neutral pions).

The simplest matrix element for the case 1^{-+} requires that the population of the Dalitz plot tend to zero along the T_{π^0} axis and the boundary. Similarly, for the case 1^{++} one would expect a vanishing population at $T_{\pi^0}=0$. Again with limited statistical significance, the Dalitz plot in Fig. 3 does not favor either of these possibilities.[8]

We conclude that our results are most consistent with the quantum numbers 0^{-+} for the η (these are the same as the quantum numbers of the χ meson introduced in the "eightfold way" of Gell-Mann[9]). Statistical limitations and background do not permit us to rule out the case 1^{--} with certainty.

We wish to acknowledge the help of Professor L. W. Alvarez, Professor M. Gell-Mann, Professor M. L. Stevenson, Dr. R. W. Huff, and N. Xuong.

---

*Work supported by U. S. Atomic Energy Commission.

†National Academy of Science Fellow.

[1]A. Pevsner, R. Kraemer, M. Nussbaum, C. Richardson, P. Schlein, R. Strand, T. Toohig, M. Block, A. Engler, R. Gessaroli, and C. Meltzer, Phys. Rev. Letters 7, 421 (1961).

[2]B. C. Maglić, L. W. Alvarez, A. H. Rosenfeld, and M. L. Stevenson, Phys. Rev. Letters 7, 178 (1961); M. L. Stevenson, L. W. Alvarez, B. C. Maglić, and A. H. Rosenfeld, Phys. Rev. 125, 647 (1962).

[3]D. D. Carmony, A. H. Rosenfeld, and R. T. Van de Walle, following Letter [Phys. Rev. Letters 8, 117 (1962)]; also D. Prowse, University of California at Los Angeles (private communication).

[4]The authors of reference 1 inform us that, within their equally limited statistics, their Dalitz plot is consistent with 1^{--}.

[5]If η is 1^{--} (like ω) then the following comparison suggests that its width should indeed be much less than our 7-Mev upper limit. It is known that $\Gamma_\omega < 24$ Mev, and $\Gamma \propto |E_1 P_2 P_3|^2 Q^2$ [the matrix element M is proportional to $E_1(\vec{P}_2 \times \vec{P}_3)$ and the area of the Dalitz plot varies as $Q^2 = (m_\omega - m_{3\pi})^2$] which drops by a factor of ~100 when we substitute $m_\eta = 550$ Mev instead of $m_\omega = 780$ Mev. Thus we expect a partial width $\Gamma < 0.24$ Mev. Presumably the dominant decay rate is $\Gamma(\eta^0 \rightarrow \pi^0 + \gamma)$, which has been estimated at 0.03 Mev [see J. J. Sakurai, Phys. Rev. Letters 1, 355 (1961)], in which case $\Gamma(\eta_{ch}^0)$ is about 0.01 Mev.

[6]The 3π final state must have $G = -1$, but C must still be +1. By the rule $G = C(-1)^I$ for neutral particles, I must then have changed to an odd number. We assume emission and absorption of a single photon ($\Delta I \leq 1$ for each process), so $I = 0$ can lead only to $I = 1$. This analysis is equivalent to that of H.-P. Duerr and W. Heisenberg, "Quantum Numbers of the ω Meson" (Max-Planck-Institut für Physik und Astrophysik, München, Germany; unpublished work).

[7]M. Gell-Mann [California Institute of Technology, Pasadena, California (private communication)] has estimated $\Gamma(\gamma\gamma)/\Gamma(\gamma\pi^+\pi^-) \approx 4$, not inconsistent with our data.

[8]Another argument against 1^{-+} and 1^{++} is that they have no way to decay copiously into neutrals. $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ must be $\ll 1$, and $\gamma + \pi^0$, $\gamma + n\pi^0$, and $\gamma + \gamma$ are all forbidden.

[9]M. Gell-Mann, California Institute of Technology Scientific Laboratory Report CT-SL-20 (unpublished).

