

Lawrence Berkeley National Laboratory

Recent Work

Title

HYPERON DECAY PARAMETERS AND THE KAN PARITY

Permalink

<https://escholarship.org/uc/item/5602n270>

Authors

Beall, E.P.
Cork, Bruce
Keefe, D.
et al.

Publication Date

1961-12-08

University of California
Ernest O. Lawrence
Radiation Laboratory

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 5545*

Berkeley, California

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

HYPERON DECAY PARAMETERS AND THE Λ PARITY

E. F. Beall, Bruce Cork, D. Keefe, P. G. Murphy, and W. A. Wenzel

December 8, 1961

HYPERON DECAY PARAMETERS AND THE Λ PARITY*E. F. Beall, Bruce Cork,[†] D. Keefe, P. G. Murphy,[‡] and W. A. WenzelLawrence Radiation Laboratory
University of California
Berkeley, California

December 8, 1961

With the results of recent experiments on the production¹ and decay² of hyperfragments, Dalitz and Liu³ have shown that a determination of the Λ parity may under certain assumptions be obtained from a measurement of the ratio of s-wave to p-wave amplitudes in the decay $\Lambda \rightarrow p + \pi^-$. A measurement of this ratio is reported here along with further results on the parameters for the decays $\Sigma^+ \rightarrow p + \pi^0$ and $\Lambda \rightarrow p + \pi^-$. The parameters of interest are usually defined as

$$\alpha = \frac{2\text{Re}(S^*P)}{|S|^2 + |P|^2}, \quad \beta = \frac{2\text{Im}(S^*P)}{|S|^2 + |P|^2}, \quad \gamma = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2},$$

where S and P are the amplitudes for s- and p-wave decay respectively.

Recently we have reported (in a paper hereinafter referred to as I) a measurement of $\alpha_0(\Sigma^+ \rightarrow \pi^0 + p)$,⁴ together with a measurement of the sign of $\alpha_\Lambda(\Lambda \rightarrow \pi^- + p)$.⁵ The experimental arrangement is described in I. Hyperons were produced by the reactions $\pi^+ + p \rightarrow \Sigma^+ + K^+$, $\pi^+ + n \rightarrow \Lambda + K^+$ in hydrogen and lithium deuteride respectively. The reactions were identified by counter and spark chamber techniques, and the polarization of the decay protons was measured by means of p-C¹² scattering in a carbon-plate spark chamber. A photograph of an event and the orientation of the equipment in space are shown in Fig. 1 (see also Fig. 1 of I).

The polarization of the proton from the decay of a spin- $\frac{1}{2}$ hyperon can be shown to be⁶

$$\underline{P} = [1/(1 - \alpha\bar{p}\cos\theta)] \{ [-\alpha + \bar{p}(1-\gamma)\cos\theta] \hat{k}_p + \gamma\bar{p} + \beta \bar{p} \times \hat{k}_p \}. \quad (1)$$

and the angular distribution is

$$D(\cos \theta) = (1/2)(1 - \alpha\bar{p} \cos \theta); \quad (2)$$

\hat{k}_p is a unit vector parallel to the momentum of the proton in the rest frame of the hyperon; $\cos \theta = \hat{k}_p \cdot \bar{p} / |\bar{p}|$; \bar{p} is the average polarization of the hyperon, and is perpendicular to the K-hyperon production plane. The proton polarization perpendicular to the K - π^+ plane, averaged over an interval in $\cos \theta$, is, then,

$$P_{\pm} = [1/(1 \mp \alpha\bar{p} |\langle \cos \theta \rangle|)] \{ \mp \alpha |\langle \cos \theta \rangle| + \bar{p}(1-\gamma) \langle \cos^2 \theta \rangle + \gamma\bar{p} \}, \quad (3)$$

the + signs corresponding to a proton being produced with momentum up with respect to the K - π^+ plane, ($\cos \theta > 0$ is defined as "up") . and - corresponding to down.

