interior, and (4) the Davis, Harmer, and Hoffman interpretation that $\sum\sigma_i\varphi_i \leq 3\times10^{-36}$ sec^{-1} per Cl^{37} atom, then an upper limit to the initial solar helium abundance lies in the range $Y_0 \cong 0.16$-0.17. This limit is uncomfortably close to a lower limit of $Y_{\rm lower} \cong 0.15$-0.18 set by demanding that the solar model have the sun's luminosity after $4\frac{1}{2}\times10^9$ yr. If all cross-section factors are varied in a direction favorable for decreasing $\sum\sigma_i\varphi_i$, but not beyond limits customarily quoted, then a "penultimate" upper limit on Y is $Y(1)\cong 0.20$. Finally, if cross-section factors are varied beyond conventional limits by extrapolating low-energy cross-section measurements differently, an "ultimate" upper limit on Y is $\overline{Y}(1)\cong 0.25$. Thus, if conventional assumptions about the sun are maintained, a close similarity between model-determined values for solar Y and estimates of Y for other galactic objects can be achieved only by adopting cross-section factors outside commonly accepted limits. This conclusion could, of course, be avoided if the Davis, Harmer, and Hoffman limit were an underestimate.

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THE 3π MASS SPECTRUM IN THE REACTION $\pi^-p\rightarrow p\pi^+\pi^-\pi^-$ AT 13 AND 20 GeV/c.*†

M. L. Ioffredo, G. W. Brandenburg, A. E. Brenner, B. Eisenstein,‡ L. Eisenstein, W. H. Johnson, Jr., J. K. Kim, M. E. Law, B. M. Salzberg, J. H. Scharenguivel, L. K. Sisterson, and J. J. Szymanski
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts
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In the 3π mass spectrum from the reaction $\pi^-p\rightarrow p\pi^+\pi^-\pi^-$ at 13 and 20 GeV/c, we observe an unstructured A enhancement and the production of the $\pi(1640)$ meson. Our data for the $\pi^-\rho^0$ mass are compared with the predictions of the one-pion exchange, the diffraction-dissociation, and the double-Regge-pole models. Only the double-Regge-pole model is able to reproduce the shape of the A enhancement.

The reaction $\pi^-p\rightarrow p\pi^+\pi^-\pi^-$ has been studied at incident π^- momenta ranging from 3.2 to 16 GeV/c in recent years.[1] The process has been characterized by strong production of the $\Delta^{++}(1236)$ and ρ^0. Of particular interest in this reaction, however, has been A-meson resonance production in the $\pi^-\rho^0$ mass spectrum between 1.0 and 1.45 GeV. The A_2 meson at a mass of 1305 MeV is the only well established resonance in the A region, while controversy exists as to whether the A_1 effect at a mass of approximately 1070 MeV is a genuine resonance or a Deck[2]-type kinematical enhancement.

We present here our results concerning the $\pi^+\pi^-\pi^-$ system in the process

$$\pi^-p\rightarrow p\pi^+\pi^-\pi^- \qquad (1)$$

at incident π^- momenta of 13 and 20 GeV/c. Our data come from 100 000 photographs taken in the Brookhaven National Laboratory 80-in. hydrogen bubble chamber, 50 000 at each of the two incident π^- momenta. We have obtained 1292 events for process (1) at 20 GeV/c from all of the available film at this energy and 1192 events at 13 GeV/c from approximately 70% of the film. The contamination from events with one or more π^0's is less than 4%. The cross section for process (1) is 1.14 ± 0.15 mb at 13 GeV/c and 0.89 ± 0.08 mb at 20 GeV/c. The errors are both statistical and systematic in origin. The 13-GeV/c cross section is based on only 20% of the film at this energy.

The "A" Enhancement.—In Figs. 1(a) and 1(b) we have plotted the mass of the $\pi^+\pi^-\pi^-$ system for all events at 13 and 20 GeV/c, respectively. There is a large enhancement in the A region between approximately 1.0 and 1.4 GeV. The arrows in the figure are there for reference purposes only; there is no resolution of the A enhancement into distinct peaks at either energy. Our experimental resolution for the 3π mass is of the order of ±20 MeV.