EVIDENCE THAT THE η MESON HAS ISOSPIN ZERO*

D. Duane Carmony, Arthur H. Rosenfeld, and Remy T. Van de Walle†
Lawrence Radiation Laboratory and Department of Physics, University of California, Berkeley, California
(Received January 2, 1962)

Pevsner et al. have reported the existence of the η meson (mass 550 Mev) produced by 1.23-Bev/c positive pions on neutron targets in deuterium[1]:

$$\pi^+ + n(+p) \rightarrow p(+p) + \eta^0. \quad (1)$$

The η^0 then decays by its charged mode:

$$\eta_{ch}^0 \rightarrow \pi^+ + \pi^- + \pi^0 + 135 \text{ Mev}. \quad (2)$$

The η is also produced by[2]

$$K^- + p \rightarrow \Lambda + \eta^0. \quad (3)$$

It is observed that the η^0 has a width $\Gamma \leq 15$ Mev and a neutral decay mode, which in fact is the dominant branching fraction. This is, the charged branching fraction f_{ch}^0 is less than $\frac{1}{3}$, where $f_{ch}^0 \equiv (\eta^0 \rightarrow \pi^+\pi^-\pi^0)/(\text{all modes})$. As discussed by Bastien et al., this means that radiative modes must be present in η^0 decay.[2] From reaction (3), we see that η can have only isospin 0 or 1. The purpose of this Letter is to rule out $I = 1$.

Using the impulse approximation, the Hulthén wave function for the deuteron, and the experimental cross section for the sequence of reactions (1) and (2), Pevsner et al. calculated the cross section for the reaction

$$\pi^+ + n \to p + \eta_{\rm ch}{}^0. \qquad (1')$$

They found $\sigma(\eta^0)f_{\rm ch}{}^0 \approx (150 \pm 30)$ μb.[3] If we assume $f_{\rm ch}{}^0 < \frac{1}{3}$, it follows that $\sigma(\pi^+ + n \to p + \eta^0)$ is greater than $3(150-30)$ $\mu{\rm b} = 360$ μb.

To rule out $I=1$, we now postulate that η is an isospin triplet: $\eta_1{}^+, \eta_1{}^0, \eta_1{}^-$. Then it must also be produced on proton targets by the reactions $\pi^\pm + p \to p + \eta^\pm$ induced by pions of the same momentum,[4] and a triangle inequality requires

$$[\sigma(\eta_1{}^+)]^{1/2} + [\sigma(\eta_1{}^-)]^{1/2} \geq [2\sigma(\eta_1{}^0)]^{1/2} = (2 \times 360\ \mu{\rm b})^{1/2}. \qquad (4)$$

The final state $p + \eta^\pm$ will produce events with both two and four visible prongs, since $\eta^\pm$ can decay into three charged particles (branching fraction $f_3{}^\pm$) or into one charged particle plus neutrals ($f_1{}^\pm$).

We have used data from two-prong events made by 1.25-Bev/c $\pi^\pm$,[5]

$$\pi^\pm + p \to p + \pi^\pm + \text{neutrals}, \qquad (5)$$

and have looked for a peak near 550 Mev in the mass spectrum of ($\pi^\pm$ + neutrals). In studying the ρ meson, we previously obtained a sample of 3200 mainly inelastic events of the type (5) yielding a slow proton ($p_{\rm lab} \leq 400$ Mev/c).

About one-fifth of the η mesons of Pevsner et al. are associated with protons with $p_{\rm lab} \leq 400$ Mev/c;[3] now the triangle inequality (4) applies at all production angles. Thus, in terms of partial cross sections σ' for slow protons, Eq. (4) becomes

$$[\sigma'(\eta_1{}^+)]^{1/2} + [\sigma'(\eta_1{}^-)]^{1/2} \geq [\tfrac{2}{5}\sigma(\eta_1{}^0)]^{1/2} = (144\ \mu{\rm b})^{1/2}. \qquad (4')$$

