LEPTONIC DECAYS OR CHARGED SIGMA HYPERONS AND CABIBBO'S THEORY OF LEPTONIC DECAYS

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(Presented by H. FILTHUTH)

A sample of about 400,000 Σ^+ and Σ^- hyperons were studied for leptonic decays of the following six types:

$$\left.\begin{array}{l}\Sigma^- \to n + e^- + \nu \\ \Sigma^- \to n + \mu^- + \nu\end{array}\right\} \frac{\Delta S}{\Delta Q} = +1; \qquad \begin{array}{r}(1,\text{a})\\(1,\text{b})\end{array}$$

$$\left.\begin{array}{l}\Sigma^- \to \Lambda + e^- + \nu \\ \Sigma^+ \to \Lambda + e^+ + \nu\end{array}\right\} \Delta S = 0; \qquad \begin{array}{r}(1,\text{c})\\(1,\text{d})\end{array}$$

$$\left.\begin{array}{l}\Sigma^+ \to n + e^+ + \nu \\ \Sigma^+ \to n + \mu^+ + \nu\end{array}\right\} \frac{\Delta S}{\Delta Q} = -1. \qquad \begin{array}{r}(1,\text{e})\\(1,\text{f})\end{array}$$

This report is based on the observation of 130 $\Sigma^\pm$ leptonic decays. The Σ hyperons were produced by K^- mesons, from the CERN PS, coming to rest in the Saclay 81 cm hydrogen bubble chamber.

A. RELATIVE STRENGTH OF $\Delta S = +\Delta Q$ AND $\Delta S = -\Delta Q$ TRANSITIONS

No definite event of the type $\Delta S = -\Delta Q$ has been seen.

We have found 52 unambiguous $\Sigma^- \to n + e^- + \nu$ events and 22 unambiguous $\Sigma^- \to n + \mu^- + \nu$ events versus zero $\Sigma^+ \to n + (e^-, \mu^+) + \nu$ events. Given the differences in production ratios of Σ^- and Σ^+ hyperons from (K^-, p) reactions at rest [1] and the criteria imposed on our events to eliminate background, the ratio of $\Sigma^+ \to n + \pi^+$ decays to $\Sigma^+ \to n + \pi^-$ decays is calculated to be 1/3.8. If we define

$$\delta = \frac{\text{rate of } \Delta Q = -\Delta S \text{ transitions}}{\text{rate of } \Delta Q = +\Delta S \text{ transitions}}$$

we find that the upper limit with 90% confidence for δ is 12%. The Columbia — Rutgers — Princeton collaboration independently obtains a similar upper limit of 15% [2].

B. $\Delta = 0$ AND $\Delta S = +\Delta Q$ HYPERON DECAY RATES; AND TESTS OF $\Delta I = 1$ RULE AND (μ, E) UNIVERSALITY

The rates, or branching ratios, of the decay modes that we have observed are summarized in Table 1, together with the predictions of the original Universal Fermi Interaction, (UFI) [3], conserved vector current (CVC) theory [4]. Our experimental branching ratio $R_{e^-} = (\Sigma^- \to n + e^- + \nu/\Sigma^- \to n + \pi^-) = (1.4 \pm 0.3) \times 10^{-3}$ is in excellent agreement with two other recent measurements that yielded $R_{e^-} = (1.37 \pm 0.34) \times 10^{-3}$ [2] and $(1.0 \pm 0.5) \times 10^{-3}$ respectively. The hypothesis [6] that the interaction in $\Sigma^\pm \to \Lambda + e^\pm + \nu$ decay transforms as $\Delta I = 1$ predicts [7] that the ratio $(\Sigma^- \to \Lambda + e^- + \nu)/(\Sigma^+ \to \Lambda + e^+ + \nu)$ equals 1.6. The data in Table 1 yield/1.1 $\pm^{1}_{0.4}$ for this ratio, in agreement with