The proton polarization data for Λ decay were divided into two groups. Group 1 included 121 events for which the decay pion was detected (i. e. , counted in the U or D counter, see 1). Group 2 included 340 events for which the decay pion was not detected. For each group, the factors $\langle \cos \theta \rangle$ and $\langle \cos^2 \theta \rangle$ were calculated from the counter geometry. The calculation included the effects of the internal momentum distribution of the target neutron, but was insensitive to the details of the distribution. The factor $\alpha\bar{p}$ was computed from the measured up-down asymmetry of the decay pions to be $\alpha\bar{p} = 0.35 \pm 0.05$. The errors in the factors $\langle \cos \theta \rangle$, $\langle \cos^2 \theta \rangle$, and $\alpha\bar{p}$ are small and have been neglected. From Eq. (3), the measured polarizations P_{\pm} for each group are then functions of

α and γ only, and (3) can be solved for α and γ as functions of P_+ and P_- . We neglecting β^2 (if time reversal invariance and the $|\Delta\vec{T}| = \frac{1}{2}$ rule hold, then the known π -N phase shifts give $\beta^2 = 0.02$); it is then easily seen that $\alpha^2 + \gamma^2 = 1$, and P_{\pm} are functions only of γ and the algebraic sign of α . The dependence of P_{\pm} on γ and $\alpha/|\alpha|$ in Eq. (3) was corrected for a background of 12% for the sample comprising Group 1, and 20% for the sample comprising Group 2. A likelihood function of the form

$$L = \left\{ \prod_i^+ [1 + P_+(\gamma, \alpha/|\alpha|) A_i \cos \phi_{Si}] \prod_j^- [1 + P_-(\gamma, \alpha/|\alpha|) A_j \cos \phi_{Sj}] \right\}$$

was computed separately for Group 1 (L_1) and for Group 2 (L_2). Here, A_i is the analyzing power of carbon and ϕ_{Si} is the angle between the scattering plane and the $K - \pi^+$ plane for the i th event. The sign convention is such that the scattering shown in Fig. 1 has $\cos \phi_S > 0$. The maximum value of L as a function of γ and $\alpha/|\alpha|$ corresponds to the most likely configuration of γ and $\alpha/|\alpha|$. The likelihood function L_1 for Group 1 predicts that α_{Λ} is negative; on the other hand, L_1 is relatively insensitive to γ_{Λ} . The likelihood function L_2 for Group 2 also predicts that α_{Λ} is negative, but in addition predicts that γ_{Λ} is positive. Because L_1 and L_2 were found to be consistent, the product $L = L_1 L_2$ is used to represent the results (Fig. 2a). The likelihood that our observed data might have arisen from a negative α can be seen to be approximately 10^3 times as high as if α were positive. If the conclusion $\alpha < 0$ is accepted, then the most likely value of $\sigma = |P|^2 / (|S|^2 + |P|^2) = [1 - \gamma_{\Lambda}] / 2$ is 0.13, corresponding to $\alpha_{\Lambda} = -0.67$.

The results of the calculations by Dalitz and Liu³ of the branching ratio

$$R(\sigma) = \frac{\Lambda H^4 \rightarrow \pi^- + He^4}{\Lambda H^4 \rightarrow \pi^- \text{ (all modes)}}$$

for the two cases $J(\Lambda H^4) = 0$ and $= 1$ are shown in Fig. 2b. The shaded strip shows the limits (\pm one standard deviation) on R determined in the emulsion experiment by Ammar et al.² (They found $R = 46/63$.) A consistent way of combining our results with those of Ammar et al. is to construct the likelihood function $L_A(R[\sigma])$ for their results (using the curves $J = 0$ or $= 1$ in Fig. 2b), and then to use the product function $F(\sigma) = L_A \mathcal{L}$ (for $\alpha < 0$). This is plotted in Fig. 2c for the two cases $J = 0$ and $J = 1$. The ratio of the peak values of F is 43/1, strongly favoring $J = 0$.

