values of $\langle J_z^2 \rangle^{1/2}$ [shown in Table I(B)] effectively summarize the information available. These values (computed from x with $2|F_1|^2 \equiv 1$) exhibit the rather extreme degree of alignment of the B required by the data for the $J^P = 2^+3^- \cdots$ assignments.

(D) We have attempted to determine, for the $J^P = 1^+$ assignment, the amount of D-wave decay amplitude. Since we find our data to be consistent with a very wide range of the ratio $|D/S|^2$ (about 0.03 to 3), we omit a detailed presentation.

In conclusion we note that our data are equally consistent with $J^P = 1^+$ and with $J^P = 2^+3^- \cdots$, so that any attempt to rule out $J^P = 2^+3^- \cdots$ is pure speculation; the following remarks are speculative but possibly relevant:

(1) In our experiment B production is rather peripheral (Fig. 2). We find it hard to believe that the extreme alignment required by the assignments $J^P = 2^+3^-4^+ \cdots$ could arise in a peripheral process. This is nevertheless a prejudice, not an argument.

(2) As mentioned previously, the assignments $J^P = 3^-5^- \cdots$ are unlikely because of the apparent absence of $\pi\pi$ and $K\bar{K}$ decay modes.

(3) If one of the assignments $J^P = 2^+4^+ \cdots$ should turn out to be correct, it would mean that the B is incompatible with a quark-antiquark model, since $q\bar{q}$ states with $I^G = 1^+$ and $J^P = 2^+4^+ \cdots$ are not possible.

We take pleasure in expressing our gratitude to J. Kirz and O. I. Dahl for their generous help in setting up the π^- beam. We are also greatly indebted to our engineers, R. W. Downing and V. J. Simaitis, and to our scanners and measures.

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[6]An excellent summary of methods useful in spin-parity analysis is given by J. D. Jackson, High Energy Physics (Gordon and Breach Publishers, Inc., New York, 1965). Our discussion is merely a specialization of well-known techniques to the ω-π system.

[7]Equation (3) includes the effects of parity conservation in $\omega \to 3\pi$. An irrelevant factor, showing the dependence on the Dalitz variables for $\omega \to 3\pi$, has been left out.

[8]$\langle J_z^2 \rangle$ is defined by $\langle J_z^2 \rangle = \mathrm{Tr}(J_z^2 \rho)$.

[9]The unnormalized moment of a function f_α is $M_\alpha = \sum_i f_{\alpha i}$. We compute errors and correlations from $\langle \delta M_\alpha \delta M_\beta \rangle = \sum_i f_{\alpha i} f_{\beta i}$.

[10]J. L. Uretsky, private communication.

[11]For a graphic demonstration of the anomalous behavior of $J=1$, see J. D. Jackson, Classical Electrodynamics (John Wiley & Sons, Inc., New York, 1962), Fig. 16.1, p. 552.

PROPERTIES OF THE g MESON*

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We have observed the g meson in $\pi^+\pi^-$, $\pi^-\pi^0$, and $\pi^-\pi^-\pi^+\pi^0$ mass spectra and have measured masses, widths, and some branching ratios. The angular distributions and total cross sections presented strongly indicate a J^P of 3^- for the g meson.

The g meson was discovered by Goldberg et al.,[1] and by Forino et al.[2] in a $\pi^+\pi^-$ state and later by Deutschmann et al.[3] and Crennell et al.[4] in a $\pi^-\pi^0$ system. It is likely that the g^- was observed in the missing-mass experiments of Maglić and coworkers.[5] Recently others have reported evidence of a 4π state[6,7] at the same energy and conflicting evidence has been given concerning a possible $\omega^0\pi$ decay mode.[8,9] We report here further confirmation of the existence of this state and evidence for a spin and parity assignment of 3^- from an analysis of 340 000 pictures obtained in the Midwestern Universities Research Association-Argonne 30-in. hydrogen bubble chamber.

