intermediate ρ was not produced.

[11]B. T. Meadows, Syracuse University High Energy Physics Memo No. 12-71, 1971 (unpublished).

[12]Besides the matrix elements included in Table II we have tried the matrix element suggested by V. Oglievetsky [see V. Oglievetsky, W. Taylor, and A. Zaslavasky, Phys. Lett. 35B, 69 (1971)], which appears to be almost identical with the 2^- dipole matrix elements and achieved the same fit probability.

[13]J. P. Dufey *et al.*, Phys. Lett. 29B, 605 (1969).

[14]We have not subtracted any background from the decay distributions of $\eta' \to \pi^+\pi^-\gamma$ since from the side bands we determined that their contribution is isotropic.

[15]The χ^2 probability that the significant moments up to $l, m=5$ are all zero is >80% in all reference frames.

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B-Meson Production in π^-d Interactions at 7 GeV/c *

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We observe substantial B-meson production in π^-d interactions at 7 GeV/c. The observed mass and width of the B are 1217 ± 12 MeV and 115 ± 40 MeV, respectively. We find that the B is produced largely in quasi-two-body final states, and, on the basis of the observed $\Delta^0 B$ production cross section, we expect a large $\pi A_2 B$ coupling which should be observable in other reactions.

Although the B meson was discovered about 10 years ago,[1] many of its properties are still relatively poorly known. Most of our knowledge concerning the B comes from the reactions $\pi^{\pm}p \to \omega\pi^{\pm}p$ (Ref. 2) and $\bar{p}p \to \omega\pi^+\pi^-$ at rest.[3] There has also been some evidence for B production in the reaction $K^-d \to p\Lambda\omega\pi^-$.[4] The data indicate that the spin-parity of the B is likely to be $J^P = 1^+$; however, assignments of 2^+, 3^-, 4^+, and higher cannot be excluded. The Particle Data Group[5] lists values of 1233 ± 10 MeV and 100 ± 20 MeV for the mass and width of the B, respectively. The available data, however, are not entirely consistent, with mass values ranging from 1200 MeV to 1260 MeV, and widths ranging from about 80 MeV to about 200 MeV. It appears that the total cross section for B production is falling rather slowly as a function of beam momentum ($\sim 1/p_{\text{beam}}$).[6]

We present here a study of B production in the reaction

$$\pi^-d \to pp\pi^+\pi^-\pi^-\pi^-\pi^0. \tag{1}$$

The data are derived from exposures of the SLAC and BNL[7] deuterium-filled bubble chambers to beams of ~7-GeV/c π^- mesons. These exposures yielded ~20 ev/μb of cross section. The film was scanned for five-pronged events which had one track that could be identified by ionization as a proton candidate, and for six-pronged events which had two proton candidates. Owing to these scanning rules, our data are unbiased only for values of the square of the momentum transfer from the deuteron to the two outgoing protons of less than 0.7 GeV^2. These events were subsequently measured and processed through the TVGP-SQUAW programs yielding a total of 1616 events belonging to reaction (1).

Figures 1(a) and 1(b) show the $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^-\pi^0$ mass spectra for these events, respectively. The shaded region of Fig. 1(b) corresponds to those $\pi^+\pi^-\pi^-\pi^0$ mass combinations whose $\pi^+\pi^-\pi^0$ mass lies within 65 MeV of the ω peak. An enhancement is visible in this mass spectrum in the B region.

