Resonances III: Meson Resonances

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MESON RESONANCES

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Introduction

The parallel session on meson resonances consisted of six talks, or mini-reviews. The topics discussed (see program) are only a selected fraction of the present-day work on meson resonances; furthermore, the information that is contained in this section of the Proceedings does not include all the items actually discussed at the session. For example, the information in Pripstein's talk is contained in two preprints generally available, and is also covered in Kruse's session, so it was unnecessary to include it here. Likewise, much of the material in the other talks is covered in Diebold's plenary session, and an effort was made to avoid duplication. Thus, the articles in this session, particularly those of Chung, Fields, and Flatté, include only a small fraction of what was covered in their talks.

Two interrelationships between the topics in this session are worth noting in the introduction. The first concerns the heavy vector mesons and the B meson. Several studies of the B(1235) → πω, which usually find predominance of J^P = 1^+, have suggested a strong 1^- contribution to this region. This, then, could be a candidate for the ρ'(1250) mentioned in Daviers' article. On the other hand, diffractive photoproduction of a meson with mass near 1250 MeV, if established, could have two interpretations: either it could be the production of a vector meson, ρ'(1250), or it could be photoproduction of the B meson. The latter possibility would be very interesting because it would be a clear-cut example of a diffraction process where the incoming and outgoing particles (the photon and the B) are from opposite spin-parity series.

The second interrelationship concerns the search for high-mass meson states. Briefly, there is a striking correlation between the lack of narrow structure observed in various NN formation experiments and the same lack in production experiments; both observations involving the disappearance of previously claimed effects.

Finally, it seems useful to point out here that the sole qualitatively new result presented in this session, in the sense of not having been previously published, (for example in the 1972 Philadelphia Conference Proceedings), is the establishment of the decay mode A_2 → ωω.
The B meson has grown into a respectable particle since its first discovery in 1963.\textsuperscript{1} Despite earlier doubts concerning strong interference effects with the \( N^* \)'s in low energy \( \pi p \) data\textsuperscript{2} and a possible anomaly associated with the decay of \( \omega \) in the B region,\textsuperscript{3} there is now little reason to doubt that it is a genuine resonance. It has been observed not only in \( \pi p \) interactions\textsuperscript{4} and \( \bar{p} p \) annihilations,\textsuperscript{5} but also in \( K^- D \)\textsuperscript{6,7} interactions and possibly in \( \bar{p} p \) interactions\textsuperscript{8} as well (see Fig. 1).

The only decay mode observed so far is that of the \( \eta \omega \), which establishes the B meson as an \( I^G = 1^+ \) object. Absence of \( \pi \eta \) or \( \bar{K} K \) decay mode would indicate that the \( J^P \) for the B meson is not likely to be \( 1^- \), \( 3^- \), \( 5^- \), etc. On the other hand, from the point of view of the quark model, a \( q \bar{q} \) state in an \( I^G = 1^+ \) state cannot couple to \( J^P = 2^+, 4^+, 6^+ \), etc. From these observations, the likely \( J^P \) states for the B meson are \( 0^- \), \( 1^+, 2^- \), \( 3^+ \), etc. (or the unnatural parity series). Available experimental evidence so far points to a \( J^P = 1^+ \) assignment for the B meson.

Let us explain at this point the formulae one uses to do the \( J^P \) analysis. The basic idea involved is that the two-step decay of the B, i.e. \( B \rightarrow \pi \pi \rightarrow \eta \omega \), is so rich in the decay correlations that they leave an indelible mark as to the \( J^P \) identity of the parent object. In other words, certain of the experimentally independent moments are in fact related to one another and the proportionality constant is a known function of the parent spin and parity.

To be more specific, let us introduce the spherical angles \( (\theta, \phi) \) for the decay of the B into \( \eta \omega \) and \( (\theta_1, \phi_1) \) for the \( \omega \) decay.\textsuperscript{9} Then the experimental moments may be written

\[
H(\theta L M) = \langle \rho_{J}^{\eta}(\phi, \theta, 0) \delta_{P}^{\omega}(\phi_1, \theta_1, 0) \rangle
\]  

