help balance transverse momentum, one obtains only a slightly improved fit.

[6] Out of 370 effective Λ decays, zero leptonic decays were found in a series of hydrogen and propane bubble chamber experiments by Eisler, Plano, Prodell, Samios, Schwartz, Steinberger, Conversi, Franzini, Manelli, Santangelo, and Silvestrini, Nevis Cyclotron Laboratory Report No. 67 (unpublished).

[7] R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

LEPTONIC DECAYS OF HYPERONS

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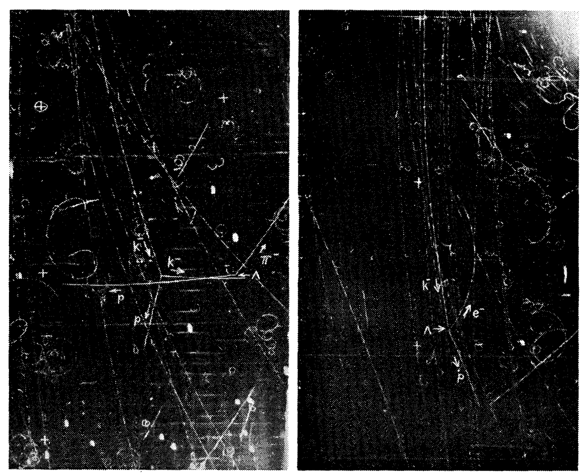
A few days after learning of the event reported in the preceding Letter one of us noticed another Λ beta decay. This second event was found in the film taken in the course of an experiment in which an electrostatically separated K^- beam[1] was passed into the Berkeley 15-inch hydrogen bubble chamber.

Our scanners have so far logged $\approx$7000 cases of hyperon production, among them almost 2000 Λ. A typical Λ production and decay is shown in Fig. 1 (a). The K happened to scatter on a proton before coming to rest, where it produced a Λ. In the course of measuring the K-p scatter, it was noticed that another event in the same picture [Fig. 1 (b)] could not possibly fit the common Λ-production and -decay process; if we restrict ourselves to well established particles we are forced to the conclusion that a Λ produced by the K^- decayed via the process $\Lambda \to p + e^- + \bar{\nu}$. The justification of this interpretation follows: The positive prong of the V must be a proton: it has high momentum, is heavily ionizing, and comes to rest in the chamber without producing any decay particles. The negative prong must be an electron, since we can show by range, curvature, and ionization that it is lighter than a muon. It left the chamber after a path length of 15 cm; a μ would have had an average momentum of at least 52 Mev/c, but the measured average momentum was 44 ± 2 Mev/c. In addition, careful examination of all four views indicates that the negative prong is very close to minimum ionization, while a nearly stopping μ would be several times minimum even at the vertex and would saturate within a few cm.

Having established the identity of the charged secondaries, we must show that the measured momenta and angles are compatible with the kinematics of a Λ produced in K^- capture and decaying via $\Lambda \to p + e^- + \bar{\nu}$. Analysis of the decay shows that the Λ had a momentum of 175 ± 100 Mev/c. This indeed overlaps the range of momentum of Λ produced in K^- capture by protons.

In order to establish a branching ratio of leptonic to pionic hyperon decay, one must estimate in what fraction of the cases one is able to distinguish the various modes. On careful analysis one can distinguish the leptonic from the pionic mode about 90% of the time. (Unfortunately we have so far analyzed only a small fraction of our data.) We also have a finite chance of recognizing "obvious" leptonic decays before they are measured, as is illustrated by the detection of the event described above. However, our detection efficiency for these "obvious" events depends on the alertness of our scanners and is hard to estimate.[2]

A summary of the present experimental status including the work of other laboratories is pre-



(a) (b)

FIG. 1. Normal and β decay of Λ. In the left-hand picture a K^- scatters on a proton before coming to rest and producing a Λ. The Λ decays via the normal mode, $\Lambda \to p + \pi^-$. Notice that the angle of the Λ decay includes the Λ direction of flight. The Λ in the right-hand picture decays via the leptonic mode, $\Lambda \to p + e^- + \bar{\nu}$. Note that the charged secondaries do not point back to the K^- ending, hence the decay is inconsistent with two-body kinematics. Both events are from the same bubble-chamber picture.

sented in Table I, Rows 1 and 2. The remainder of Table I is devoted to comparison of experiment and theory.