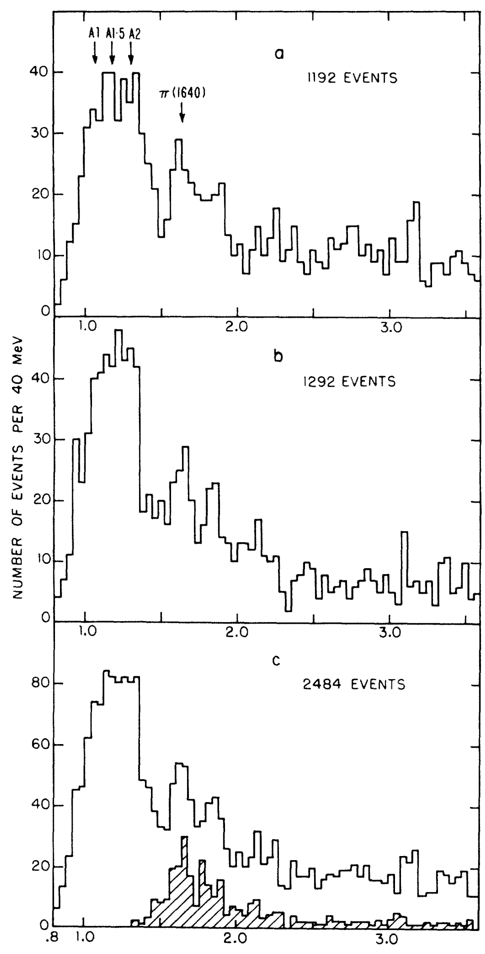

FIG. 1. The $\pi^+\pi^-\pi^-$ mass distributions: (a) at 13 GeV/c, (b) at 20 GeV/c, (c) for the sum of the 13- and 20-GeV/c data. The shaded histogram is for events with $1.15 \leq m(\pi^+\pi^-) \leq 1.35$ GeV and $m(p\pi^+)$ not in $\Delta^{++}(1236)$ (1.15-1.35 GeV). The arrows indicate the position of reported resonances.

In Fig. 2 we again plot the 3π mass at both energies, but now we require that at least one $\pi^+\pi^-$ combination be in the ρ^0 mass region and we have excluded events whose $p\pi^+$ mass is in the $\Delta^{++}(1236)$ mass region. When we make these cuts 70% of the events in A region at 13 GeV/c and 77% at 20 GeV/c remain.

We see from Fig. 2 that there is no significant structure in the A enhancement in the $\pi^-\rho^0$ mass spectrum at either energy. As was true for the uncut 3π spectra, the only significant difference between the two energies in the $\pi^-\rho^0$ mass distribution is the sharper falloff at 20 GeV/c occurring in the A_2 region at a mass of approximately 1.35 GeV. This suggests that the A_2 cross section decreases more rapidly with energy than does the cross section for the rest of the A enhancement.

We have attempted to determine how much of the A enhancement can be accounted for by various models which have been proposed to describe the reaction $\pi^-p \rightarrow p\rho^0\pi^-$. We will consider the following three models: a one-pion-exchange model (OPEM) calculation by Wolf,[3] the diffraction-dissociation model[4] (DDM), and the double-

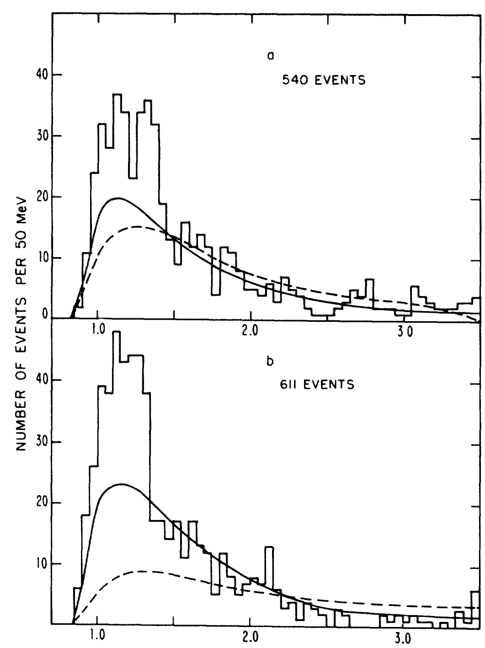

FIG. 2. The $\pi^-\rho^0$ mass distributions for events with $0.66 \leq m(\pi^+\pi^-) \leq 0.86$ GeV and $m(p\pi^+)$ not in $\Delta^{++}(1236)$ (1.15-1.35 GeV): (a) at 13 GeV/c, (b) at 20 GeV/c. The solid curves are the absolute predictions of OPEM as calculated by Wolf; the dashed curves are the predictions of DDM normalized to the number of events with $m(\pi^-\rho^0) > 1.5$ GeV.

