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ISOTOPIC SPIN CONSERVATION IN K⁻ INTERACTIONS WITH NUCLEAR MATTER

S. Gasiorowicz

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ISOTOPIC SPIN CONSERVATION IN K\(^-\) INTERACTIONS WITH NUCLEAR MATTER

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July 14, 1955

Recently K\(^-\) particles of momentum 250 - 360 Mev/c have been extracted from the Bevatron in numbers sufficiently large to make experiments on their interaction with nuclear matter feasible. Preliminary results\(^1\) appear to conform to the scheme of Gell-Mann,\(^2\) and on the basis of that scheme the following considerations are presented. The K particles interact with matter "strongly," conserving isotopic spin (and its z component) by undergoing either direct scattering (d.s.) or "strangeness"-exchange scattering (s.e.) provided this is not forbidden by the conservation laws. For K\(^+\) particles only the former can take place, but with K\(^-\) particles both processes occur. For K particles of momentum 250 Mev/c, the kinetic energy available in the c.m. system is 40 Mev for d.s. and 140 - 220 Mev for s.e. Thus the reaction

\[
K + n \rightarrow \gamma + 2\pi
\]

is energetically possible. We shall nevertheless neglect it since the pions would be emitted close to threshold, and the phase space factor would tend to make the cross section for this process negligible. Also, since the cross sections for K\(^-\) reactions are approximately geometrical,\(^3\) the K\(^-\)-nucleon interaction cannot be a great deal weaker than the \(\pi\)-nucleon interaction, and therefore competing processes of the type

\[
K + n \rightarrow K + n + \gamma
\]

will also be neglected.

It is useful to expand the various initial and final states into isotopic spin eigenstates, and to use their orthogonality to obtain the matrix elements for the processes which we wish to consider. This is done in Table I.\(^4\)

As can be seen from this table, there are seven unknowns and eight independent cross sections (as it is almost impossible to distinguish between the final states involving the \(\lambda^0\) and the \(\Sigma^0\)). One can, however, reduce the number of unknowns by making the assumption that the difference in the matrix elements involving the emission of a \(\lambda^0\) and a \(\Sigma^0\) is only one of energy, i.e., that the \(\lambda^0\) and the \(\Sigma^0\) only differ in mass and isotopic spin, which is consistent with the Gell-Mann scheme. Assuming the final pion is emitted in a P-state at these energies, we shall write

\[
J^J_i/G_i^J = \frac{(p^2/\omega)_{\pi\Sigma}}{(p^2/\omega)_{\pi\Lambda}} \frac{P_{\pi}}{P_{\Lambda}} \equiv \frac{1}{\alpha^2} \approx \frac{1}{3}
\]
Table I

A list of all possible K⁻ interactions, their matrix elements and differential cross sections

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Final state wave function</th>
<th>Matrix element</th>
<th>Differential cross section</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$\frac{1}{\sqrt{2}}(Y_{i} + Y_{o})$</td>
<td>$\frac{1}{2}(I_{i} + I_{o})$</td>
<td>$\frac{1}{4}[I_{i}^{2} + I_{o}^{2} + 2Re I_{i} I_{o}^{*}]$</td>
</tr>
<tr>
<td>II</td>
<td>$\frac{1}{\sqrt{2}}(Y_{i} - Y_{o})$</td>
<td>$\frac{1}{2}(I_{i} - I_{o})$</td>
<td>$\frac{1}{4}[I_{i}^{2} + I_{o}^{2} - 2Re I_{i} I_{o}^{*}]$</td>
</tr>
<tr>
<td>III</td>
<td>$Y_{i}$</td>
<td>$I_{i}$</td>
<td>$I_{i}^{2}$</td>
</tr>
<tr>
<td>IV</td>
<td>$Y_{i}$</td>
<td>$\frac{1}{\sqrt{2}}G_{i}$</td>
<td>$\frac{1}{2}G_{i}^{2}$</td>
</tr>
<tr>
<td>V</td>
<td>$Y_{i}$</td>
<td>$G_{i}$</td>
<td>$G_{i}^{2}$</td>
</tr>
<tr>
<td>VI</td>
<td>$\frac{1}{\sqrt{3}}[Y_{i} - \sqrt{3} Y_{o} + \sqrt{2} Y_{o}]$</td>
<td>$-\frac{1}{\sqrt{2}}J_{i} + \frac{1}{\sqrt{6}}J_{o}$</td>
<td>$-\frac{1}{\sqrt{2}}J_{i} + \frac{1}{\sqrt{6}}J_{o}$</td>
</tr>
<tr>
<td>VII</td>
<td>$\frac{1}{\sqrt{3}}[\sqrt{2} Y_{o} - Y_{o}]$</td>
<td>$\frac{1}{\sqrt{6}}J_{o}$</td>
<td>$\frac{1}{3}J_{o}^{2}$</td>
</tr>
<tr>
<td>VIII</td>
<td>$\frac{1}{\sqrt{6}}[Y_{i} + \sqrt{3} Y_{i} + \sqrt{2} Y_{o}]$</td>
<td>$\frac{1}{\sqrt{2}}J_{i} + \frac{1}{\sqrt{6}}J_{o}$</td>
<td>$\frac{1}{\sqrt{2}}J_{i} + \frac{1}{\sqrt{6}}J_{o}$</td>
</tr>
<tr>
<td>IX</td>
<td>$\frac{1}{\sqrt{2}}(Y_{i} - Y_{o})$</td>
<td>$-\frac{1}{\sqrt{2}}J_{i}$</td>
<td>$\frac{1}{2}J_{i}^{2}$</td>
</tr>
<tr>
<td>X</td>
<td>$\frac{1}{\sqrt{2}}(Y_{i} + Y_{o})$</td>
<td>$\frac{1}{\sqrt{2}}J_{i}$</td>
<td>$\frac{1}{2}J_{i}^{2}$</td>
</tr>
</tbody>
</table>