The form of the universal Fermi interaction proposed by Feynman and Gell-Mann[3] calls for the branching fractions $f = \Gamma_{\text{lept}}/\Gamma$ listed in Row 3 of Table I. For each mode it predicts the detection of a number of leptonic decays $n_{\text{lept}} = nDf$, where n is the total number of decays seen, D is the detection efficiency for leptonic decay, and f is the predicted branching fraction. Thus one would expect to find a number of Λ beta decays $nDf(\Lambda \to e) = 24.5$, and only two have been found. Similarly $nDf(\Lambda \to \mu) = 5$ (none

Table I. Summary of leptonic decay of hyperons. The first two rows give the effective number n_{eff} of decays reported by several groups: $n_{\text{eff}} = n_{\text{obs}} \times D$ (n_{obs} = total number of decays observed, D = chance of distinguishing leptonic decay from normal decay). The meaning of the μ numbers in parentheses is described in the reference 2. Row 3 lists leptonic branching fractions according to the universal interaction of Feynman and Gell-Mann.[a] They calculate only electronic rates; we got mesonic rates by scaling proportionally to phase space. (Approximation good to few percent.) Row 4 gives relative branching fractions $f = \Gamma_{\text{lept}}/\Gamma$; Γ_{lept} taken proportional to phase space, and $\Gamma = 1/\tau$, where τ is mean life as listed in report of 1958 Conference on High-Energy Physics at CERN (unpublished), p 270 ff. Row 5 lists the "normalized fractions," (1/1000) (f/f_Λ) representing leptonic fraction of decay based on assumption that 1 Λ per 1000 decays electronically.

	Λ (including neutral decays)[b] $\to$		$\Sigma^- \to$		$\Sigma^+ \to$	
	e^-	μ^-	e^-	μ^-	e^+	μ^+
1. Effective number of decays nD:						
$K^- + p$ (bubble chamber)[c]	107	230 (935)	66	69 (323)	46	48 (175)
Assoc. production, Berkeley[d]	1042	1042	49	66		
Assoc. production, Brookhaven[e]	380	380	62	62		
$K^- + p$, emulsion, Berkeley[f]			12	14	19	21
$K^- + p$, emulsion, Livermore[g]			12	5	28	10
Total	1529	1652	201	216	93	79
2. Leptonic decays reported	2[h]	0	1[i]	0[i]	0[i]	0[i]
3. Leptonic fractions f from F and G-M[a]	1.6%	0.3%	5.6%	2.5%	...	...
4. Relative fractions $f/f(\Lambda \to e)$ based on relative phase space	1	0.17	3.7	1.7	1.5	0.63
5. "Normalized leptonic fractions" assuming 1 Λ per 1000 decays electronically	1/1000	1/6000	1/270	1/590	1/680	1/1590

[a] See reference 3.

[b] Λ are quoted as if the mode $\Lambda \to n + \pi^0$ were directly observed. In many cases it has been easier to compute n_Λ by dividing the $p + \pi^-$ decays by the branching fraction 0.63.

[c] This includes the data given by Alvarez, Bradner, et al., University of California Radiation Laboratory Report UCRL-3775, July, 1957 (unpublished).

[d] Crawford, Cresti, Good, Kalbfleisch, Stevenson, and Ticho, preceding Letter [Phys. Rev. Lett. 1, p. 377 (1958)].

[e] Eisler et al., Nevis Cyclotron Laboratory Report No. 67, June, 1958 (unpublished).

[f] Barkas et al., University of California Radiation Laboratory Report UCRL-8372, June, 1958 (unpublished); also private communication from John N. Dyer.

[g] Freden, Gilbert, and White (private communication).

[h] One event comes from the experiment described above,[d] one from this experiment.

[i] J. Hornbostel and E. O. Salant, Phys. Rev. 102, 502 (1956). The decay is most likely $\Sigma^\pm \to e^\pm$, but could also be $\Sigma^\pm \to \mu^\pm$. Five normal decays were reported, but they cannot be included in Row 1 because no leptonic detection efficiency D is reported.

found), $nDf(\Sigma^- \to e^-) = 11.2$, $nDf(\Sigma^- \to \mu^-) = 5.4$ (at most one $\Sigma^- \to e^-$ or μ^- found). Thus a total of 41 events are predicted, and at most three have been found.

Without recourse to a specific theory one can interrelate the data by introducing the hypotheses that all hyperons are coupled to lepton pairs with roughly the same strength and that the matrix elements are energy-insensitive. The leptonic decay rates Γ_{lept} are then proportional to phase space, and the branching fractions f are proportional to $\Gamma_{\text{lept}}/\Gamma$, where Γ is the total experimental decay rate. Row 4 of the table gives the relative branching fractions $f/f(\Lambda \to e)$. For ease in comparison with the experimental totals we also list, in Row 5, the "normalized fractions" $(1/1000)f(\Lambda \to e)$ which represent the leptonic fraction of decay based on the observation that on the order of one Λ per thousand decays electronically and the assumption that the rates are proportional to phase space.