We may summarize our conclusion on Λ -decay parameters as follows:

1. Our results combined with those of Ammar et al.² indicate, on the basis of the calculations by Dalitz and Liu,³ that the spin of ΛH^4 is 0. If this is so, then the occurrence of the reaction¹ $K^- + He^4 \rightarrow \Lambda H^4 + \pi^0$ proves that the $K\Lambda N$ parity is odd, provided only that the ΛH^4 is produced in its ground state. This argument is independent of the initial angular momentum state of the production reaction.
2. The negative sign of α_Λ , based on results from this experiment, from Birge and Fowler,⁷ and from Leitner et al.,⁸ is now established. It follows⁹ that $\alpha < 0$ also for the decay mode $\Lambda \rightarrow n + \pi^0$. The magnitude of α_Λ , however, is still not well known. Our experiment gives $\alpha_\Lambda = -0.67^{+0.18}_{-0.24}$, and $\gamma_\Lambda = +\sqrt{1-\alpha_\Lambda^2} = +0.74^{+0.13}_{-0.32}$. (The errors correspond to the $1/e$ points on the likelihood function \mathcal{L} in Fig. 2a.¹⁰ Note that \mathcal{L} falls off more slowly than a Gaussian distribution in the direction of small γ_Λ .) This is in agreement with the latest published result by Crawford et al.,¹¹ namely $|\alpha_\Lambda| > 0.66 \pm 0.13$.

Regarding the decay $\Sigma^+ \rightarrow p + \pi^0$, the result $a_0 = 0.75 \pm 0.17$ was reported in I on the basis of an approximate (one-parameter) likelihood analysis. A more extensive and rigorous analysis of the polarization data using a three-parameter likelihood function which takes into account the dependence of the polarization on β_0 and γ_0 (Eq. 1) predicts $a_0 = +0.73^{+0.16}_{-0.11}$, and $-0.3 < a\bar{p} < 0.3$, where the limits on a_0 and on $a\bar{p}$ correspond to the $1/e$ points on the likelihood surface. An uncertainty of 5% in the analyzing power A has been included in the errors; all other uncertainties are believed to be negligible. It should be noticed that the inclusion of the extra parameters in the maximum-likelihood estimation modifies slightly the value of a_0 given in I and, in particular, leads to somewhat smaller errors. Because \bar{p} was small, in agreement with the measurements by the Yale group,¹² very little of significance can be inferred about β_0 and γ_0 .

A more restricted result is obtained if time-reversal invariance and the $|\Delta T| = 1/2$ rule are assumed. Then, using the known π -N phase shifts, one can show that the quantity $\tan \psi = \beta_0/a_0$ must have either of the values -0.22 or $+0.04$. Likelihood contours for the two cases are plotted against $a\bar{p}$ and $|S_0/P_0|$ in Fig. 3 (for $a_0 > 0$). The four maxima give the same value for a_0 within 1%, namely

$$a_0 = +0.78^{+0.11}_{-0.13} \quad (\text{for } \tan \psi = -0.22, +0.04).$$

The limits given by the errors correspond to the extreme values on the $1/e$ curves.

An important consequence of the small value of the Σ -hyperon polarization found in this experiment and in the Yale experiment¹² should be noted. Both experiments involved the reaction $\pi^+ + p \rightarrow \Sigma^+ + K^+$ at a pion momentum $p_\pi = 1.2$ Bev/c. It has often been assumed that the small asymmetry

