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EVIDENCE FOR LOW RATES FOR $\beta$ DECAY OF $\Sigma^-$ AND $\Delta$ HYPERONS

William E. Humphrey, Janos Kirz, Arthur H. Rosenfeld,
J. Leitner, and Y. L. ihoe

March 15, 1961
EVIDENCE FOR LOW RATES FOR $\beta$ DECAY OF $\Sigma^-$ AND $\Lambda$ HYPERONS\(^{1,2}\)

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March 15, 1961

According to the theory by which strangeness-violating Fermi interactions take place with the same coupling constant as strangeness-preserving weak interactions,\(^1\) the hyperon decays

$$\Sigma^- \rightarrow e^- + n + \bar{\nu}$$  \hspace{1cm} (1a)

and

$$\Lambda \rightarrow e^- + p + \bar{\nu}$$  \hspace{1cm} (1b)

were expected to occur with branching fractions of 5.6% and 1.6% respectively. Electron spectra rather close to phase space. Actually experimental rates are already known to fall below these rates by about an order of magnitude,\(^2,3\) and these data are further substantiated in this letter.

The muonic decays $\Sigma^- \rightarrow \mu^- + n + \bar{\nu}$ and $\Lambda \rightarrow \mu^- + p + \bar{\nu}$ were expected with branching fractions of 2.5% and 0.3% respectively, and are probably also by a factor of ten or more. These rare muonic decays are hard to separate from background, especially from normal pionic sigma decay followed by pion decay flight; accordingly we shall not discuss muonic decay in this letter.

The strangeness-conserving beta decay

$$\Sigma^- \rightarrow e^- + \Lambda + \bar{\nu}$$  \hspace{1cm} (2)

is still expected to occur with a branching fraction of $2 \times 10^{-4}$.\(^4\) The beta from $\Sigma^0$

$$\Sigma^0 \rightarrow e^+ + n + \nu,$$  \hspace{1cm} (3a)

The production $S/\Lambda \Omega = 800 \mu a.$
Our $\Sigma^+$ and $\Lambda$ particles were produced in the Berkeley 15-inch hydrogen bubble chamber by the reactions

$$ \begin{align*}
K^+ n &\rightarrow \Sigma^+ + \pi^0, \\
K^- p &\rightarrow \Lambda + \pi^0, \\
\Sigma^0 + \pi^0 &\rightarrow \Lambda + \gamma,
\end{align*} \tag{3a}$$

where the $K^-$ is captured at rest or interacts at very low energy. In order to be able to separate some of the $\beta$ decays of $\Sigma$ from the dominant pionic mode $\Sigma^+ \rightarrow \pi^+ + n$, we used the criterion that the visible decay particle (the electron candidate) should have a laboratory momentum $p \leq 100 \text{ Mev/c}$ and a track length $\geq 5 \text{ cm}$ to assure reliable momentum measurements.

In order to eliminate two major sources of background we did not include in the sample $\Sigma^-$ particles, which left either a very short or a very long track in the chamber.

(a) When a zero-length $\Sigma^-$ $\beta$-decays, the $e^-$ could be confused with the $e^-$ of the electron pair from the chain

$$ K^- + p \rightarrow \Lambda + \pi^0; \quad \pi^0 \rightarrow e^+ + e^- + \gamma, \tag{6} $$

where $p(e^+)$ is close to that of the $\pi^+$ of reaction (3). Similarly, $\Sigma^-$ of range $< 1 \text{ mm}$ were excluded.

(b) When a $\Sigma^-$ $\beta$-decays very near the end of its range, the $e^-$ can be confused with a very close Compton electron from the chain initiated by $\Sigma^-$ capture

$$ \Sigma^- + p \rightarrow \Sigma^0 + n; \quad \Sigma^0 \rightarrow \gamma + \Lambda; \quad \gamma \rightarrow \text{Compton}. \tag{7} $$

The decay mode

$$ \Sigma^+ \rightarrow p + \pi^0 \tag{8} $$

(where the proton track can be readily identified by ionization and range) was examined. Its contribution to the branching fraction was taken into account.
Most of our $\Sigma$ events were obtained with the 1950 $K^-$ beam. About 50,000 $K^-$ particles (at approx. 2 per picture for $2 \times 10^{11}$ protons per pulse) entered the chamber, with an average $p = 230$ Mev/c. These yielded 6700 $\Sigma^-$ decays and 1500 $\Sigma^+$ decays through Channel (5), which satisfied the above criteria, and were also flat enough (dip $\leq 45$ deg) to permit preselection on scanning projectors. Momentum templates and correction tables for dip, magnification, and similar effects were used to select the sample to be measured. The efficiency of this process is close to 100% at low electron momenta, but losses near 100 Mev/c reduce the over-all efficiency to about 85%.

