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A threshold $p\omega$ -enhancement in a reaction $ap \to ap\omega$ was observed in several hydrogen bubble chamber experiments with different kinds of beam particles: π^- at 7 GeV/c /1/; 4.5, 6 and 14 GeV/c/2/ ; π^+ at 14 GeV/c/3/ ; K^- at 4.6, 5 GeV/c/4/ and 4.2 GeV/c/5/ ; K^+ at 12 GeV/c/6/; $\bar{p}$ at 5.7 GeV/c /7/; p at 6.6 GeV/c /8/ and 19 GeV/c/9/. A narrow structure near the mass of 1800 MeV ($\Gamma \sim 100$ MeV), observed in the experiments /2,3,5,7/ rules out a possible explanation of the N(1800) enhancement by the Deck type mechanisms /10/.

The subsequent $N \to p\omega$ and $\omega \to 3\pi$ decays were studied in the t -channel (THF) and s -channel (SHF) helicity frames with angles $\Omega = \phi, \theta$ referring to the ω meson momentum and $\Omega_n = \phi_n, \theta_n$ referring to the ω decay-plane-normal direction in the ω rest frame*. Two main features of these sequential decays are to be pointed out.

(i) The $\cos\theta$ and ϕ distributions are found to be rather flat /1-3,5,7/; the moments $\langle D^L_{M0}(\phi,\theta,0)\rangle$ for $L \leq 4$ and the $p\omega$ mass less than 1900 MeV are consistent with zero both in THF and in SHF /2,7/.

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*In fact, the ω decay was studied in a slightly different system with the axis z chosen along the beam (or $p\omega$) direction in the ω rest frame and not in the $p\omega$ rest frame. However, a small $p\omega$ mass makes it possible to neglect the relativistic rotation induced by the corresponding Lorentz transformation.

(ii) At the same time the $\cos\theta_n$ distribution in THF has a large $\cos^2\theta$ contribution /6,7/ - the ρ_{00} element of the ω spin density matrix in THF has a rather large value: $\rho_{00} = 0.72 \pm 0.04$ below 1900 MeV in the $\bar{p}p$ experiment /7/.

The feature (i) and the near threshold $p\omega$ mass indicate an s-wave $p\omega$ state with the spin J = 1/2 or 3/2. As we'll see, however, both the features (i) and (ii) are sufficient to determine the spin of the N(1800) enhancement. Let us first note that (i) can take place in the two following cases (we neglect now a possible inteference with background).

(a) All the diagonal N-spin density matrix elements in THF (or SHF) are the same; $\rho_{mm} = \frac{1}{2J+1}$ and the nondiagonal elements have vanishing real parts. This condition is automatically fulfilled for J = 1/2 as a consequence of parity conservation.

(b) All the diagonal N-spin density matrix elements in the $N \to p\omega$ decay are the same, $r_{KK} = \sum_{\lambda_\omega = \lambda_p + K} |A_{\lambda_\omega}(\lambda_p)|^2 = \frac{1}{2J+1}$, where the elements r_{KK} are expressed through the normalized N decay helicity amplitudes

$$A_{\lambda_\omega}(\lambda_p) = \langle \lambda_\omega \lambda_p | \hat{A} | J, J_z = \lambda_\omega - \lambda_p \rangle , \sum_{\lambda_\omega \lambda_p} |A_{\lambda_\omega}(\lambda_p)|^2 = 1 .$$

Of course, the condition (b) is possible for the spin $J \leq 3/2$ only.

Note that from the relation $\rho_{mm} = \frac{1}{2J+1}$ it follows that the $\cos\theta_n$ distribution in THF (or SHF) should be flat ($\rho_{00} = 1/3$) because in this case, after integration over $d\phi$, no direction is favoured. Therefore only the condition (b) can explain both the features (i) and (ii), and we come to the conclusion that the N spin is $J = 3/2$*.