($\alpha_{\bar{p}} = 0.01 \pm 0.17$) found in the decay of Σ^- hyperons produced in the charge-symmetric reaction $^{13}\pi^- + n \rightarrow \Sigma^- + K^0$ at $p_{\pi} = 1.2$ Bev/c is evidence for $\alpha_{\bar{p}} \approx 0$. This conclusion, which is valid only if \bar{p} is large, tacitly assumes that the high polarization found (for Σ^+) at $p_{\pi} = 1.13$ Bev/c⁹ persists at 1.2 Bev/c. The new polarization results therefore weaken the arguments for $\alpha_{\bar{p}} \approx 0$ and make it highly desirable to measure $\alpha_{\bar{p}}$ at $p_{\pi} = 1.13$ Bev/c. For the moment the principal evidence for $\alpha_{\bar{p}} \approx 0$ rests on the assumption of the $|\Delta T| = 1/2$ rule and time-reversal invariance.⁹

We are grateful to Dr. R. H. Dalitz and Dr. A. Pais for helpful discussions and moral support.

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

† At present on leave from LRL at CERN, Geneva, Switzerland.

‡ Work performed while on leave from the Rutherford High Energy Laboratory, Harwell, Didcot, Berkshire, England.

1. M. M. Block, E. B. Brucker, C. C. Chang, R. Gessaroli, T. Kikuchi, A. Kovacs, C. M. Meltzer, A. Pevsner, P. Schlein, R. Strand, H. O. Cohn, E. M. Harth, J. Leitner, L. Monari, L. Lendinara, and G. Puppi, in Proceedings of the 1960 Annual International Conference on High Energy Physics at Rochester (Interscience Publishers, Inc., New York,) p. 419
2. R. G. Ammar, R. Levi Setti, W. E. Slater, S. Limentani, P. E. Schlein, and P. H. Steinberg, Nuovo cimento 19, 20 (1961).
3. R. H. Dalitz and L. Liu, Phys. Rev. 116, 1312 (1950).
4. E. F. Beall, Bruce Cork, D. Keefe, P. G. Murphy, and W. A. Wenzel, Phys. Rev. Letters 7, 285 (1961).
5. Details of this experiment are described by E. F. Beall in his thesis, Lawrence Radiation Laboratory Report UCRL-9919, Oct. 1961 (unpublished).
6. See, for example, R. H. Dalitz, Società Italiana di Fisica, Rendiconti della Scuola Internazionale di Fisica "Enrico Fermi," Corso XI, p. 299.
7. R. W. Birge and W. B. Fowler, Phys. Rev. Letters 5, 254 (1960).
8. J. Leitner, L. Gray, E. Harth, S. Lichtman, M. Block, B. Brucker, A. Engler, R. Gessaroli, A. Kovacs, T. Kikuchi, C. Meltzer, H. O. Cohn, W. Bugg, A. Pevsner, P. Schlein, M. Meer, N. T. Grinellini, L. Lendinara, L. Monari, and G. Puppi, Phys. Rev. Letters 7, 264 (1961).
9. B. Cork, L. T. Kerth, W. A. Wenzel, J. W. Cronin, and R. L. Cool, Phys. Rev. 120, 1000 (1960).

10. The measure of uncertainty in a maximum-likelihood estimate is often defined differently by different authors. For a discussion of this point see, for example, M. Annis, W. Cheston, and H. Primakoff, *Revs. Modern Phys.* 25, 818 (1953). These authors suggest an alternative measure (Eq. 47, loc. cit.).
11. F. S. Crawford, Jr., M. Cresti, M. L. Good, F. T. Solmitz, and M. L. Stevenson, *Phys. Rev. Letters* 2, 11 (1959).
12. C. Baltay, H. Courant, W. J. Fickinger, E. C. Fowler, H. L. Kraybill, J. Sandweiss, J. R. Sanford, D. L. Stonehill, and H. D. Taft, *Revs. Modern Phys.* 33, 374 (1961).
13. P. Franzini, A. Garfinkel, J. Keren, A. Michelini, R. Plano, A. Prodell, M. Schwartz, J. Steinberger, and S. E. Wolf, *Bull. Am. Phys. Soc.*, Ser. II, 5, 224 (1960); also M. Schwartz (Columbia University), private communication.