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Table 1

Summary of branching ratios of leptonic decays

Decay	UFI Prediction	$R=\frac{\Sigma^{\pm} \to \text{leptons}}{\Sigma^{\pm} \to \pi^{\pm} + n}$	No. of events used
$\Sigma^- \to e+n+\bar{\nu}$	580×10^{-4}	$(14\pm3)\times10^{-4}$	31
$\Sigma^- \to \mu+n+\bar{\nu}$	260×10^{-4}	$(6.6\pm1.4)\times10^{-4}$	22 (μ^- stop)
$\Sigma^- \to \Lambda+e^-+\nu$	1.8×10^{-4}	$(0.75\pm0.28)\times10^{-4}$	11 ($\Lambda \to p\pi^-$)
$\Sigma^+ \to \Lambda+e^++\nu$	1.1×10^{-4}	$(0.66\pm0.35)\times10^{-4}$	1 ($\Lambda \to p\pi^-$), 3 (Λ Not observed)
$\Sigma^+ \to e^++n+\nu$	0	$<2.3\times10^{-4}$	0
$\Sigma^+ \to \mu^++n+\nu$	0	$<2.6\times10^{-4}$	0

this prediction, within the large statistical er rors.

A test of the hypothesis of equal (μ, ν) and (e, ν) couplings in hyperon decay can be made by comparing the decay rates of $\Sigma^- \to n + \mu^- + \nu$ and $\Sigma^- \to n + e^- + \nu$. Ignoring all interactions other than allowed vector and axial vector, μ, e universality predicts that $w(\Sigma^- \to n + \mu^- + \nu)/w(\Sigma^- \to n + e^- + \nu) = 0.45$, essentially the ratio of phase space for the two decay modes. From Table 1 we can see that our experimental result for this ratio is 0.47 ± 0.14, in excellent agreement with μ, e universality.

C. COMPARISON OF CABIBBO'S THEORY OF WEAK INTERACTIONS WITH EXPERIMENT

In brief, Cabibbo [8] postulates that the strongly interacting charged currents coupled to leptons transform under SU_3 transformations like members of an octet. It follows that there are only two types of currents, $\Delta S = 0$, $\Delta I = 1$ and $\Delta S = +\Delta Q$, $\Delta I = 1/2$. The currents are further assumed to be linear combinations of vectors and axial vectors with respect to space time. In the limit of exact SU_3 symmetry, all the vector currents are conserved. The original idea of a universal four fermion interaction is modified by assuming that the sum of the squares of unrenormalized vector coupling constants for the $\Delta S = 0$ and $\Delta S = +\Delta Q$ currents equals the square of the $\mu \to e + \nu + \tilde{\nu}$ coupling constant. Hence one can define an angle θ such that $j_\mu(\Delta S = 0) \sim \cos\theta$ and $j_\mu(\Delta S = +\Delta Q) \sim \sin\theta$. The axial vector currents, which are not conserved, are assumed to be proportional to the same angle factors, and to have the same renormalization factors for all hyperon decays as for the $n \to p$ beta decay. Cabibbo [8] has shown with preliminary hyperon leptonic decay data that with the assumptions outlined above, there exists an angle, $\theta \simeq 0.26$, that fits roughly, not only the baryon leptonic decays but also the $K^+ \to \mu^+ + \nu$ and $K^+ \to \pi^0 + e^+ + \nu$ decays.

In what follows we carry out a least square fit to all the pertinent data using Cabibbo's theory. We find two distinct acceptable fits to the data.

As experimental input, we take the eight pieces of data listed in Table 2.