In addition to this, a 1958 $K^-$ experiment produced 1400 $\Sigma^-$ decays and 300 $\Sigma^+$ decays through Channel (5) which satisfy our selection criteria. All these events have been measured, therefore the efficiency for the search is close to 100%.

If we combine the efficiency with the fraction of the phase space for $0 \leq p_e \leq 100$ Mev/c (which is about $1/3$), the effective branching-fraction denominator becomes

$$1/3(0.85 \times 6700 + 1400) = 2400 \text{ for } \Sigma^-, \text{ and}$$

$$1/3(0.85 \times 1500 + 300) = 525 \text{ for } \Sigma^+ \text{ through Channel (5)}. $$

If we include the $\Sigma^+$ decays through Channel (8) our effective denominator becomes 1050 for $\Sigma^+$. Two further sources of background were considered:

(a) About 1 in 300 $\Sigma^-$ particles interacts in flight, and by Process (7) or similar means produces an $e^-$ within 5 mm. The probability for this is less than $10^{-6}$; we exclude the cases in which a visible $\Lambda$ decay makes the reaction easily detectable.
(b) If the chamber is not operating at optimum sensitivity, p one and tracks
with \( p = 100 \text{ Mev/c} \) can be close to minimum-ionizing. Then if the decay \( \Lambda \) is not identified by range or delta rays, the decay modes
\[
\Sigma^\pm \rightarrow \pi^\pm + n + \gamma
\]
and
\[
\Sigma^\pm \rightarrow \pi^\pm + n \text{ followed by } \pi^\pm \rightarrow \mu^\pm + \nu
\]
within a few millimeters could simulate \( \beta \) decay with a small probability.

The results of our search are as follows:

We found three \( \Sigma^- \) decays which had charged decay particles with \( p < 100 \text{ Mev/c} \). One of these has a decay track of \( 91 \pm 3 \text{ Mev/c} \), and could be a background event of the second type mentioned above, since the ionization does not rule out particles heavier than an electron. The second one is shown in Fig. 1; it has a decay electron of \( 49 \pm 2 \text{ Mev/c} \), and is therefore either a strangeness-violating \( \beta \) decay (1a) or a strangeness-conserving \( \beta \) decay (2).

The third candidate has a decay electron of \( 93 \pm 5 \text{ Mev/c} \). This event could, however, be due to Chain (6), because the \( \pi^+ \) from reaction (5) doubles back on incoming \( K^- \) track, thereby obscuring the \( \Sigma^- \) production vertex.

No candidates for \( \Sigma^+ \beta \) decay were found.

Next we discuss the 900 visible \( \Lambda \) decays produced by the 1958 \( K^- \) beam. These were measured, and the ones that did not fit the kinematics for picnic decay were examined for coplanarity. Other than one event found by inspection, no certain \( \beta \) decays were found.

Our efficiency for finding \( \Lambda \beta \) decays is about 70\%. Therefore the effective denominator (including the unseen \( \Lambda \rightarrow n + \pi^0 \) decays) is
\[
(3/2) \times 900 \times 0.70 = 950
\]

Our current information on \( \beta \) branching fractions is now summarized:
Table I

<table>
<thead>
<tr>
<th>World survey of events reported up to Nov. 1958(^7)</th>
<th>(\Sigma^-)</th>
<th>(\Sigma^+)</th>
<th>(\Lambda)</th>
<th>(\Sigma)</th>
<th>(\Sigma^+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dyer(^9)</td>
<td>67</td>
<td>130</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Berkeley propane bubble chamber(^{10})</td>
<td>2000</td>
<td>2000</td>
<td>10000</td>
<td>1?</td>
<td>0</td>
</tr>
<tr>
<td>Baglin et al. (Freon chamber)(^{11})</td>
<td>150</td>
<td>-</td>
<td>4500</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Helium chamber(^{12})</td>
<td>60</td>
<td>70</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Franzini and Steinberger (propane chamber)(^{13})</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>This letter</td>
<td>2400</td>
<td>1050</td>
<td>950</td>
<td>1+2?</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>4900</td>
<td>3350</td>
<td>17000</td>
<td>2+n?</td>
<td>0</td>
</tr>
</tbody>
</table>

The branching fractions calculated from Table I are little more than low limits. For every sure leptonic decay there are usually several "possibles."