LEGENDS

Fig. 1. Schematic drawing and photograph of a typical example of $\pi^+ + p \rightarrow \Sigma^+ + K^+$, $\Sigma^+ \rightarrow p + \pi^0$, $p + C^{12} \rightarrow p + C^{12}$, $K^+ \rightarrow \mu^+ + \nu$. The unphotographed tracks have been distorted for the sake of clarity. This particular proton scattering has $\cos\phi_S > 0$ (to the left) and $\sin\phi_S > 0$ (up).

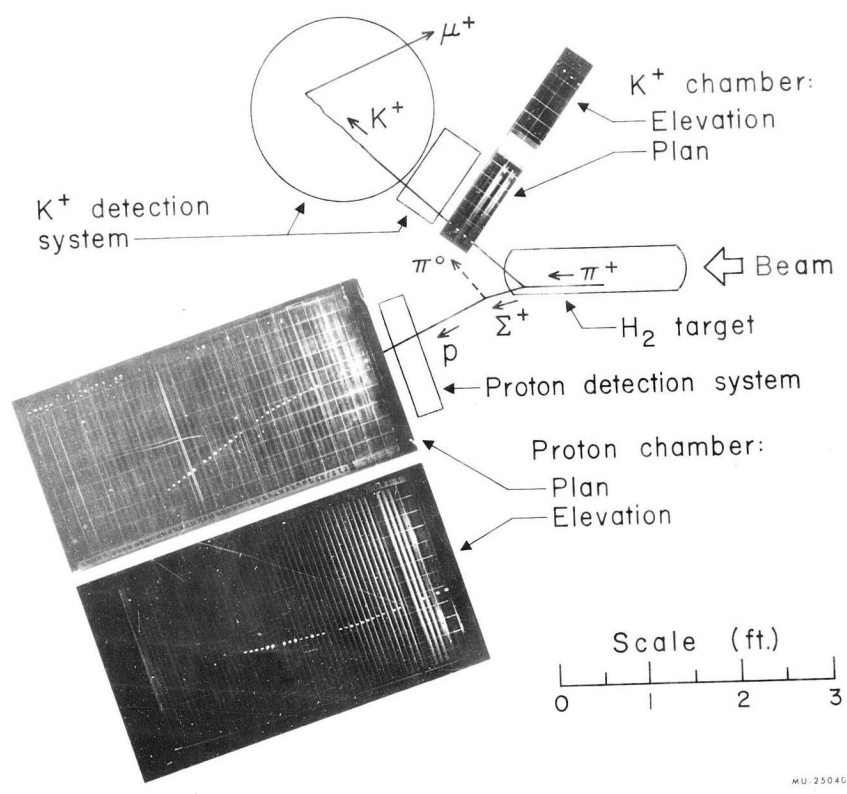
Fig. 2. (a) The likelihood function \mathcal{L} of $\sigma_\Lambda (= 1 - \gamma_\Lambda / 2 = [1 \pm \sqrt{1 - a_\Lambda^2}] / 2)$ and of the sign of a_Λ .

(b) The ratio $F(\sigma) = [\Lambda H^4 \rightarrow \pi^- + He^4] / [\Lambda H^4 \rightarrow \pi^- \text{ (all modes)}]$ as a function of σ_Λ . The two curves $J = 0$ and $J = 1$ are those calculated by Dalitz and Liu (reference 3). The horizontal strip shows the result by Ammar et al.

(reference 2), $R = 0.67^{+0.06}_{-0.05}$.