Let us further discuss the question of the N parity. For the spin $J = 3/2$ we can write the ρ_{00} element in the form

$$\rho_{00} = \frac{1}{3} - \frac{2}{3}(\rho_{\frac{3}{2}\frac{3}{2}} - \rho_{\frac{1}{2}\frac{1}{2}})\, f \quad , \qquad (1)$$

where the factor f, determined by the N decay amplitudes, satisfies the inequality $-0.8 \lesssim f \lesssim 1$ with the maximal value $f = 1$ obtained for pure s-wave decay amplitudes simply related to the Clebsch-Gordan coefficients $A_\lambda(\lambda_p) = \frac{1}{2}(1\lambda \frac{1}{2} - \lambda_p | \frac{3}{2} \lambda - \lambda_p)$. These amplitudes also fulfill the condition (b) which for the spin $J = 3/2$ requires $|A_{-1}(+)|^2 = \frac{1}{4}$. According to (1), for the ρ_{00} element in a $3/2 \to p\omega$ decay we have the inequality $0 \le \rho_{00} \le 2/3$. The experimental value $\rho_{00} = 0.72 \pm 0.04$ /7/ is near the upper ρ_{00} bound and thus indicates an s-wave $p\omega$ state and $\rho_{\frac{3}{2}\frac{3}{2}} = 0$**.

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* The Ω distribution $W(\Omega) = \sum_{LM} \frac{2L+1}{4\pi} t^{J*}_{LM} T^{J}_{L0} D^{L*}_{M0}(\Omega)$ becomes flat if the multipole parameters $t^{J*}_{LM} = \sum_{\Lambda\Lambda'} \rho_{\Lambda\Lambda'}(J\Lambda' LM | J\Lambda)$ or $T^{J}_{L0} = \sum_{K} r_{KK}(JKL0|JK)$ vanish for $L > 0$, i.e., if $Re\,\rho_{\Lambda\Lambda'} = 0$ for $\Lambda \neq \Lambda'$ and $\rho_{\Lambda\Lambda} = \frac{1}{2J+1}$ or $r_{KK} = \frac{1}{2J+1}$. Furthermore, $\rho_{00} = \frac{1}{3} + \frac{5}{3}\sum_{m} H(2m20)$ where the joint moments $H(\ell m LM) = \langle D^{L}_{Mm}(\Omega) D^{\ell}_{m0}(\Omega^{H}_{n}) \rangle$ (Ω^{H}_{n} refers now to the decay-plane-normal direction in the ω helicity frame: $z^{H} \parallel \vec{p}_{\omega}, y^{H} = z \times z^{H}$) are proportional to the multipole parameters t^{J*}_{LM}, i.e., $\rho_{00} = 1/3$ for $J = 1/2$ and, if $\rho_{\Lambda\Lambda} = \frac{1}{2J+1}$, also for $J \geqq 3/2$.

** Of course, the high ρ_{00} value ($\lesssim 0.6$) can also be realized with $f = -0.8$ and $\rho_{\frac{3}{2}\frac{3}{2}} = 1/2$. However, in this case rather essential higher waves (d- or f-waves) should contribute which seems unreasonable for the $p\omega$ mass so near the $p\omega$ threshold. Besides, in the $\pi^- p$ experiment /2/ the unaveraged $\rho_{00}(\phi, \theta)$ values were found to be independent of the decay angles ϕ, θ which also indicates an s-wave $p\omega$ state.

Table 1

Decay multipole parameters $T^{JL}_{\ell m}$ needed for the joint moments $H(\ell m LM) = t^{J*}_{LM}\, T^{JL}_{\ell m}$. The arrows indicate predictions for an s-wave $J \to p\omega$ decay