Figure 1 shows the mass plots for the 2π and 4π charged and neutral states. Evidence for the g may be seen in both (2π) states and in the $(4\pi)^-$ state. No evidence is seen for the g in the $(4\pi)^0$ state; this fact will be discussed later. The number of counts in the $\pi^+\pi^-$ system is 135 ± 20 as compared with 110 ± 20 in the $\pi^-\pi^0$ state. The

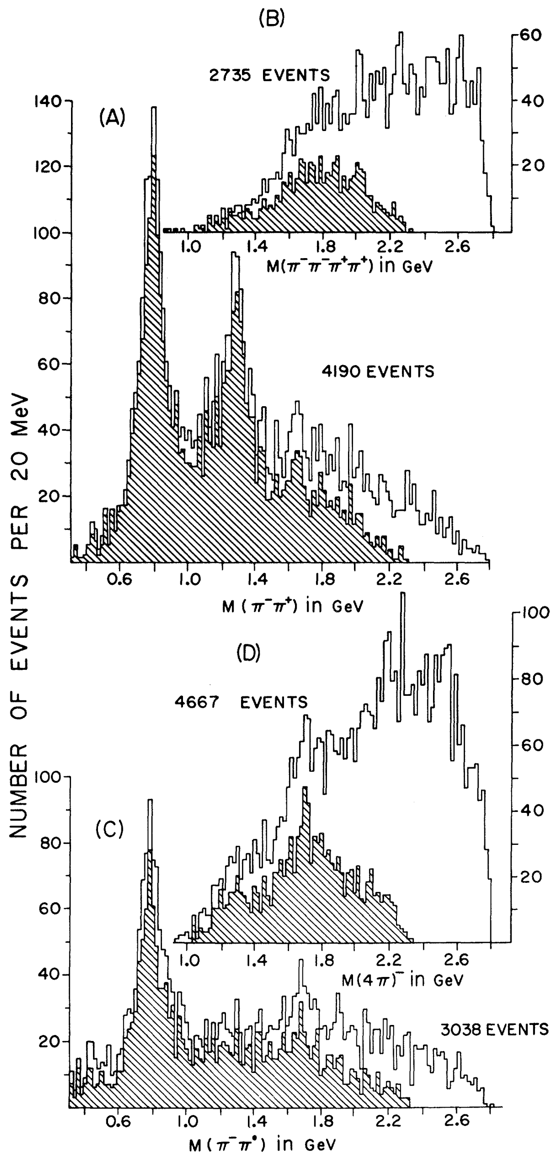

FIG. 1. $\pi\pi$ and $\pi\pi\pi\pi$ mass spectra. (a) $M(\pi^-\pi^+)$ from the reaction $\pi^-p \to \pi^-\pi^+n$. Shaded events in all figures correspond to events with t (target$\to$nucleon) < 0.3 $(\mathrm{GeV}/c)^2$. (b) $M(\pi^-\pi^-\pi^+\pi^-)$ from $\pi^-p \to \pi^-\pi^-\pi^+\pi^+n$. (c) $M(\pi^-\pi^0)$ from $\pi^-p \to \pi^-\pi^0p$. (d) $M(\pi^-\pi^-\pi^+\pi^0)$ from $\pi^-p \to \pi^-\pi^-\pi^+\pi^0p$.

g seems to be produced quite peripherally in both charge states as may be seen from the fact that the signal is not reduced by making a cut on momentum transfer to the nucleon. All the data are consistent with the production occurring by means of the one-pion-exchange mechanism. Figure 2 shows the π-π scattering angular distribution and the Treiman-Yang angle distribution. The near isotropy in the Treiman-Yang angle distribution together with the very sharp t dependence of the production process are both indicative of pion exchange. One expects a 2:1 ratio of neutral to charged events if (1) the isospin is 1, (2) production is by one-pion exchange, and (3) the partial width for decay into two pions is the same for the neutral and charged state. The numbers given above are nearly consistent with $I=1$ assignment.

If we examine the $(4\pi)^-$ and $(4\pi)^0$ states in Fig. 1, we see no evidence for the g meson in the neutral state but a substantial signal in the $(4\pi)^-$ state. Further breakdowns in Fig. 1 indicate some indication of a signal in the $\pi^-\omega^0$ state which substantiates an $I=1$ assignment. The results are consistent with the rest of the $(4\pi)^-$ events being in a $\rho^-\rho^0$ state although this is difficult to prove rigorously at the present level of statistics. We show the $\rho^-\rho^0$ and $\pi^-\omega^0$ mass spectra in Fig. 3(a). We find $[g^- \to (2\pi)^-]/[g^- \to (4\pi)^-] = 0.8\pm 0.2$. We find also $[g^- \to \pi^-\omega^0]/[g^- \to (4\pi)^-] = 0.25\pm 0.10$. In the case of the $(4\pi)^0$ system there is essentially no signal in the region of the g. This is difficult to understand unless the main