Our measuring resolution (σ) in the $\pi^+\pi^-\pi^0$ mass spectrum at the mass of the ω is ~20 MeV. In order to both improve our mass resolution and to provide a means of ω selection, we further fitted all events that had made acceptable fits to the one-constraint hypothesis of reaction (1) and which had at least one $\pi^+\pi^-\pi^0$ mass combination less than 1000 MeV to the two-constraint reaction

$$\pi^-d \to pp\omega\pi^-\pi^-, \quad \omega \to \pi^+\pi^-\pi^0. \tag{2}$$

A total of 605 events made acceptable fits to this hypothesis.[8] The shaded area of Fig. 1(a) shows the $\pi^+\pi^-\pi^0$ mass combinations identified as ω's by this two-constraint fit. Figure 1(c) shows the $\omega\pi^-$ mass spectrum for the events identified as belonging to reaction (2). The B meson is clearly visible at ~1220 MeV. The dashed curve is the result of a low-order polynomial fit to the histogram assuming no resonant peak. If the observed enhancement were a statistical fluctuation, it

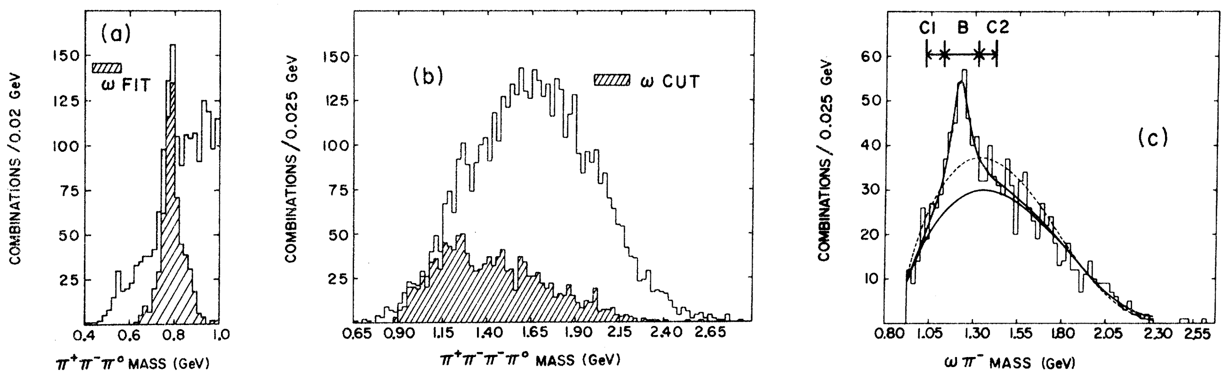

FIG. 1. (a) $\pi^+\pi^-\pi^0$ mass spectrum for reaction (1); the cross-hatched events are the $\pi^+\pi^-\pi^0$ combinations selected as ω's using the 2-constraint fit of reaction (2). (b) $\pi^+\pi^-\pi^-\pi^0$ mass spectrum for reaction (1); the cross-hatched events correspond to those combinations whose $\pi^+\pi^-\pi^0$ mass lies within 65 MeV of the ω peak. (c) $\omega\pi^-$ mass spectrum for reaction (2). The dashed curve is the result of a low-order polynomial fit to the histogram while the solid curves are the result of a fit of the data to a Breit-Wigner resonance shape and a polynomial representation of the background. The B-mass region extends from 1117 MeV to 1317 MeV while the control regions $C1$ and $C2$ go from 1017 MeV to 1117 MeV and from 1317 MeV to 1417 MeV, respectively.

would represent an unlikely 5 standard deviation fluctuation above this curve. The solid curves show the result of a fit of the data to a Breit-Wigner resonance shape and a polynomial representation of the background.[9] The mass and width of the Breit-Wigner curve were varied and the best fit was obtained for a mass of 1217 ± 12 MeV and an observed full width at half maximum (Γ) of 130 ± 40 MeV. Correcting the observed width for our experimental resolution, which is ~15 MeV at the B mass, we obtain a value of 115 ± 40 MeV for the width of the B.[10] After correcting for unseen ω decays and for losses at high momentum transfer,[11] this same fit yields a cross section of 23 ± 5 μb for the reaction $\pi^- d \to p p B^- \pi^-$. This compares with a value of ~40 μb for the reaction $\pi^+ p \to B^+ p$ at 7 GeV/c.[6]

We attempted to gain some information about the spin-parity of the B by using polarization information from the ω decay. To this end we examined the angular distribution of the normal to the ω-decay plane in the ω helicity frame. This distribution (not shown) is consistent with $\sin^2\theta$, implying an absence of longitudinal ω polarization, and ruling out the 0^- spin-parity assignment for the B. Attempts to gain further information about the B spin-parity using the Berman-Jacob method[12] were inconclusive.