It might be reasonable to double the fraction above, yielding 1/1000 \(\Sigma^- \rightarrow \mu^- e^-\); 0/1000 \(\Sigma^+ \rightarrow e^+\); and 2/1000 \(\Lambda \rightarrow e^-\). This guess should then be credible within a factor of 2, again assuming the electron spectrum does not deviate drastically from phase space.

If we compare this with the original predictions by Feynman and Gell-Mann\(^1\) we have

<table>
<thead>
<tr>
<th>(\Sigma^- \rightarrow e^- + n + \nu)</th>
<th>Experiment</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\approx 0.1%)</td>
<td>5.6%</td>
<td></td>
</tr>
<tr>
<td>(\Lambda \rightarrow e^- + p + \nu)</td>
<td>(\approx 0.2%)</td>
<td>1.6%</td>
</tr>
<tr>
<td>(\Sigma^+ \rightarrow e^+ + n + \nu)</td>
<td>(\approx 0)</td>
<td>0</td>
</tr>
</tbody>
</table>
The discrepancy is about 10 to 1 for $\Lambda$ decay and perhaps more for $\Sigma$ decay; we conclude that $\beta$ decays of hyperons cannot be explained by forms of Fermi interaction such as that of Feynman and Gell-Mann having the same coupling constant at each permitted vertex.

We wish to thank Dr. Donald H. Miller and Dr. Ronald R. Ross for valuable discussions and suggestions. The efficient work of our scanners, especially David J. Church and Lawrence A. Drews, is greatly appreciated.
FOOTNOTES

*Work done under the auspices of the U.S. Atomic Energy Commission.

4. Note that for 1/3 of these decays the $\Delta$ will subsequently decay via its neutral channel and the over-all event then becomes indistinguishable from the low-energy electron cases of reaction (1a).
6. Some of the events included in this sample have already been reported in Ref.
7. P. Nordin, J. Orear, L. Reed, A. H. Rosenfeld, F. T. Solmitz, H. D. Taft, and R. D. Tripp, Phys. Rev. Letters 1, 380 (1958). The survey in that paper did not include the $\Delta$ denominator we are now reporting, although it did include the one $\beta$ decay in the numerator.
8. J. Hornbostel and E. O. Salant, Phys. Rev. 102, 502 (1956). In this experiment only five normal $\Sigma$ decays were found, and no detection efficiency for $\beta$ decays was reported. The event listed is a probable $\beta$ decay of a $\Sigma$ particle of undetermined charge.
10. Wilson M. Powell (Lawrence Radiation Laboratory), private communication. The Powell group did not scan specially for $\beta$ decays. However, bremsstrahlung and curling up make a large fraction of the electrons easy to spot. The $2000 \Sigma^{-}$ and $\Sigma^{+}$ represent approx $1/3$ of the propan group's sample (we assume they also have a $1/3$ probability of finding a $\Sigma\beta$ decay). The possible $\Sigma^{-} \rightarrow e^{-} + n + \bar{\nu}$ decay could also be a $K$ decay, since $\Sigma$ production did not have an associated pion.

The $10,000 \Lambda$'s represent about $1/2$ of the group's sample of 14,000 corrected for the unseen $n^{0} + n$ decays. The factor of $1/2$ assumes that they can identify electrons below 85 Mev/c.


12. Martin M. Block (Duke University), private communication.


This event is definitely a strangeness-changing decay (1a). The $e^{-}$ momentum rules out the possibility of $\Sigma^{-} \rightarrow \Lambda + e^{-} + \bar{\nu}$. 
Fig. 1. $\beta$ decay of $\Sigma^-$ produced in the reaction $K^- + p \rightarrow \Sigma^- + \pi^+$. The $K^-$ particle scatters elastically before being captured. A $\delta$ ray of 5 Mev/c originates from the first 2.5 mm of the decay track. The momentum beyond the $\delta$ ray was measured as $43 \pm 1.2$ Mev/c. The length of the $\Sigma^-$ track ($2.2 \pm 0.3$ mm) indicates that the $\Sigma^-$ did not stop before decay.