Regge-pole model[5] (DRPM).

The OPEM calculation of Wolf uses the cross sections for physical $\pi\pi$ and πp scattering as input, makes off-the-mass-shell corrections according to Benecke and Durr,[6] and imposes a cutoff at 1.0 $(\mathrm{GeV}/c)^2$ in momentum transfer squared. Any interference between the two possible OPE diagrams is neglected and symmetrization effects due to the two identical π^-'s in the final state are ignored. This OPEM calculation successfully fits the π^+p and π^-p mass distributions and the details of $\Delta^{++}(1236)$ production in this experiment. The solid curves in Figs. 2(a) and 2(b) are the absolute predictions of the OPEM calculation by Wolf for the $\pi^-\rho^0$ mass spectra. The calculation fits the tail of the $\pi^-\rho^0$ mass distribution at each energy fairly well; it cannot account, however, for all of the events that we observe in the A enhancement.

The DDM has been calculated according to the prescription of Ross and Yam.[4] We have neglected any form factors for the three diagrams involved in this model. The dashed curves in Figs. 2(a) and 2(b) are the predictions[7] of the DDM for the $\pi^-\rho^0$ mass spectra. The model predicts a cross section which is a factor of 3.5 times too large at 13 GeV/c and 7 times too large at 20 GeV/c. We have, therefore, normalized the DDM shape at each energy to the number of events with $\pi^-\rho^0$ mass greater than 1.5 GeV. Regardless of the normalization, however, the prediction of the DDM, as we have calculated it here, is too broad to account for the entire A enhancement at either energy.

The DRPM has been calculated using a matrix element suggested by Berger.[8] We consider only contributions from the diagram shown in the insert in Fig. 3(a) in which a Pomeranchukon trajectory is exchanged in I and a pion trajectory is exchanged in II. The expression used for the matrix element squared is

$$|M|^2 = N_0(S_1\cdots)^2 \frac{\exp(8t_1)}{(1-\cos\pi\alpha_\pi)}\{S_0^{-1}(S_2\cdots)\}^{2\alpha_\pi},$$

where

$$N_0 = \tfrac{1}{2}g^2(m_\rho^2-4m_\pi^2)(\pi\sigma_{\pi N}\alpha_\pi')^2,$$

$$S_1\cdots = S_1 - t_2 - m_N^2 + \tfrac{1}{2}(t_1+t_2-m_\pi^2),$$

$$S_2\cdots = S_2 - t_1 - m_\pi^2 - \tfrac{1}{2}t_2^{-1}(m_\rho^2-m_\pi^2-t_2)(t_1+t_2-m_\pi^2).$$

S_1 and S_2 are the mass squared of the π^-p and $\pi^-\rho^0$ systems, respectively, and t_1 and t_2 are the momentum transfer squared to the proton and the ρ^0, respectively. In our calculation we have used $g^2/4\pi = 2.2$, $S_0 = 0.8\ \mathrm{GeV}^2$, $\sigma_{\pi N} = 30$ mb, and $\alpha_\pi = t_2 - m_\pi^2$. To remain within the "peripheral" region of applicability of the model, we have required that the magnitude of the momentum transfer squared to the ρ^0 be less than 1.0 $(\mathrm{GeV}/c)^2$ and that the mass of the π^-p system be greater than 2.0 GeV. When these cuts are made on the data, 76% of the $\pi^-\rho^0$ events in the A region at 13 GeV/c and 89% of the $\pi^-\rho^0$ events at 20 GeV/c remain, while most of the events in the tail of the distributions are removed. The model predicts a cross section at each energy which is 65% of that experimentally observed for the "peripheral" region events.[9] For the purposes of making comparisons with the data, we have normalized the DRPM predictions to the number of "peripheral" events at each energy. The solid curves in Figs. 3(a) and 3(b) are the normalized predictions of the DRPM for the $\pi^-\rho^0$ mass distributions at 13