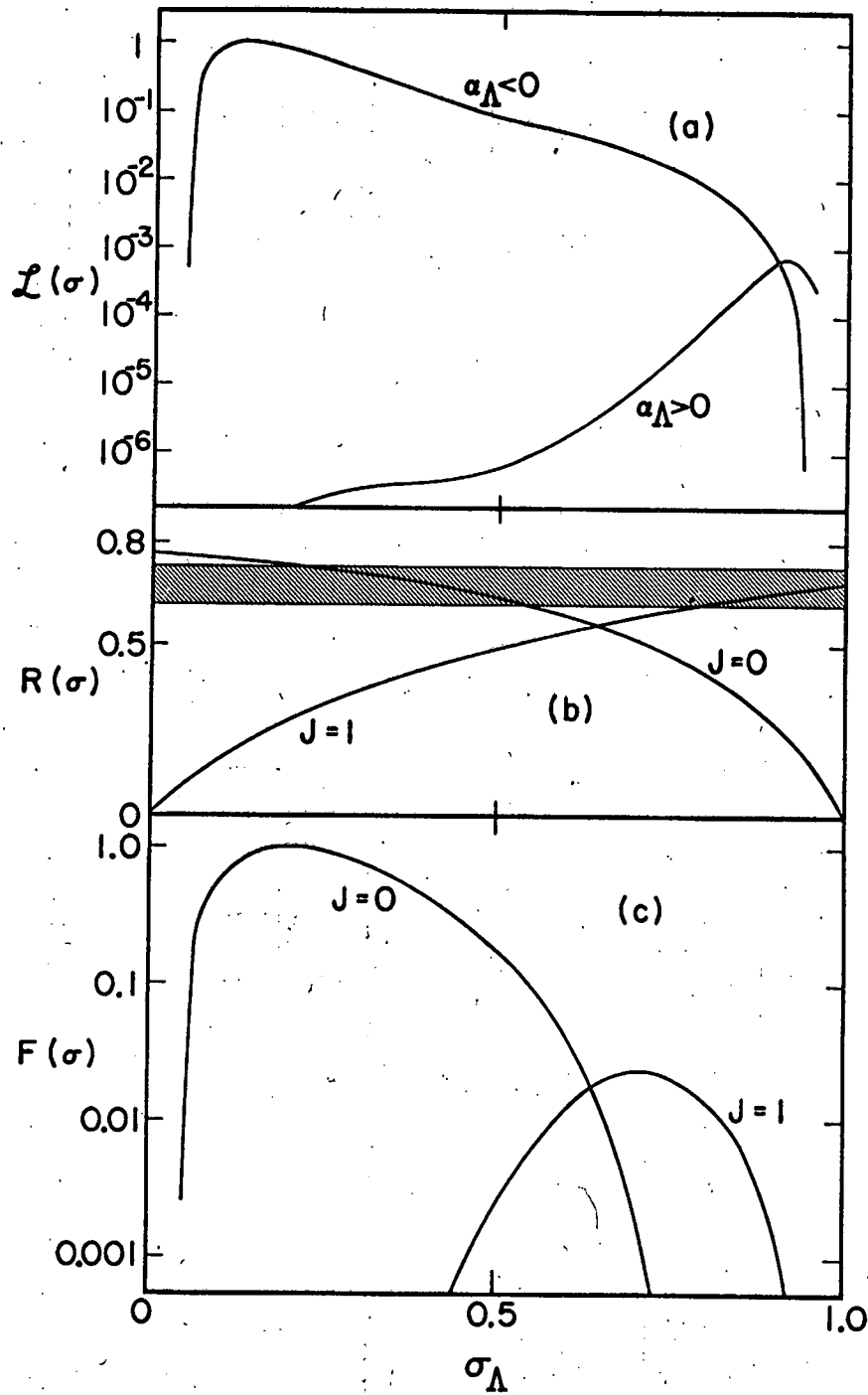
(c) The function $F = L_\Lambda \mathcal{L}$ for $a_\Lambda < 0$. The two cases correspond to $J = 0$ and $J = 1$.

Fig. 3. Common logarithm of the likelihood as a function of $a\bar{p}$ and $|S|/|P|$ for $\Sigma^+ \rightarrow p + \pi^0$ (for $a_0 > 0$) for (a) $\tan\psi = -0.22$, (b) $\tan\psi = +0.04$.