\textsuperscript{1}Work supported by the U. S. Atomic Energy Commission.
in terms of the usual D functions. For purposes of the $J^P$ analysis, the following moments turn out to be particularly important (for details, see Chung\textsuperscript{10}):

\[
\begin{align*}
H(00LM) + 5H(20LM) &= a(LM) |F_0| \text{(even L)} \\
H(00LM) - \frac{5}{2} H(20LM) &= a(LM) |F_1|^{\frac{1}{2}} \left[ 1 - \frac{L(L + 1)}{2J(J + 1)} \right] \text{(even L)} \\
5H(212M) &= a(2M) \text{Re}(F_1 F_0^*) \left[ \frac{2}{J(J+1)} \right]^{\frac{3}{2}} \\
5H(222M) &= a(2M) \varepsilon |F_1|^{\frac{1}{2}}
\end{align*}
\tag{2}
\]

where $a(LM)$ is a quantity which depends on the $\bar{u}$ density-matrix elements, $F_0$ and $F_1$ are the decay helicity coupling constants normalized such that $|F_0|^2 + 2|F_1|^2 = 1$, and $\varepsilon$ is $+1$ ($-1$) for unnatural (natural) parity series, i.e. $0^-$, $1^+$, $2^-$, $3^+$, etc. ($1^-$, $2^+$, $3^-$, etc.). If $J^P = 1^+$, the amplitudes for orbital angular momenta in the $B$ decay may be written

\[
D = \frac{\sqrt{3}}{2} (F_0 + F_1) \\
S = \frac{\sqrt{3}}{2} (F_0 + 2F_1)
\tag{3}
\]

The last moment in (2) can also be determined in a way different from (1):

\[
\mathcal{M}(222M) = \frac{\sqrt{6}}{5} \langle D_2^2 (\phi, \theta, \varphi_1) \rangle
\tag{4}
\]

This relation for $M = 0$ gives the formula first given by Berman and Jacob\textsuperscript{11} and used in the $J^P$ analysis by Ascoli, \textit{et al.}\textsuperscript{12} and others.\textsuperscript{13,14} The formulae as given in (1) and (2) have been used by Armenise, \textit{et al.},\textsuperscript{15} while Ott, \textit{et al.},\textsuperscript{16} have used both (1) and (4) in their $J^P$ analysis of the $B$ meson.

A summary of the $J^P$ analysis performed so far on the $B$ meson, including the papers submitted to this Conference, is given in Table I. All the analyses find $J^P = 1^+$ as the favored spin-parity assignment (except Ref. 15 which might suffer from lack of statistics). The two high-statistics experiments on $\pi p$ interactions, Ascoli, \textit{et al.},\textsuperscript{12} and Ott, \textit{et al.},\textsuperscript{16} find that $J^P = 1^+$ is favored, although other high spin-parity states cannot be ruled out. They
also find the ratio $|D/S|$ in the neighborhood of 0.17 to 0.18 and significantly different from zero. The work of Frenkîel, et al., on the other hand, concerns the $B$ produced in the reaction $\bar{p}p$ (at rest) $\rightarrow \pi^+\pi^-$. Assuming that the annihilation takes place in either $^3S_1$ or $^1S_0$ state, they find that the $B$ bump consists of two resonant states, $J^P = 1^+$ and $J^P = 1^-$, a mystery which is not likely to be resolved until a more thorough analysis on both the $np$ and $\bar{p}p$ data are done in the future.

In summary, one can say that the $B$ is a healthy resonant state with the quantum numbers $I^G = 1^+$ and $\pi\omega$ as the only certified decay mode. It is most likely to be a $J^P = 1^+$ object, although other higher spin-parity states cannot be ruled out. A more complete $J^P$ analysis on the $np$ data, which includes the interference effect of the $B$ and the background, is in order, not only to rule out conclusively the higher spin-parity states, but also to answer the question of whether the $B$ bump does not consist of more than one spin-parity state.
REFERENCES AND FOOTNOTES

9. The angles $\Theta, \phi$ describe the direction of the $\omega$ in the $B$ rest system and the angles $\Theta_1, \phi_1$ that of the normal to the $\omega$ decay plane in the helicity frame of the $\omega$ with the $x$ axis in the plane of the $\omega$ and the original $z$ axis (in the $B$ rest frame).