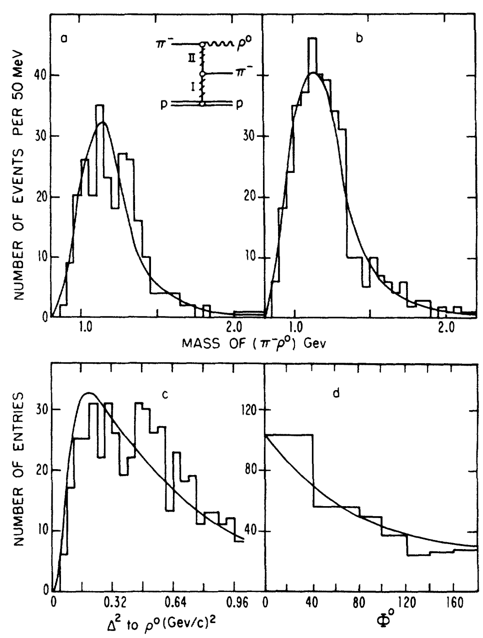

FIG. 3. (a), (b) The $\pi^-\rho^0$ mass distributions at 13 and 20 GeV/c, respectively, (c) the momentum transfer squared to the ρ^0 at 20 GeV/c, (d) the Treiman-Yang angle in the $p\pi^-$ rest system at 20 GeV/c; all for events with $0.66 \le m(\pi^+\pi^-) \le 0.86$ GeV, $m(p\pi^-) > 2.0$ GeV, and Δ^2 to the $\rho^0 < 1.0\ (\mathrm{GeV}/c)^2$. The solid curves are the predictions of the DRPM normalized to the number of events. The insert in (a) shows the diagram used in the DRPM calculation.

and 20 GeV/c, respectively. Except for some events in the A_2 mass region, the model agrees with the shape of the A enhancement at 13 GeV/c. It should be noted that a system having spin and parity 2^+, such as the A_2, cannot be produced by the DRP process which involves Pomeranchukon exchange. At 20 GeV/c, the model is able to reproduce the shape of essentially the entire A enhancement.

We have also compared the DRPM predictions with other aspects of the data. Figures 3(c) and 3(d) show the momentum transfer squared to the ρ^0 and the Treiman-Yang angle in the $p\pi^-$ rest system at 20 GeV/c. The solid curves show that the normalized predictions of the model are in good agreement with the data. The agreement with these quantities is equally good at 13 GeV/c (not shown). The model also describes well the mass of the $p\pi^-$ system and the momentum transfer squared to the proton at both energies. Chew and Pignotti[10] have pointed out, however, that this success of the DRPM does not necessarily mean that there is no resonance production in the "A" region.

The π(1640) meson.—At both energies we observe production of the π(1640) meson[11] (also known as the A_3) at a mass of approximately 1650 MeV in the $\pi^+\pi^-\pi^-$ mass spectra. The production cross section for the π(1640) is 41 ± 6 μb at 13 GeV/c and 28 ± 4 μb at 20 GeV/c. The errors are statistical only. These cross sections were obtained by counting the number of events in the π(1640) peaks in Figs. 1(a) and 1(b) above an estimated background determined by extrapolating from neighboring mass regions in the 3π spectrum.

In order to increase the statistics in the $\pi^+\pi^-\pi^-$ mass spectrum, we have added together our results at 13 and 20 GeV/c. Figure 1(c) shows the result of this addition for the 3π mass. The π(1640) is a 3.5-standard-deviation effect in the added mass distribution. There is also some evidence for an enhancement at a mass of 1840 MeV which could correspond to the R_4 (1830) or the φ_A (1830).[12] Our statistics, however, are not sufficient to establish the existence of this 1840 enhancement.