Table 2

Data used to test Cabibbo's theory of leptonic decays

Quantity	Value	Source
1. $\left(\frac{\Lambda \to p+e^-+\nu}{\text{all } \Lambda}\right)$	$-(1.0\pm0.1)\times10^{-3}$	[15], weighted average
2. $\left(\frac{\Sigma^- \to n+e^-+\nu}{\Sigma^- \to n+\pi^-}\right)$	$(1.39\pm0.2)\times10^{-3}$	Table 1 and [2]
3. $\left(\frac{\Sigma^- \to \Lambda+e^-+e}{\Sigma^- \to n+\pi^-}\right)$	$(0.75\pm0.28)\times10^{-4}$	Table 1
4. $\left(\frac{\Xi^- \to \Lambda+e^-+\nu}{\text{all } \Xi^-}\right)$	$(2.4\pm1.4)\times10^{-3}$	[9]
5. $(G_V^{n\to p}/G_V^{\mu\to e})$	0.975 ± 0.010	[16]
6. (G_A/G_V) $(n \to p)$	1.15 ± 0.05	[10]
7. $\frac{K^+ \to \mu^++\nu}{\text{all } K^+}$	0.60 ± 0.04	[11]
8. $\frac{K^+ \to \pi^0+e^++\nu}{\text{all } K^+}$	0.050 ± 0.005	[11]

The parameters that enter into the theory are the angle θ, defined above, and the strengths of the F and D reduced matrix elements of the axial vector current. The CVC hypothesis implies that only F_V terms exist for the vector part. The equations that must be satisfied are the following:

$$\left(\frac{\Lambda^0 \to p+e^-+\nu}{\text{all }\Lambda}\right) = 0{,}37 \times 10^{-2} \sin^2\theta \times$$

$$\times \left(\frac{3}{2}\right)\left[1+2{,}98\left(F+\frac{1}{3}D\right)^2\right]; \quad (2)$$

$$\left(\frac{\Sigma^- \to n+e^-+\nu}{\text{all }\Sigma^-}\right) = 1{,}52 \times 10^{-2} \sin^2\theta\,(1) \times$$

$$\times [1+2{,}95\,(D-F)^2]; \quad (3)$$

$$\left(\frac{\Sigma^- \to \Lambda^0+e^-+\nu}{\text{all }\Sigma^-}\right) =$$

$$= 0{,}60 \times 10^{-4} \cos^2\theta \left(\frac{2}{3}\right)[3{,}00D^2]; \quad (4)$$

$$\left(\frac{\Xi^- \to \Lambda^0+e^-+\nu}{\text{all }\Xi^-}\right) = 5{,}7 \times 10^{-3} \sin^2\theta \times$$

$$\times \left(\frac{3}{2}\right)\left[1+2{,}98\left(F-\frac{1}{3}D\right)^2\right]; \quad (5)$$

$$\left(\frac{\sigma_V^{n\to p}}{\sigma_V^{\mu\to e}}\right)^2 = \cos^2\theta; \quad (6)$$

$$\left(\frac{\sigma_A}{\sigma_V}\right)_{n\to p} = F+D. \quad (7)$$

In obtaining the numbers in eqs. (2—7), we have adopted $G_V^{\mu\to e} = 1.025/M_p^2$ as deduced from the μ lifetime, $\tau_\mu = 2.200\ \mu$ sec [12], and masses and lifetimes from Barkas and Rosenfeld [13] and Ticho [9].

We have searched for the best values of the parameters θ, F and D in the sense of the minimum value of the chi-squared funotion computed with (i) all eight pieces of data in Table 2, and (ii) the first six, omitting the K^+ decay data. The results are listed in Table 3, along with the probabilities of the chi-squared values for 5 and 3 degrees of freedom for the solutions (i) and (ii). The values of some of the experimental quantities deduced from these solutions are also given. The χ^2 probability values indicate two acceptable types of solutions called A and B. The addition of the K^+ data hardly changes the solutions and is in surprisingly good agreement with the hyperon data. Solution A is of the type originally obtained by Cabibbo [8]. Solution B is closer to the type of hyperon decay pattern suggested by G. Zweig [14], based on «aces». Solution A, on the other hand, has the character suggested by the generalized Goldberger — Treiman relations. Figure illustrates the positions of these two solutions in the F, D space and also shows how each baryon leptonic decay experiment serves to impose conditions in this space.

The Cabibbo angle θ is not sensitive to the type of solution, but is always within the limits $0.25 < \theta < 0.27$. The assumption of an octet current is to some extent born out by the relative magnitudes of the $\Lambda \to p$ and $\Sigma \to n$ beta decays.

