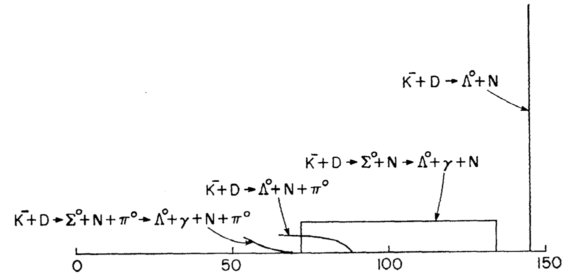

FIG. 1. Λ^0 energy spectrum from $K^- + d$ reactions.

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[1] Similar considerations have been made by T. D. Lee, Phys. Rev. **99**, 337 (1955) and by S. Gasiorowicz, University of California Radiation Laboratory Report No. UCRL-3074 (unpublished).

[2] This momentum dependence is obtained on neglecting interactions among the three particles in the final states. The qualitative behavior is probably not very sensitive to such interactions.

the strangeness selection rules of Gell-Mann.[3] So far the last one rests on no direct experimental proof. It is, however, fundamental to all such considerations in that it is the essence of the isotopic spin conservation law.

Since the K^-+d system is in a single isotopic spin state, the conservation of the magnitude of isotopic spin restricts the final states to which transitions can lead. In particular, the two reactions,

$$K^-+d\rightarrow\Sigma^-+p, \tag{3}$$

$$K^-+d\rightarrow\Sigma^0+n\rightarrow\Lambda^0+\gamma+n, \tag{4}$$

must take place in the ratio 2:1 if isotopic spin is conserved.

Reaction (3) is easy to identify. To identify reaction (4), we notice that it could be confused with the reactions:

$$K^-+d\rightarrow\Lambda^0+n, \tag{5}$$

$$K^-+d\rightarrow\Lambda^0+n+\pi^0, \tag{6}$$

$$K^-+d\rightarrow\Sigma^0+n+\pi^0\rightarrow\Lambda^0+\gamma+n+\pi^0, \tag{7}$$

$$K^-+d\rightarrow\Lambda^0+n+\pi^0+\pi^0 \tag{8}$$

TABLE I. Energy spectrum of hyperons from the capture of K^- mesons in hydrogen and deuterium.[a]

Reaction	Kinetic[b] energy of Λ^0 (Mev)	Kinetic energy of $\Sigma^\pm$ (Mev)
$K^-+d\rightarrow\Lambda+n$	145	
$K^-+d\rightarrow\Sigma^0+n\rightarrow\gamma+\Lambda^0+N$	$<134-0.16x$	
	$>72-0.80x$	
$K^-+d\rightarrow\Lambda^0+n+\pi^0$	<88	
$K^-+d\rightarrow\Sigma^0+n+\pi^0\rightarrow\Lambda^0+\gamma+N+\pi^0$	<69	
$K^-+d\rightarrow\Sigma^-+p$		108
$K^-+p\rightarrow\Lambda^0+\pi^0$	28.5	
$K^-+p\rightarrow\Sigma^0+\pi^0\rightarrow\Lambda^0+\gamma+\pi^0$	$<28-0.035x$	
	$>4.9-0.19x$	
$K^-+p\rightarrow\Lambda^0+\pi^0+\pi^0$	<9.0	
$K^-+p\rightarrow\Sigma^\pm+\pi^\mp$		15

[a] x = rest energy of Σ^0 in Mev minus 1188 Mev.
[b] In computing the energy of Λ^0, the following rest energies were used: $(E_0)_{K^-}=493$ Mev, $(E_0)_{\Sigma^\pm}=1188$ Mev, $(E_0)_{\Lambda^0}=1115$ Mev, $(E_0)_{\pi^0}=135$ Mev.

Reactions (4) and (5), however, are easily distinguished from the others and from each other because they produce Λ^0 particles of different energies.

In Fig. 1 we plot the spectrum of the Λ^0. It is seen that the various reactions occupy quite different portions of the spectrum. The shape of the spectrum for reaction (4) is a rectangle as shown, provided the Σ^0 is unpolarized when produced. If the shape turns out to be different from a rectangle, one can conclude that the Σ^0 must be polarized, and the degree of complication

[3] M. Gell-Mann (to be published).

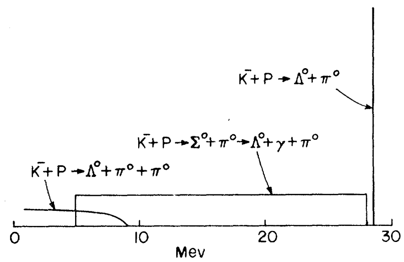

FIG. 2. Λ^0 energy spectrum from K^-+p reactions.

of the spectrum (straight line, parabola, etc.) gives a lower limit to the spin of Σ^0.

The spectrum is strongly reminiscent of the γ spectrum in the π^-+p capture experiment[4] which gave the $\pi^--\pi^0$ mass difference. In a very similar way the mass of Σ^0 can be calculated from the end points of the Λ^0 spectrum in reaction (4). This is apparent from Table I where the relation is given.

The Λ^0 spectrum from the capture of K^- in hydrogen is plotted in Fig. 2. The end points of the spectrum in this case are unfortunately quite insensitive to the mass of Σ^0 (see Table I).

In addition to yielding the Σ^0 mass and a test of the conservation of isotopic spin, these experiments of K^- capture in deuterium and hydrogen could also provide information of the following kinds:

(1) The lifetimes of Λ^0 and $\Sigma^\pm$.

(2) The relative transition probabilities $a:b:c$ of the reactions

$$K^-+p\rightarrow\Sigma^-+\pi^+, \tag{9a}$$

$$K^-+p\rightarrow\Sigma^0+\pi^0, \tag{9b}$$

$$K^-+p\rightarrow\Sigma^++\pi^-. \tag{9c}$$

These should satisfy the inequalities

$$\sqrt{a}+\sqrt{c}\geqq 2\sqrt{b}\geqq |\sqrt{a}-\sqrt{c}|,$$

which follow from the invariance of the transition matrix under all isotopic spin rotations.

(3) If the mass of K^0 is smaller than K^- by more than 3.5 Mev/c^2, a reaction similar to that of Eq. (1),

$$K^-+d\rightarrow n+n+K^0, \tag{10}$$

is energetically possible and yields similar information. The phase space available is rather small so that it is in unfavorable competition with reactions (3) to (8). However, if even one such event is found, it is a strong indication that the K meson has nonzero spin. Since the energy released is certainly small, it is highly improbable that any but S states are involved. The facts that the deuteron has spin one and the two neutrons must be in a singlet state then require that the K meson must have spin other than zero to conserve angular momentum.

[4] Panofsky, Aamodt, and Hadley, Phys. Rev. **81**, 565 (1951).