In the shaded histogram in Fig. 1(c) we have plotted the 3π mass, adding the data for both energies, requiring that at least one $\pi^+\pi^-$ combination be in the f^0 mass region and excluding events whose $p\pi^+$ mass is in the Δ^{++}(1236) mass region. We observe an enhancement in the π^-f^0 mass spectrum at the mass of the π(1640). A πf^0 decay mode has been observed for the π(1640) in other experiments.[13] We have investigated the predictions of both the OPEM and the DRPM for the π^-f^0 mass spectrum. The OPEM cannot account for all of the events that we observe in the π^-f^0 peak at the π(1640) mass. The "peripheral" cuts which define the region of applicability of the DRPM remove 45% of the π^-f^0 events in the π(1640) peak, and although the DRPM prediction is not inconsistent with the data, the limited statistics do not allow us to make a meaningful comparison of the data with the model. Using the OPEM calculation of Wolf as a background and assuming that the events in the peak at the π(1640) mass are due to a π^-f^0 decay mode, we obtain a cross section of 14 ± 4 μb at 13 GeV/c and 12 ± 3 μb at 20 GeV/c for the production and decay of the π(1640) into π^-f^0. The errors are statistical only. Examination of Fig. 2 shows that the π(1640) does not have a significant $\pi^-\rho^0$ decay mode.

We would like to thank G. Wolf for providing us with the predictions of his OPEM calculation, E. L. Berger for useful discussions concerning the DRPM and D. Gillespie and G. Luste for providing us with a copy of their Monte Carlo program. We are indebted to H. Foelsche for his help with the π^- beam, and to Bronwyn Hall for her work with our analysis programs. It is a pleasure to acknowledge the assistance of the staff and operating crews of the alternating-gradient synchrotron and the Brookhaven National Laboratory 80-in. bubble chamber and our own staff of scanning personnel. Finally, we wish to thank Professor J. C. Street and Professor K. Strauch for their continued help and encouragement.

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‡Present address: University of Illinois, Urbana, Illinois.

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HYPERON NONLEPTONIC DECAY ACCORDING TO THE *CP*-NONCONSERVING THEORY OF OAKES*

Carl H. Albright†
Department of Physics, Northwestern University, Evanston, Illinois
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The effect of CP nonconservation in hyperon nonleptonic decay is evaluated according to a recent theory of Oakes. Only the ratio β/α for the $\Sigma_+{}^+$ decay mode is predicted to show a sizable effect which, in fact, demands an order of magnitude greater accuracy than has been obtained to date experimentally.

Oakes[1] has recently extended the Cabibbo theory[2] of weak interactions by adding a neutral current-current interaction of the $V+A$ type to the conventional charged current-current interaction of the $V-A$ variety. In so doing, Oakes has assumed that the neutral currents transform as members of the U-spin triplets belonging to the same octets as the charged currents; moreover, a CP-nonconserving part of the weak interaction is introduced by rotating the third components of the U-spin triplets about the 6 direction through a very small angle.

This proposed theory is appealing in the sense that all eight components of the octet currents can now be given a physical interpretation.[3] In addition, the neutrino may be regarded as a four-component spinor whose left-handed character is manifest when it is coupled through a charged current, while its right-handed character is revealed when it is coupled through the proposed neutral current.

Whether or not one considers these features theoretically compelling, the validity of the theory, of course, hinges on its experimental predictions. Oakes[1] has systematically evaluated the consequences of this theory of CP nonconservation for the leptonic, semileptonic, and several classes of nonleptonic interaction—in particular the K decays. He finds no serious discrepancy with any of the current experimental information. In this note we wish to pursue the consequences of this theory for CP nonconservation in hyperon nonleptonic decay.

The charged hadronic currents are written as[4]

$$J_\mu^{(\pm)} = \cos\theta_C(J_\mu + J_\mu^5)^{(1\pm i2)} + \sin\theta_C(J_\mu + J_\mu^5)^{(4\pm i5)}, \tag{1}$$

and the proposed neutral hadronic current is given by

$$J_\mu^{(0)} = \cos\varphi(J_\mu - J_\mu^5)^{(3-\sqrt{3}\times 8)} + i\sin\varphi(J_\mu - J_\mu^5)^{(6-i7)} - i\sin\varphi(J_\mu - J_\mu^5)^{(6+i7)}, \tag{2}$$

where J_μ is the vector current, J_μ^5 is the axial current, the superscripts in brackets refer to the SU(3) indices, and the Cabibbo angle $\theta_C \simeq 0.26$ while $\varphi \simeq 0.001$. With the hadronic part of