J	ℓ	m	$L=0$	$L=1$	$L=2$	$L=3$
$\frac{1}{2}$	0	0	1			
	2	0	$\frac{2}{5}(\rho^{\omega}_{00}-\rho^{\omega}_{11}) \to 0$			
		± 1		$\mp i\frac{2\sqrt{2}}{5} \mathrm{Im}\,\rho^{\omega}_{10} \to 0$		
$\frac{3}{2}$	0	0	1		$\frac{4}{\sqrt{5}}(g_{1-1}-\frac{1}{4}) \to 0$	
	2	0	$\frac{2}{5}(\rho^{\omega}_{00}-\rho^{\omega}_{11}) \to 0$		$\frac{2}{5\sqrt{5}}(\rho^{\omega}_{11}+2g_{11}-1) \to -\frac{1}{5\sqrt{5}}$	
		± 1		$\mp i\frac{2}{5}\sqrt{\frac{2}{5}} \mathrm{Im}(g_{10}-\frac{\sqrt{3}}{2} g_{0-1}) \to 0$	$-\frac{2}{5}\sqrt{\frac{6}{5}} \mathrm{Re}\, g_{0-1} \to -\frac{1}{5\sqrt{5}}$	$\mp i\frac{4}{5}\sqrt{\frac{3}{35}} \mathrm{Im}(g_{10}+\sqrt{3} g_{0-1}) \to 0$
		± 2			$-\frac{4}{5}\sqrt{\frac{3}{35}} \mathrm{Re}\, g_{1-1} \to -\frac{1}{5\sqrt{5}}$	$\mp i\frac{4}{5}\sqrt{\frac{3}{7}} \mathrm{Im}\, g_{1-1} \to 0$

This conclusion may be further confirmed by studying the joint moments $H(\ell m LM)$* (see, for example, /11/). In the parity conserving $J \to p\omega$ decay, with maximal orbital momentum ℓ_0, only the moments with $\ell = 0, 2$ and $L \le \min(2J, 2\ell_0 + \ell)$ can be different from zero. In Table I, for $J \le 3/2$, we express these moments through the parameters $g_{\lambda\lambda'} = A_\lambda(+)A^*_{\lambda'}(+)$ (note that $\rho^H_{\lambda\lambda'} = \sum_{\lambda_p} g_{\lambda\lambda'}(\lambda_p)$ are the ω-meson spin density matrix elements in the ω helicity frame) and through the multipole parameters t^{J*}_{LM} listed in Table II. Note that the "canonical" joint

Table 2

Multipole parameters $t^{J*}_{LM} = \sum_{\Lambda\Lambda'} \rho_{\Lambda\Lambda'}(J\Lambda' LM | J\Lambda)$.

J	$M \backslash L$	0	1	2	3
$\frac{1}{2}$	0	1			
	±1		$-\sqrt{\frac{2}{3}}\rho_{\frac{1}{2}-\frac{1}{2}}$		
$\frac{3}{2}$	0	1		$\frac{2}{\sqrt{5}}(\rho_{\frac{3}{2}\frac{3}{2}} - \rho_{\frac{1}{2}\frac{1}{2}})$	
	±1		$-i2\sqrt{\frac{2}{15}}\,Im(\sqrt{3}\rho_{\frac{3}{2}\frac{1}{2}} + \rho_{\frac{1}{2}-\frac{1}{2}})$	$\mp 2\sqrt{\frac{2}{5}}\,Re\,\rho_{\frac{3}{2}\frac{1}{2}}$	$-i\frac{4}{\sqrt{35}}\,Im(\rho_{\frac{3}{2}\frac{1}{2}} - \frac{\sqrt{3}}{2}\rho_{\frac{1}{2}-\frac{1}{2}})$
	±2			$2\sqrt{\frac{2}{5}}\,Re\,\rho_{\frac{3}{2}-\frac{1}{2}}$	$\pm i2\sqrt{\frac{2}{7}}\,Im\,\rho_{\frac{3}{2}-\frac{1}{2}}$
	±3				$-i\frac{2}{\sqrt{7}}\,Im\,\rho_{\frac{3}{2}-\frac{3}{2}}$

moments $C(\ell m_1 L_1 M_1) = \langle D^{L_1}_{M_1 0}(\Omega) D^{\ell}_{m_1 0}(\Omega_n)\rangle$ related to the "helicity" joint moments

$$C(\ell m_1 L_1 M_1) = \sum_{Lm} H(\ell m LM)(\ell m_1 L_1 M_1 | LM)(\ell m L_1 0 | Lm)$$

can be different from zero only if $L_1 \le \min(2\ell_0, 2J + \ell)$. Therefore the canonical moments are especially useful for detecting the maximal orbital momentum ℓ_0. In particu-

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*See footnote on page 5.

lar, in the case of a pure s -wave $J = 3/2$ $p\omega$ state the only nontrivial nonzero moments are $C(2m00) = -\frac{1}{\sqrt{5}} t^{*}_{2m}$.