Since the dominant decay mode of η^0 is radiative ($\eta_1{}^0 \to \pi^0 + \gamma$, $\gamma + \gamma$, etc.), it seems likely that the charged η decays with a branching fraction $f_1{}^\pm > \frac{1}{2}$. For simplicity, we shall assume this here; below we show that the assumption is not necessary. Assuming $f_1{}^\pm > \frac{1}{2}$, we must find

$$[\sigma'(\eta_1{}^+ f_1{}^\pm)']^{1/2} + [\sigma'(\eta_1{}^- f_1{}^\pm)']^{1/2} > (72\ \mu{\rm b})^{1/2}. \qquad (4'')$$

Among our 3200 two-prong measurements, we found ≈ 350 that would not fit single π^0 production (or elastic scattering) and hence must be mainly reactions such as

$$\pi^\pm + p \to p + \pi^\pm + 2\pi^0,$$

or else might correspond to

$$\pi^\pm + p \to p + \eta^\pm. \qquad (6)$$

Integrated over all (π^+ + neutral) masses, the total cross section $\sigma'(\pi^+ + \text{neutrals})$ is 160 μb, and $\sigma'(\pi^- + \text{neutrals})$ is 71 μb. These events display a smooth mass spectrum, as one would expect for $\pi^\pm + 2\pi^0$. Our mass resolution is ± 11 Mev. In the region 550 ± 16 Mev, we find $(8 \pm \sqrt{8})$ π^+ events, representing 5.4 ± 2 μb. This sets the scale for our estimate that we would have detected a superimposed peak of 6 μb among the π^+ events. Similarly, we find $(2 \pm \sqrt{2})$ π^- events (1.2 ± 1 μb), and would have noticed an extra 3 μb. Thus we find

$$[\sigma'(\eta_1{}^+ f_1{}^\pm)]^{1/2} + [\sigma'(\eta_1{}^- f_1{}^\pm)]^{1/2} \leq (6\ \mu{\rm b})^{1/2} + (3\ \mu{\rm b})^{1/2} = (16.4\ \mu{\rm b})^{1/2}. \qquad (4''')$$

This is in evident contradiction to Eq. (4''), which was based on the postulate that the η_1 had isospin 1.

Next we drop the assumption that η decay is dominantly radiative. (For instance, if η is a spinless meson, the mode $\eta \to \pi + \gamma$ is forbidden. Then η^0 could decay radiatively into two gamma rays, but $\eta^\pm$ might decay entirely into three pions.) If three-pion modes dominate, it can be shown that, for any spin assignment, our experiment loses sensitivity only by a factor of three, so $I=1$ is still ruled out (see Appendix).

It should be pointed out that Prowse et al. have done a similar experiment looking for the other (τ) decay mode of $\eta_1{}^\pm$ and have failed to find it.[6] These two experiments, taken together, seem to exhaust all possibility that the η meson has isospin 1.

We wish to thank Professor Aihud Pevsner for helpful discussions and to acknowledge the cooperation of Professor L. W. Alvarez and members of his group. The data were taken in the $\pi^\pm$ beam of Professor F. S. Crawford, Jr. We also wish to thank Professor Murray Gell-Mann and Dr. R. W. Huff for helpful discussions.

Appendix. Let us consider the situation if the charged η does not decay via a γ ray. Since the Q value for $\eta \to 3\pi$ is only 135 Mev, we assume that this mode will dominate only if it is allowed by G parity. Then isospin will be conserved. We must then discuss the three possible three-pion states, $J = 0^-$, 1^+, and 1^-, all with $I=1$.

First we discuss $J=0^-$. (Apart from Q value, this is the familiar τ meson.) Its isospin state is mainly the symmetric vector,

$$\vec{I}_S = \vec{\pi}_1(\vec{\pi}_2\cdot\vec{\pi}_3) + \vec{\pi}_2(\vec{\pi}_3\cdot\vec{\pi}_1) + \vec{\pi}_3(\vec{\pi}_1\cdot\vec{\pi}_2)$$

$$= \vec{\pi}_1(\pi_2^+\pi_3^- - \pi_2^0\pi_3^0 + \pi_2^-\pi_3^+) + \cdots + \cdots.$$

