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Study of Y_1^* Resonant Amplitudes between 1660 and 1900 MeV*

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ABSTRACT

A partial-wave analysis of the reaction $K^- n \rightarrow \Lambda \pi^-$ has confirmed the spin-parity assignments for Y_1^* (1765) and Y_1^* (2030) and measured the mass, width, and $\Lambda\pi$ branching ratio of Y_1^* (1765) as 1776 ± 6 MeV, 129 ± 16 MeV and 0.14 ± 0.02, respectively. A tentative spin-parity assignment for Y_1^* (1660) and Y_1^* (1915) is also made.

The cross section for the pure isotopic-spin I = 1 channel $K^- + p \rightarrow \Lambda + \pi^0$ in the c.m. energy interval 1660 to 1900 MeV shows a broad rise centered around 1780 MeV.[1] We have analyzed the angular distributions and polarizations in the reaction $K^- + n \rightarrow \Lambda + \pi^-$ in this energy interval, in order to study Y_1^* resonant amplitudes in the $\Lambda\pi$ channel.

The known I = 1 resonances between 1660 and 1900 MeV are $Y_1^*(1660)$ and $Y_1^*(1765)$. In addition, amplitudes due to $Y_1^*(1915)$ and $Y_1^*(2030)$ may be present in the energy interval under study.

$\underline{Y_1^*(1660)}$. This resonance has J = 3/2, $x_{\bar{K}N} \cong 0.15$ and $x_{\Lambda\pi} \cong 0.05$, where x_R is the branching ratio in the channel R.[2] The parity is uncertain.

$\underline{Y_1^*(1765)}$. The assignment I, $J^P = 1,\ 5/2^-$ has been deduced from a study of the reaction K^- + nucleon $\rightarrow Y_0^*(1520) + \pi$;[3] $x_{\bar{K}N} = 0.5$, and $x_{\Lambda\pi}$ is not known.

$\underline{Y_1^*(1915)}$. This resonance was recently discovered as a bump in the K^-n total cross section; $(J + 1/2)\, x_{\bar{K}N} = 0.31$, but J, P and $x_{\Lambda\pi}$ are unknown.[4]

$\underline{Y_1^*(2030)}$. A study of the reactions $K^- + p \rightarrow \Lambda + \pi^0$ and $K^- + p \rightarrow \bar{K}^0 + n$ in the K^- momentum interval 1220 to 1700 MeV/c has given I, $J^P = 1,\ 7/2^+$, with $x_{\bar{K}N} = 0.25$ and $x_{\Lambda\pi} = 0.16$.[5]

The analysis described below leads to the following results:

(i) The bump at 1780 MeV in the cross section for K^- + nucleon $\rightarrow \Lambda + \pi$ is due to a Y_1^* resonance of mass 1776 ± 6 MeV, width 129 ± 16 MeV, $J^P = 5/2^-$, and $x_{\Lambda\pi} = 0.14 \pm 0.02$. We identify this resonance with $Y_1^*(1765)$ and confirm the previous I J^P assignment.[3]

(ii) We verify that the parity of $Y_1^*(2030)$ is positive.

(iii) The parity of $Y_1^*(1660)$ is probably negative; a conclusive parity determination is not possible because the $Y_1^*(1660)$ amplitude is relatively weak in the $\Lambda\pi$ channel and there is insufficient data around 1660 MeV in this experiment.

(iv) There are some indications that $J^P = 5/2^+$ and $x_{\Lambda\pi} = 0.12 \pm 0.08$ for $Y_1^*(1915)$. This spin-parity assignment would make $Y_1^*(1915)$ a candidate for the Regge recurrence of the Σ hyperon.

(v) We observe that the relative phase ϕ of $Y_1^*(1765)$ and $Y_1^*(2030)$, each at the resonant energy, is 162 ± 9 deg; this phase difference is always 0 deg in the elastic channel. It also seems probable that $Y_1^*(1765)$ is in phase with $Y_1^*(1915)$ at the resonant energy, but 180 deg out of phase with $Y_1^*(1660)$. These observations can be related to the relative signs of the coupling constants $\mathscr{g}_{KNY^*}$ and $\mathscr{g}_{\Lambda\pi Y^*}$, as discussed below.

EXPERIMENTAL DETAILS

A total of 22 000, 75 000, 63 000 and 91 000 pictures of K^--deuterium interactions at 815, 915, 1015, and 1110 MeV/c, respectively, were taken in the Lawrence Radiation Laboratory's (LRL) 25-in. bubble chamber. The average beam intensity was 9 K^- per picture.