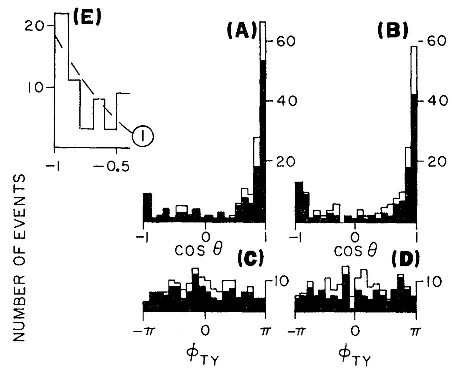

FIG. 2. Di-pion scattering angle and Treiman-Yang angle distribution for events in the g-meson region ($M_{\pi\pi}$: 1.63-1.73 GeV). (a), (b) Cosθ distribution for $\pi^-\pi^+$ and $\pi^-\pi^0$, where θ is the scattering angle of $\pi^- \to \pi^-$ (out) in the di-pion center of mass. (c), (d) Treiman-Yang angle distribution for $\pi^-\pi^+$ and $\pi^-\pi^0$. (e) Combined cosθ for $\pi^-\pi^+$ and $\pi^-\pi^0$ in the backward hemisphere. $[P_1(\cos\theta)]^2$ is drawn in. Shaded events correspond to $t < 0.3$ $(\mathrm{GeV}/c)^2$.

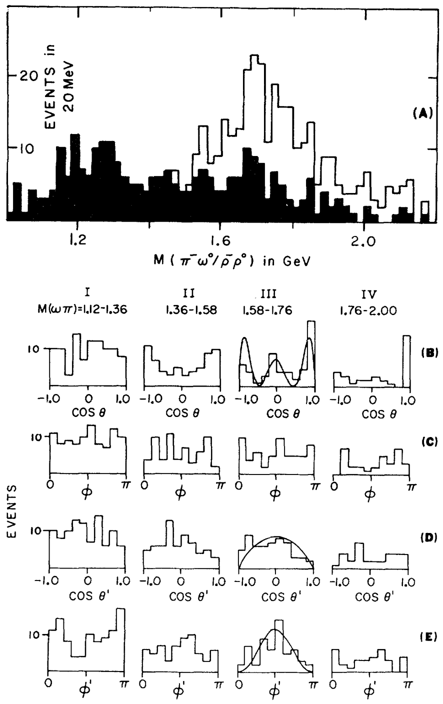

FIG. 3. $M(\pi^-\omega^0)$ distribution and the decay angles of $\pi^-\omega^0$ system. (a) Effective mass of $\pi^-\omega^0$ (shaded) and $\rho^-\rho^0$ (open) for events with $t < 0.3$ $(\mathrm{GeV}/c)^2$. $M(\omega) = 740$–820 MeV, $M(\rho) = 650$–850 MeV were used. For events having both $\pi^-\omega^0$ and $\rho^-\rho^0$ configurations, $\pi^-\omega^0$ are plotted. (b)-(e) Angular distributions of θ, φ, θ', and φ', respectively (see text for definitions), for different $M(\pi^-\omega^0)$ regions. The solid lines represent the expected decay distributions for a one-pion-exchange production of a $J^P = 3^-\pi^-\omega^0$ state: $W(\cos\theta) = \sin^2\theta \times (5\cos^2\theta - 1)^2$, $W(\cos\theta') = \sin^2\theta'$, $W(\varphi') = \sin^2\varphi'$.

channel of decay into 4π system is $\rho\rho$ or $\pi\omega$. If $I = 1$, then $J = 1, 3, 5$, etc., since we observe a 2π decay. If the dominant decay mode were a pair of ρ's in a ${}^5P_3$ configuration, such a combination would be forbidden for a $\rho^0\rho^0$ combination because of Einstein-Bose statistics and, also, isospin forbids a $\rho^0\rho^0$ decay mode. We cannot analyze $\rho^+\rho^-$ decays since there are three neutral particles in the final state. Other configurations of the 4π's such as $\pi^-A_2^+, \pi^+A_2^-$ would be analyzable. However, a search for $A_2^-\pi^0$ and $A_2^0\pi^-$ in the g-meson mass region of the $(4\pi)^-$ state gives negative results. We should also mention that we see a strong signal in the $\pi^-\pi^+\pi^-(\geq 2\pi^0)$ mass spectrum in the g region. Qualitatively the signal is as strong as the $\rho^0\rho^-$ signal. There is also a negative g-parity state in this region.