Table 3

Least square solutions to Cabibbo's theory of leptonic decays using the data of Table as 2 input

	Sol. A.		Sol. B.	
	(i)	(ii)	(i)	(ii)
No. of input data	8	6	8	6
No. of constraints	5	3	5	3
(χ^2) probability	(4.75) 45%	(3.51) 32%	(7.92) 17%	(7.04) 8%
θ	0.264	0.272	0.249	0.246
F	0.437	0.436	0.715	0.749
D	0.742	0.742	0.409	0.377
$\Lambda \to p+e^-+\bar{\nu}$/all Λ	0.91×10^{-3}	0.96×10^{-3}	1.08×10^{-3}	1.10×10^{-3}
$\Sigma^- \to n+e^-+\bar{\nu}$/all Σ^-	1.32×10^{-3}	1.38×10^{-3}	1.19×10^{-3}	1.28×10^{-3}
$\Sigma^- \to \Lambda+e^-+\bar{\nu}$/all Σ^-	0.61×10^{-4}	0.59×10^{-4}	0.19×10^{-4}	0.16×10^{-4}
$\Xi^- \to \Lambda+e^-+\bar{\nu}$/all Ξ^-	0.65×10^{-3}	0.66×10^{-3}	1.06×10^{-3}	1.06×10^{-3}
A/V for $\Sigma^- \to e^-+n+\bar{\nu}$	+0.305	+0.292	—0.306	—0.372
A/V for $\Lambda^- \to e^-+p+\bar{\nu}$	+0.685	+0.684	+0.851	+0.875

Further support for Cabibbo's theory is given by a calculation that we have carried out, minimizing chi-squared with independent angles θ and θ' for the vector and axial vector currents respectively, using only the baryon leptonic decay data. We find for solutions of both types, A and B, that the best values of θ and θ′ are equal within a few percent to 0.26.