Collecting all these terms (some cancel), we can calculate the branching fractions $f_{\rm ch}^0$ for the η_1^0:

$$f_{\rm ch}^0 = \pi^+\pi^-\pi^0/(\pi^+\pi^-\pi^0 + \pi^0\pi^0\pi^0) = \tfrac{2}{5},$$

and f_3^+ for the η_1^+:

$$f_3^+ = \pi^+\pi^+\pi^-/(\pi^+\pi^+\pi^- + \pi^+\pi^0\pi^0) = \tfrac{4}{5}.$$

Thus, in their four-prong events, Pevsner et al. see two-fifths of all 0^- η events produced; in our two-prong events we see one-fifth, i.e., our sensitivity is half as good as theirs, whereas for the radiative assumption our sensitivity was three-halves theirs. They see $\sigma(\eta_1^0)f_{\rm ch}^0 = 150 \pm 30$ μb, so their partial cross section associated with slow protons $\sigma'(\eta_1^0)f_{\rm ch}^0$ is 30 ± 6 μb. Our sensitivity being half as good as theirs $(f_1^+/f_{\rm ch}^0 = \tfrac{1}{2})$, we expect $\sigma'(\eta_1^0)f_1^+ = 15 \pm 3$ μb. Inequality (4′′) then becomes

$$[\sigma'(\eta_1^+f_1^\pm)]^{1/2} + [\sigma'(\eta_1^-f_1^\pm)]^{1/2} > (30 \pm 6\ \mu\text{b})^{1/2},$$

which is again in contradiction to Eq. (4′′′). Some added radiative decays will only increase our relative sensitivity.

Next we discuss the $1^\pm$ states. These can have some component of the isosymmetric form $\vec{I}_S$, but there will also enter one of the nonsymmetric form, of which a typical term is

$$\vec{I}_N = \vec{\pi}_3 \times (\vec{\pi}_1 \times \vec{\pi}_2) = \vec{\pi}_1(\vec{\pi}_2\cdot\vec{\pi}_3) - \vec{\pi}_2(\vec{\pi}_1\cdot\vec{\pi}_3).$$

In the total rates, the I_N and I_S parts will not interfere, since they are associated with different spatial symmetries. Since I_N is antisymmetric in one pair of pions, it can contain no $3\pi^0$ component, and its branching fraction $f_{\rm ch}^0$ is 100%. Collecting terms, we find $f_3^+ = \tfrac{1}{2}$. Thus again our sensitivity compared to that of Pevsner et al. is one-half, regardless of which isospin states are present, and again $1^\pm$ states ($I = 1$) are ruled out.

---

*Work supported by the U. S. Atomic Energy Commission.

†On leave of absence from the Inter-University Institute for Nuclear Sciences, Brussels, Belgium.

[1]A. Pevsner, R. Kraemer, M. Nussbaum, C. Richardson, P. Schlein, R. Strand, T. Toohig, M. Block, A. Engler, R. Gessaroli, and C. Meltzer, Phys. Rev. Letters 7, 421 (1961).

[2]P. Bastien, J. Berge, O. Dahl, M. Ferro-Luzzi, D. Miller, J. Murray, A. Rosenfeld, and M. Watson, preceding Letter [Phys. Rev. Letters 8, 114 (1962)].

[3]A. Pevsner, John Hopkins Institute, Baltimore, Maryland (private communication).

[4]We used $P_\pi = 1.25$ Bev/c, 20 Mev/c higher than studied by Pevsner et al. This extra 20 Mev/c compensates somewhat for the fact that the internal momentum of the neutrons in deuterons raises the average c.m. energy.

[5]D. D. Carmony and R. T. Van de Walle, Lawrence Radiation Laboratory Report UCRL-9932, October 28, 1961 (unpublished).

[6]D. Prowse, P. Schlein, R. Sluter, D. Stork, and H. Ticho, University of California at Los Angeles (private communication). R. D. Walker [University of Wisconsin, Madison, Wisconsin (private communication)] has also examined 1.9-Bev π^+ events for η^+ and found none.