We conclude, by comparing these "normalized fractions" with the experimental totals and the three observed events, that there is as yet no evidence against the hypothesis that hyperon leptonic decay rates are proportional to phase space but that the absolute rate seems lower than predicted by Feynman and Gell-Mann.

We wish to thank Luis W. Alvarez, Hugh Bradner, J. Donald Gow, and all the rest of our group for their help and support.

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†On leave from Yale University, New Haven, Connecticut.

[1] Horwitz, Murray, Ross, and Tripp, University of California Radiation Laboratory Report UCRL-8296, June, 1958 (unpublished).

[2] A certain fraction of the muonic decays should be quite striking. If the μ is of sufficiently low momentum ($\lesssim 60$ Mev/c), it will come to rest in the chamber and exhibit the characteristic $\mu^\pm \to e^\pm$ decay. If we assume that the μ-momentum spectrum is proportional to phase space, we find that about 1/3 of the μ from $\Lambda \to \mu$ (and 1/10 from $\Sigma^\pm \to \mu^\pm$) should come to rest in our chamber. If our scanners were 100% efficient in detecting these stopping μ, our number of effective events should be increased by the numbers given in parentheses in Table I. An event in which a low-energy electron is emitted or which clearly does not fit two-body kinematics [like the event in Fig. 1 (b)] may also be recognized on inspection, but we omit them from further consideration because they would in general not be so striking as stopping μ.

[3] R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

ERRATA

OPTICAL PROPERTIES OF CRYSTALLINE BORON. W. G. Spitzer and W. Kaiser [Phys. Rev. Lett. 1, 230 (1958)].

The following errors on page 232 are to be noted: In line 10, $h\nu > 1.2$ ev should be $h\nu > 1.5$ ev; in line 13, $0.6 \leq h\nu \leq 1.2$ ev should be $0.6 \lesssim h\nu \lesssim 1.5$ ev.

CHANGES IN 1955 ATOMIC CONSTANTS OCCASIONED BY REVISION OF μ_e/μ_0. E. Richard Cohen and Jesse W. M. DuMond [Phys. Rev. Lett. 1, 291 (1958)].

In Table I, the line which now reads

$$h = 6.62391 \times 10^{-27} \text{ erg sec}$$

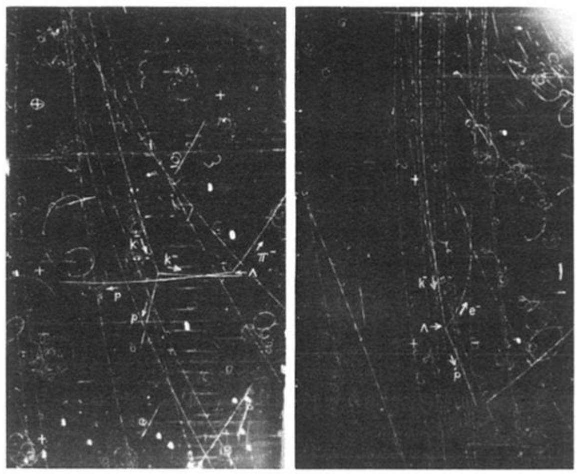
should in fact read

$$h = 6.62491 \times 10^{-27} \text{ erg sec.}$$

ANNOUNCEMENT

This is a further reminder that the period of free subscription to PHYSICAL REVIEW LETTERS for all subscribers to THE PHYSICAL REVIEW will end with Volume 1, Number 12 of this Journal (issue of December 15, 1958). Thereafter, a charge will be made in accordance with the schedule on the masthead page.

Subscriptions are handled by the American Institute of Physics. Persons who have not yet returned the Institute's billing form may simply mark "N" in the appropriate box, and recompute their charges accordingly. For the benefit of those who returned the form without noticing that such positive action is required, we have inserted in this issue a supplementary order form.



(a) (b)

FIG. 1. Normal and β decay of Λ. In the left-hand picture a K^- scatters on a proton before coming to rest and producing a Λ. The Λ decays via the normal mode, $\Lambda \rightarrow p + \pi^-$. Notice that the angle of the Λ decay includes the Λ direction of flight. The Λ in the right-hand picture decays via the leptonic mode, $\Lambda \rightarrow p + e^- + \bar{\nu}$. Note that the charged secondaries do not point back to the K^- ending, hence the decay is inconsistent with two-body kinematics. Both events are from the same bubble-chamber picture.