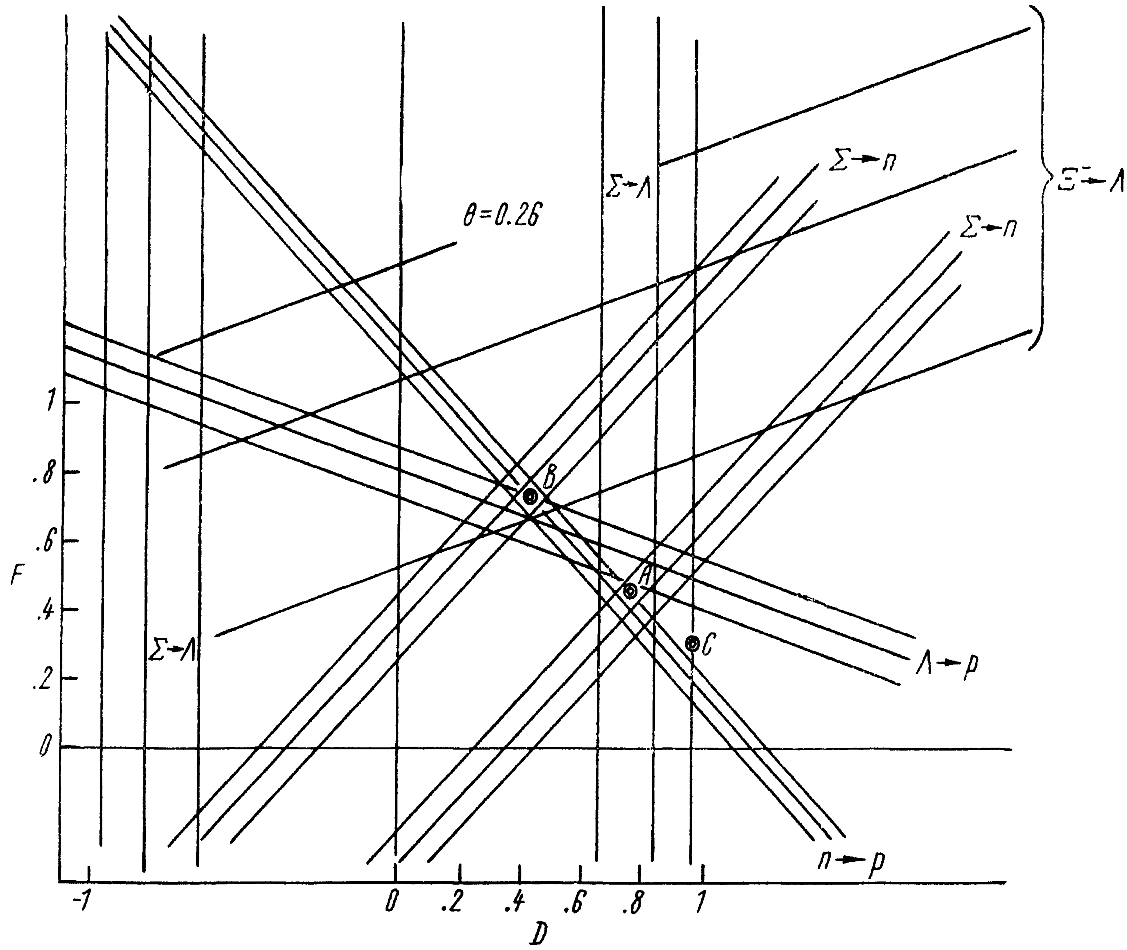

Fig. Comparison of experimental data on baryon leptonic decays with Cabibbo's theory for $\theta = 0.26$. The parameter F and D are the strengths of the two independent reduced matrix elements of the axial vector current. Table 2 and Eqs. (2)—(7) in the text list the experimental data and formuls used to construct this Figure. The points A and B denote the best fit solutions obtained by minimizing chi-squared. Point C denotes the original solution of Cabibbo based on earlier data.

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DISCUSSION

L. Jauneau

Concerning the leptonic decay of Σ and Λ,* I would like to give the results of a collaboration between

CERN, Ecole Polytechnique, University College of London, and University of Bergen:

1) 16 $\Sigma^- \to e^-$ events, giving a branching ratio of $1.15 \pm 0.4 \times 10^{-3}$,

2) No $\Sigma^+ \to e^+$ event out of 11 000 Σ^+ decays,

3) $2\Lambda \to \mu^- \nu P$ events, giving a branching ratio of $1.5 \pm 1.2 \times 10^{-4}$.

R. Nataf

Is it possible to improve the experiment reported by Rubbia in order to obtain an experimental information on PC invariance of strange currents, which is till now very poor? This would come from the sign of the tricdron made by $\vec{p}$, $\vec{e}$, moments directions in the rest system of Λ_0, with the normal to its production plane.

C. Rubbia

This is possible in principle however one has to remind that the initial momentum of our A's and the momentum of outgoing proton are not known and the sensitivity of the best can be considerably reduced by the averaging over the particles which are not measured.

N. Dallaporta

I wish to mention briefly the results obtained on the same experiment as reported by Prof. Lagartique by the Padua group of Mrs. Baldo Ceolin and coworkers. The analysis of 67 events, selected according to special criteria, yield for the violation parameter x the following results: a) from the time distribution of the total member of leptonic decays: $x = 0{,}3 \begin{smallmatrix} +0{,}15 \\ -0{,}20 \end{smallmatrix}$. This result is not considered to be significantly different from the Paris result of the maximum likelihood function has a very wide maximum of allowing a precise determination of x. Therefore the Padua group prefers to rely on the result obtained by: b) the relative frequencies of events of different signs, yielding $x = 0{,}35 \begin{smallmatrix} +0{,}20 \\ -0{,}15 \end{smallmatrix}$ and for the mass difference $\Delta m = 1.0 \pm 0.3$. The chief support in favour of some violation of $\Delta Q = \Delta S$ is given by the relatively high member of short time e^- events (altogether 6 instead of 0,3 as expected for non-violation). In conclusion, one may say that while analysis of type a) yields a result which is not in substantial disagreement with $\Delta Q = \Delta S$ this rule is not easily to be reconciled with the distribution of event's, according to analysis of type b).