Unfortunately, a p -wave $3/2^{+} \to p\omega$ decay can occur with the same normalized decay amplitudes as predicted by a pure s-wave. However, if the $p\omega$ enhancement is a p -wave effects, we should expect a rather strong s -wave background near the $p\omega$ threshold* interfering with the p -wave. Such an interference should result in odd moments $\langle D^{L}_{00}(\Omega)\rangle$ changing rapidly in the 1800 MeV mass region which is not the case found in the experiment /2,3,5,7/. This fact strongly supports the 1800 MeV enhancement to be an s -wave $3/2^{-}$ $p\omega$ state which interferes with the background s- wave without producing nonzero moments $\langle D^{L}_{00}(\Omega)\rangle$, $L \geq 1$.

There are several additional facts also supporting an s -wave $p\omega$ near threshold state and $3/2^{-}$ assignment for the 1800 MeV $p\omega$ enhancement.

(i) The character of $d\sigma / dt$ (in $\pi^{-}p$, $K^{-}p$ and $\bar{p}p$ reactions the slope parameter is $b \sim 6\,(\mathrm{GeV}/c)^{-2}$ /2,5,7/), energy behaviour of the low $p\omega$ mass production cross section ($\sigma \sim p^{-n}$, $n \sim -0.7$ /2/), small $\rho_{\frac{3}{2}\frac{3}{2}}$ value in THF (possible t -channel helicity conservation) and s -wave $p\omega$ state fit well with the diffraction picture of the low mass $p\omega$ production /13/.

(ii) The fact that no D_{13} resonance in the πN elastic phase shift analysis was reported /14/ may be due to a strong D_{13} coupling to the inelastic channels /15/. Actually, an evidence for a new resonance D_{13} near 1700 MeV comes from a partial wave analysis of the reaction $\pi N \to \pi\pi N$ /16/. Such a state is also required by the

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*Note in this context that some phase shift solutions /12/ show a rapid change in the elasticity of S_{11} in this region. The possibility of $J^{P} = 1/2^{-}$ background s -wave is also indicated in the $\bar{p}p$ experiment /7/, where the ω decay in THF becomes isotropic for the $p\omega$ mass higher than 1900 MeV.

L-excitation quark model /17/. In this context it is pointed out /15/ that there is an evidence for a D_{13} resonance in K^-p with a large coupling to $\omega\Lambda$ and mass just above the $\omega\Lambda$ threshold /18/.

(iii) In a formation experiment $\pi^-p \to \omega n$ a steep linear rise of the cross section with c.m. ω momentum was observed, and an explanation by a strong s-wave $p\omega$ resonance was suggested /15/. Such a possibility is also supported by a formation experiment /19/ of $\pi^+n \to \omega p$, where a suggestive peak near $p\omega$ threshold was observed with an isotropic production angular distribution and $\rho_{00} \simeq 0.6$, thus indicating a $3/2^-$ $p\omega$ s-wave state.

In conclusion, let us summarize the results concerning spin parity J^P of the $p\omega$ enhancement. Strong anisotropy, found in the ω decay-plane-normal distribution with respect to the incoming proton /6,7/, excludes $J = 1/2$. If we further take into account the isotropic ω angular distribution in the $p\omega$ rest frame, the spins $J > 3/2$ are excluded. The value $\rho_{00} = 0.72 \pm 0.04$, found in the $\bar{p}p$-experiment /7/ in the t-channel helicity frame, is near the maximal value $\rho_{00} = 2/3$ allowed in the $3/2 \to p\omega$ decay, and it is explained by the pure s-wave $3/2 \to p\omega$ decay and $\rho_{\frac{3}{2}\frac{3}{2}} = 0$ in the t-channel helicity frame.

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*In a formation experiment $\pi^+n \to \omega p$ only total $\pm 1/2$ spin projections on the c.m.s. beam direction are allowed, i.e., according to (1), we have $\rho_{00} = 1/3\,(1+f)$, $(f \simeq 1$.

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