To investigate the possibility of quasi–two-body B production in our reaction, we examine a scatter plot of the $\omega\pi^-$ mass versus the invariant mass of the proton and the other π^- meson [Fig. 2(a)]. (We have chosen the spectator to be the proton with the lower value of momentum and do not include it in this or all subsequent plots.) An excess of events is apparent in the $\Delta^0(1236)B$ overlap region; there is also possibly a small excess in the overlap between the B and the N^* region around 1600 MeV.[13] To investigate these further, Fig. 2(b) shows the mass of the $p\pi^-$ system produced opposite the B, where we have taken the B region to be 200 MeV wide and centered at 1217 MeV. A strong Δ^0 signal is observed, and, again, an additional enhancement in the 1600-MeV N^* region. Figure 2(c) shows the distribution of the background-subtracted $p\pi^-$ mass produced opposite the B, where we have subtracted from the events in the B mass region the $p\pi^-$ mass spectra for 100-MeV-wide control regions above and below the 200-MeV-wide mass band of the B [see Fig. 1(c)]. Clear enhancements are visible at the Δ^0 mass and in the 1600-MeV N^* region. Correcting for all decay modes, we obtain cross sections of 26 ± 10 μb for the reaction $\pi^- d \to p B^- \Delta^0$ and 23 ± 9 μb for the reaction $\pi^- d \to p B^- N^{*0}$, where our Δ^0 and N^* cuts extend from threshold to 1400 MeV and from 1400 MeV to 1720 MeV, respectively. (Because we are unable to distinguish between the different N^*'s in the 1600-MeV mass region we have arbitrarily assumed that the N^* decay rates into two-body and three-body final states are the same.) We note that about 70% of the B production in reaction (1) appears to proceed through quasi-two-body channels.

Reactions of the type $\pi^\pm p \to B^\pm p$ can proceed through either isoscalar or isovector exchange, with the exchanged particle being either an ω meson or an A_2 meson, respectively (see Fig. 3). The N^*B production in reaction (1) can also proceed through the same exchanges; in contrast, however, $\Delta^0 B$ production can only proceed through

$I=1$ exchange. Fox has calculated the cross section for $\Delta^0 B$ production in our experiment assuming A_2 exchange.[14] He predicts a value of 32 μb for this cross section, a result consistent with our observed value of 26 ± 10 μb.

In Fig. 3(d) we display $t - t_{min}(t')$ for the B mass cut where we define t to be the square of the momentum transfer from the incident π^- to the outgoing $\omega\pi^-$ system. We also show the same distribution after background subtraction in Fig. 3(e). The t' spectrum is fairly flat, consistent with a large A_2-exchange component.

We are thus observing a rather large cross section for a reaction presumably proceeding through the exchange of an A_2 meson. This implies a large $\pi A_2 B$ coupling at the upper vertex in Fig. 3(c). This coupling should also be observable in other reactions and might manifest itself as a decay mode of the A_2 into $B\pi$. Although the A_2 mass is slightly below the $B\pi$ threshold, a low-mass enhancement should be apparent in the $B\pi$ mass spectrum due to the Breit-Wigner tails of the decay $A_2 \to B\pi$. We speculate that the reaction $\pi^+ n \to \omega\pi^+\pi^- p$, despite background problems, would