17. $\pi\pi$ Resonances and $\pi\pi$ s-wave Structures as Observed in $\bar{p}p$ Annihilations at Rest, P. Frenkel, et al., College de France-CERN, Nucl. Phys. B47, 61 (1972).
Table I. $J^*$ Summary

| Reference | $E$ Events above background | $M/\Gamma$ (MeV) | Favored $J^P$ | $|F_0|^2$ | $|D/S|$ for $J^P = 1^+$ |
|-----------|-----------------------------|------------------|--------------|--------|-------------------|
| (12) Ascoli, et al., (U. of Illinois) $\pi^p$ at 5.0 & 7.5 GeV/c | 686 $\pm$ 35 | $1232 \pm 5$ | $1^+(90\%), 2^-(23\%)$ | 0.184 $\pm$ 0.051 | 0.174 $\pm$ 0.068 (b) |
| | | $144 \pm 21$ | $2^+(2\%)$ | | (1.78 $\pm$ 0.27) (c) |
| (13) Werbrouck, et al. (TNNB Collab.) $\pi^p$ at 3.0 & 5.0 GeV/c | 226 $\pm$ 20 | | $1^+, 2^+, 3^-, \ldots$ | 0.06 $\pm$ 0.10 | 0.4 $\pm$ 0.2 |
| (14) Afzal, et al. (DGHMS Collab.) $\pi^p$ at 11 GeV/c | 130 $\pm$ 14 | $B^+\{1235 \pm 15$ | $1^+, 2^+ (d)$ | 0.09 $\pm$ 0.07 | 0.2 $\sim 1.7$ |
| | | $120 \pm 50$ | | | |
| | | $B^-\{1268 \pm 16$ | $3^+ \text{unlikely}$ | | |
| | | $130 \pm 50$ | | | |
| (16) R. Ott, et al. (Berkeley) $\pi^p$ at 7.1 GeV/c | 1200 $\pm$ 43 | $1235 \pm 5$ | $1^+$ favored | 0.18 $\pm$ 0.06 | 0.18 $\pm 0.07$ (e) |
| (17) P. Frenkel, et al. (Paris-CERN) $\bar{p}p$ at rest | ~1400 $\pm$ 14 | $1^+\{1228 \pm 5$ | $1^+$ and $1^- (f)$ | | |
| | | $126 \pm 10$ | | (J$\geq 2$ not tried) | |
| | | $1^-\{1256 \pm 10$ | | | |
| | | $129 \pm 20$ | | | |
| (15) N. Armenise, et al. (BBF Collab.) $\pi^p$ at 9.1 GeV/c | 158 $\pm$ 34 | $1250 \pm 10$ | $1^- (d)$ | 0.17 $\pm 0.04$ | $\sim 0$ |
| | | $140 \pm 15$ | | ($1^+$ Bkg.) | |

(a) Numbers estimated by Reviewer.
(b) This number has been estimated by assuming $F_0$ and $F_1$ are relatively real and $F_0 \cdot F_1 > 0$.
(c) Same as (b) but $F_0 \cdot F_1 < 0$.
(d) This $J^*$ analysis ignores the background in the $B$ region.
(e) Error on this guessed by Reviewer.
(f) This analysis uses the Zemach amplitudes to describe the reaction $\bar{p}p \rightarrow \pi^+ \pi^-$ and finds that both $1^+$ and $1^-$ states are required for the $B$ bump.
Fig. 4(a). $\pi^+\omega$ effective mass from $\pi^+p + \pi^+\omega$ at $7.1\text{ GeV/c}$ (Ref. 16); $0.765 \leq M(3\pi) \leq 0.805\text{ GeV}$.

Fig. 4(b). $\pi^+\omega$ effective mass from $\bar{p}p$ (at rest) $\rightarrow \pi^+\pi^-\omega$ (Ref. 17); $0.755 \leq M(3\pi) \leq 0.809\text{ GeV}$. 

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Tran Thanh Van: You have said that B decays mainly into $\pi\omega$ -- then the B-meson exchange must be important in $\pi N \rightarrow \omega N$. If we take the assumption $J^P = 2^+$ for the B meson (natural parity), the density matrix element for $\omega$ production $\rho_{00}(\omega) \equiv 0$, contrary to experiment $\rho_{00}(\omega) = 0.4 - 0.5$. On the contrary, with $J^P = 1^+$ B meson a simple description of $\omega$ production is nicely obtained [Lett. Nuovo Cimento 2, 135 (1971)]. Conclusion: $J^P = 1^+$ is absolutely needed.

J. L. Rosner: Coglazier-Rosner predict $\Gamma_D = 0.22 \Gamma_S$ for $B \rightarrow \omega\pi$. 