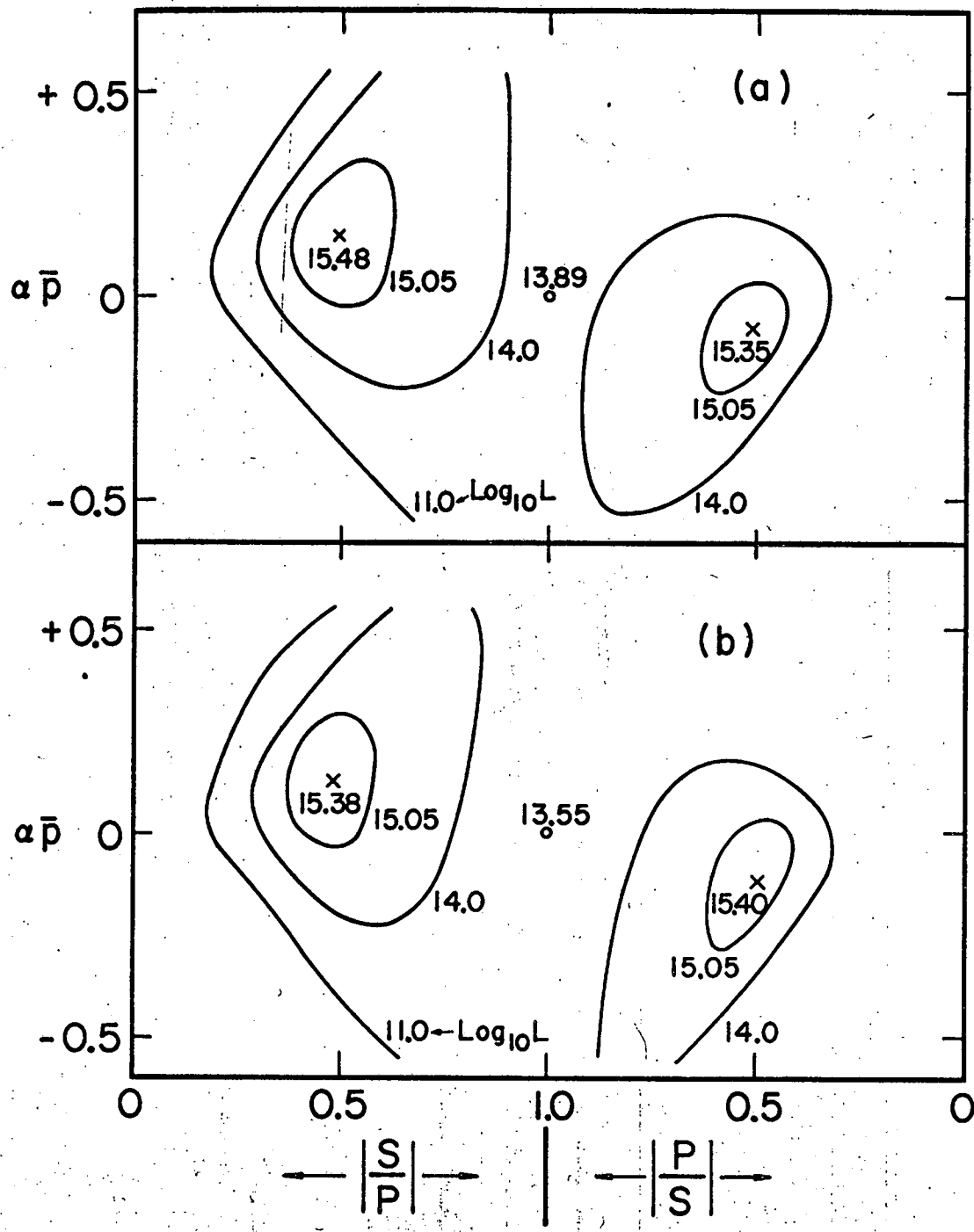
MU 25046

Fig. 1



MUB-868

Fig 2



MUB-867

Fig 3