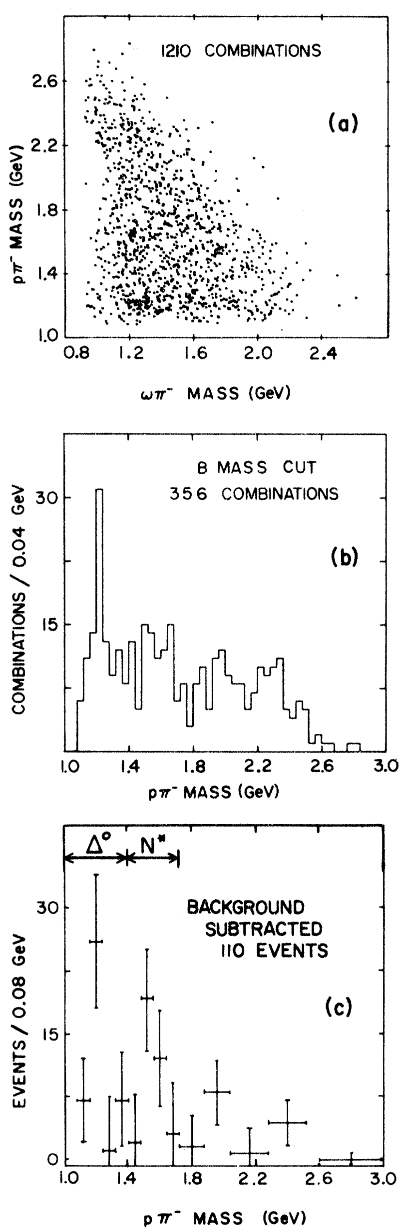

FIG. 2. (a) $\omega\pi^-$ mass versus $p\pi^-$ mass for reaction (2); (b) $p\pi^-$ mass produced opposite the B; (c) $p\pi^-$ mass produced opposite the B after background subtraction. See text for method of background subtraction. The Δ^0 and N^{*0} regions extend from threshold to 1400 MeV and from 1400 MeV to 1720 MeV, respectively.

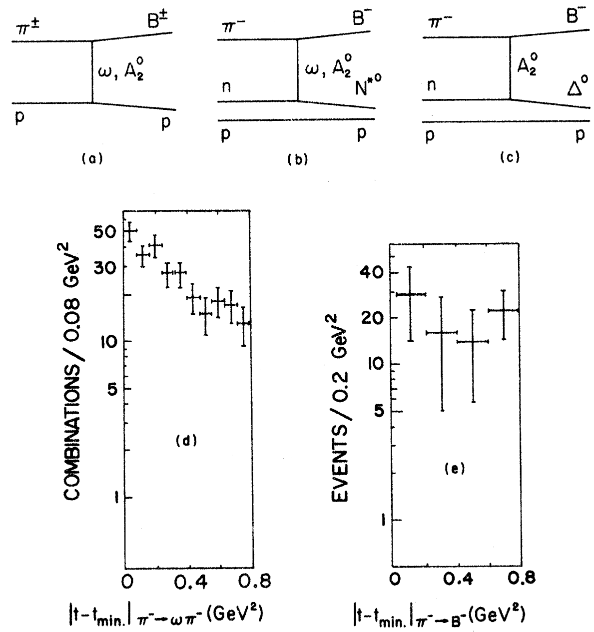

FIG. 3. (a)–(c) Exchange diagrams for the reactions $\pi^\pm p \to B^\pm p$, $\pi^- d \to pB^- N^{*0}$, and $\pi^- d \to pB^-\Delta^0$, respectively; (d) t' ($\pi^- \to \omega\pi^-$) for $\omega\pi^-$ masses in the B region shown for $t' < 0.8$ GeV^2; (e) t' ($\pi^- \to B^-$) after background subtraction shown for $t' < 0.8$ GeV^2.

TABLE I. Summary of properties of the B meson.[a]

Mass	1217 ± 12 MeV
Γ	115 ± 40 MeV
$\sigma(\pi^- d \to ppB^-\pi^-)$	23 ± 5 μb
$\sigma(\pi^- d \to pB^-\Delta^0(1236))$	26 ± 10 μb
$\sigma(\pi^- d \to pB^- N^{*0}(1600))$	23 ± 9 μb

[a] Cross sections have been corrected for unobserved decay modes and for scanning losses.

be the ideal process in which to search for the decay $A_2 \to B\pi$.[15]

In conclusion, we observe substantial B-meson production in $\pi^- d$ interactions at 7 GeV/c. We have measured the mass and width of the B, but can conclude little about its spin-parity. We observe that the B is produced largely in quasi-two-body final states, and on the basis of the observed $\Delta^0 B$ production cross section, we expect a large $\pi A_2 B$ coupling, which should be observable in other reactions. A summary of our findings is given in Table I.