where the factor $\frac{\rho_{\pi}}{\rho_{\Lambda}}$ takes into account the difference in phase space available to the reaction products.

One can also introduce a classification of the processes by their final states, which is a little more in conformance with the experimental situation (Table II), and write down a number of relations between the various cross sections, which should hold true under the assumptions made.

The usefulness of these relations for emulsions is somewhat diminished by the fact that the pions in the final state can interact with the nucleus and whenever they undergo charge exchange scattering or form a star, the elementary final state is disguised. In a hydrogen or deuterium bubble-chamber, however, all the final states are distinguishable, so that these relations could be checked. If the K⁻ beam is appreciably contaminated by $\Sigma^{-}$, then depending on the assignment of isotopic spin and strangeness for the $\Sigma$, these relations are more or less complicated. If the $\Sigma$ is viewed as having the same I and $S$ as the K⁻, the number of unknowns is essentially doubled so that no check is possible. If, however, one makes the assignment $\Sigma^{2}$ (I= 0; S = ± 2), then the lines IV - X in Table I are unaltered and in I and III the cross sections have $I_{F}^{2}$ added to them.
Table II

Classification of processes by final states

<table>
<thead>
<tr>
<th>Final state</th>
<th>Hydrogen</th>
<th>Deuterium (†) (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. K⁻ out</td>
<td>$\frac{1}{4} \left[ I_1^2 + I_2^2 + 2 \alpha \epsilon I_1^* I_0 \right] $</td>
<td>$\frac{1}{4} \left[ 5I_1^2 + I_2^2 + 2 \alpha \epsilon I_1^* I_0 \right] $</td>
</tr>
<tr>
<td>2. charged hyperon</td>
<td>$\frac{1}{2} J_1^2 + \frac{1}{3} J_0^2$</td>
<td>$J_1^2 + \frac{1}{3} J_0^2$</td>
</tr>
<tr>
<td>3. charged meson</td>
<td>$\frac{1}{2} J_1^2 + \frac{1}{3} J_0^2$</td>
<td>$J_1^2 \left( 1 + \alpha^2 \right) + \frac{1}{3} J_0^2$</td>
</tr>
<tr>
<td>4. charged hyperon and</td>
<td>$\frac{1}{2} J_1^2 + \frac{1}{3} J_0^2$</td>
<td>$\frac{1}{2} J_1^2 + \frac{1}{3} J_0^2$</td>
</tr>
<tr>
<td>charged meson</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. neutral hyperon*</td>
<td>$\frac{1}{2} \alpha^2 J_1^2 + \frac{1}{6} J_0^2$</td>
<td>$\left( \frac{3}{2} \alpha^2 + \frac{1}{2} \right) J_1^2 + \frac{1}{3} J_0^2$</td>
</tr>
<tr>
<td>6. &quot;stop-in-flight&quot;</td>
<td>$\frac{1}{2} \alpha^2 J_1^2 + \frac{1}{6} J_0^2 + \frac{1}{4} \left( I_1^2 + I_2^2 - 2 \alpha \epsilon I_1^* I_0 \right)$</td>
<td>Same as for hydrogen</td>
</tr>
</tbody>
</table>

† Assuming $N = Z$, the results for deuterium can be applied to emulsions by multiplying by $A/2$.

* These cross sections are not observable in emulsions at this time.

REFERENCES

1. S. Goldhaber, private communication.
4. We use different notation for the three classes of processes which differ by more than the isotopic spin.
5. Since the wavelength of a 250 Mev/c K meson is appreciably smaller than the radius of the deuteron, these cross sections are calculated additively from the proton and neutron cross sections.