In Fig. 2 we show the angular distributions of $\pi^-\pi^+$ and $\pi^-\pi^0$ in the g region. The $\pi\pi$ scattering angle distributions are asymmetric and are consistent with a J of 2 or 3 in the forward and backward hemisphere.[10] In Fig. 3 we show the angular distribution of $\cos\theta$, φ, and φ' for four different $\pi^-\omega^0$ mass regions. The angles are defined as follows: θ is the angle between the incident and outgoing π^- in the $\pi^-\omega^0$ center-of-mass system; φ is the Treiman-Yang angle; θ' is the angle between the normal to the ω-decay plane and the ω^0 line of flight in the ω^0 rest frame. φ' is the corresponding azimuthal angle, measured from the x axis which lies in the $\pi^-\omega$ production plane. The θ, φ, and θ' distributions in the B region show what seems to be an S-wave $\pi^-\omega^0$ decay which is consistent with a 1^+ assignment for the B with a mass of 1280 ± 30 MeV and Γ of 80 ± 20 MeV. The g region shows a radically different angular distribution. The curve drawn on the $\cos\theta$ histogram corresponds to an $l = 3$, $m = \pm 1$ final state as expected from the decay of a 3^- object, produced by one-pion exchange, into a π^- and an ω^0. We have tested the 3^- hypothesis for the ω^0-π^- decay in the g region. We find a χ^2 of 5.5 (75 %) for nine degrees of freedom for the folded $\pi^-\omega^0$ distribution. A test of 5^- and 1^- gives a probability of 3 % and 10^{-4} %, respectively. The characteristic 3^- signal is strongly associated with the events with $(3\pi)^0$ in the ω^0 region. If the $\pi\omega$ system is produced by one-pion exchange then the θ'-φ' distribution takes a simple form of $\sin^2\theta' \sin^2\varphi'$ which is consistent with the data shown.

The ρ^0-ρ^- system also shows some evidence of a P-wave decay of the system, although a considerable background makes strong conclusions impossible. The strongest effect in the $\rho\rho$ system is the correlation between the decay plane of each ρ in the g-system rest frame. This would be consistent with an $l = 1$ $S_{\rho\rho} = 2$ configuration.

One can make further efforts to estimate the J of the g from the size of the elastic and inelastic π-π cross sections from our observed mass spectra. If we make a relative comparison of $\sigma_{\mathrm{el}}(\pi\pi) + \sigma_{\mathrm{inel}}(\pi\pi)$ in the region of the g and the region of the ρ^0, we find $[k^2\sigma(\pi\pi)]_{g^-}/[k^2\sigma(\pi\pi)]_{\rho^0} = 0.6 \pm 0.1$. In making this deduction we have assumed that production occurs as a result of π-π collisions and used the same kinematic cuts on momentum transfer to the nucleon to correct for kinematic differences which occur as a result of the mass differences. Our results give $J = 3 \pm 1$ for the g. Thus we would conclude from all the data presented that $J^P = 3^-$ is the strongly preferred spin and parity assignment. Our masses and widths are 1675 ± 10 and 90 ± 20 MeV for the g^-, and 1655 ± 10 and 80 ± 20 MeV for the g^0. We also note some indication of a peak at 1900 MeV of width 40 MeV in the $\pi^-\pi^0$ spectrum which has been evident in previous experiments.[3,5]

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[9]Ian Butterworth, review paper presented in Proceedings of the International Conference on Elementary Particles, Heidelberg, Germany, 1967, edited by H. Filthuth (North-Holland Publishing Company, Amsterdam, The Netherlands, 1968).

[10]It is perhaps worth repeating that $J=2$ is an impossible spin assignment since $I=1$. The peak in the backward hemisphere seems to be a signature of the g meson as it is not found in the adjacent energy regions. Thus these distributions are further evidence for $J=3$ for the g.