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†A. P. Sloan Research Fellow.

[1]M. Abolins *et al.*, Phys. Rev. Lett. 11, 381 (1963).

[2]See, for example, G. Ascoli *et al.*, Phys. Rev. Lett. 20, 1411 (1968), and R. L. Ott, Ph.D. Thesis, Lawrence Berkeley Laboratory, 1972 (unpublished).

[3]C. Baltay *et al.*, Phys. Rev. Lett. 18, 93 (1967); R. Bizzarri *et al.*, Nucl. Phys. B14, 169 (1969).

[4]R. E. Berg *et al.*, Nucl. Phys. B39, 509 (1972); S.A.B.R.E. Collaboration, Phys. Lett. 33B, 631 (1970).

[5]Particle Data Group, Phys. Lett. 39B, 1 (1972).

[6]T. Ferbel, in *Meson Spectroscopy*, edited by C. Baltay and A. H. Rosenfeld (Benjamin, New York, 1968), p. 372.

[7]For a complete description of the data analysis see W. M. Katz, Ph.D. Thesis, University of Rochester, 1971 (unpublished), and D. Cohen, Ph.D. Thesis, University of Rochester, 1973 (unpublished). See also D. Cohen *et al.*, Phys. Rev. D 7, 661 (1973), and D. Cohen *et al.*, Nucl. Phys. B53, 1 (1973).

[8]For the ~20% of the events that made more than one acceptable ω fit we accepted the permutation with the lowest χ^2. We note that the events were also fitted to the hypothesis $\pi^- d \to pp\eta\pi^-\pi^-$, and events for which the lowest χ^2 fit corresponded to η production were not included in the ω sample.

[9]The data were fitted by the maximum-likelihood method to an expression of the form $B(m)[1+R(m)]$, where $B(m)$ is a polynomial representing the background and $R(m)$ is a simple Breit-Wigner form representing the resonance.

[10]The folding of a Breit-Wigner resonance shape with $\Gamma = 115$ MeV and a Gaussian resolution function with $\sigma = 15$ MeV as calculated by numerical integration yielded a distribution with $\Gamma = 130$ MeV. Since the resonance shape and resolution function are not well known, the folding was also carried out replacing each of these distributions by other test functions as a consistency check. Similar results were obtained.

[11]The losses at large values of momentum transfer were determined from a special scan carried out on a sample of the film which did not require the nonspectator proton to be dark.

[12]S. M. Berman and M. Jacob, SLAC Report No. 43, 1965 (unpublished).

[13]Due to our scanning rules, biases may exist in the $p\pi^-$ mass spectrum above ~1600 MeV.

[14]G. Fox, private communication. For a discussion of the method employed see G. Fox, in *Experimental Meson Spectroscopy—1972*, proceedings of the Third International Conference, Philadelphia, 1972, edited by Kwan-Wu Lai and Arthur H. Rosenfeld (A.I.P., New York, 1972), p. 271.

[15]We note that there may already be some evidence for the existence of an $\omega\pi\pi$ decay mode of the A_2. See R. Diebold, in *Proceedings of the Sixteenth International Conference on High Energy Physics, National Accelerator Laboratory, Batavia, Ill., 1972,* edited by J. D. Jackson and A. Roberts (National Accelerator Laboratory, Batavia, Illinois, 1973), Vol. 3, p. 1; C. Defoix *et al.*, Phys. Lett. 43B, 141 (1973). (These authors do not suggest that this decay mode of the A_2 is associated with the decay $A_2 \to B\pi$.)