We measured 23 580 events having the topology of the interaction sequence

$$K^- + d \rightarrow \Lambda + \pi_1^- + p_1, \; \Lambda \rightarrow \pi^- + p, \tag{1}$$

with momentum of the proton p_1 between 0 and 230 MeV/c. The track of p_1 was not measurable below 90 MeV/c; 6294 events had a measurable proton (p_1) track. The events were measured on the LRL Flying-Spot Digitizer (4984 events) and on a Franckenstein (18 596 events).

A total of 4117 events fitted the reaction (1) hypothesis, and lay within the assigned fiducial region. The momentum distribution of the protons (p_1) agrees with the Hulthen form of the deuteron wave function, and, therefore, we assume that the observed interaction is $K^- + n \rightarrow \Lambda + \pi^-$, with the proton in the role of spectator. The only contamination is the reaction $K^- + n \rightarrow \Sigma^0 + \pi^-$, which comprises less than 10% of our sample.

Figure 1 shows the measured angular distribution of the pion and the Λ polarization in the reaction $K^- + n \rightarrow \Lambda + \pi^-$. The data is divided into 10 intervals in c.m. energy; the c.m. energy was taken as the magnitude of the four-momentum of the $\Lambda\pi^-$ system. Each event in the angular distribution was weighted by the factor $1/(P_p \; S_\pi \; S_\Lambda)$, where P_p is the probability of the Λ decaying within the fiducial volume and ranges from 0.71 to 0.97 depending on the momentum of the Λ and the position of the K^- interaction vertex. The factor S_π, which varies from 0.6 to 1.0, corrects for scanning bias involving events in which π^- is almost collinear with K^-. Scanning bias against certain configurations of Λ decay is accounted for by S_Λ, which is a function of lambda momentum and varies from 0.93 to 0.96. The observed angular distributions were converted to differential cross sections by using the published cross sections for the reaction $K^- + p \rightarrow \Lambda + \pi^0$.[1] The polarization of the Λ was calculated from the observed Λ-decay asymmetry relative to the production normal $\hat{n} = \hat{K} \times \hat{\pi}_1 / |\hat{K} \times \hat{\pi}_1|$, according to the formula $\underset{\sim}{P}_\Lambda \cdot \hat{n} = \frac{3}{\alpha_\Lambda} \langle \hat{p} \cdot \hat{n} \rangle$, where $\hat{p}$ is a unit vector parallel to the momentum of the proton in Λ decay, and α_Λ is 0.66.

ANALYSIS

The angular and polarization distributions may be expressed in the form:

$$\frac{d\sigma}{d\Omega} = \lambda^2 \sum_m A_m P_m(\hat{K} \cdot \hat{\pi}) \qquad (2)$$

$$\left(\frac{d\sigma}{d\Omega}\right) \quad \underset{\sim}{P} = \hat{n} \cdot \lambda^2 \sum_m B_m P_m^1(\hat{K} \cdot \hat{\pi}), \qquad (3)$$

where $P_m(\hat{K} \cdot \hat{\pi})$ is the Legendre polynomial of order m, $P_m^1(\hat{K} \cdot \hat{\pi})$ is the first associated Legendre polynomial and λ is the incident c. m. wavelength divided by 2π. The quantities A_m and B_m are functions of the complex transition amplitudes $T_\ell^{\pm}$ for states with $J = \ell \pm 1/2$, and $\sigma = 4\pi \lambda^2 A_0$.[6]

Coefficients A_m and B_m were determined by fitting the experimental distributions in Fig. 1 to Eqs. (2) and (3) by using the method of least squares. Figure 2 shows A_m/A_0 and B_m/A_0 plotted against c. m. energy; the coefficients are divided by A_0 so that the figure shows only the information learned in this experiment.

Certain deductions can be made from the A and B coefficients in Fig. 2. All the data can be fitted by an expansion to $m \leq 6$, indicating that amplitudes with $J > 7/2$ are not required in this energy region. The absence of an A_7 coefficient shows that only one amplitude with $J = 7/2$ is required to fit the data. The rapid energy variation of the A coefficients suggests that at least one resonant amplitude is strongly present. As already noted, the total cross section for $K^- + \text{nucleon} \rightarrow \Lambda + \pi$ shows a pronounced bump at 1780 MeV. This is most likely due to $Y_1^*(1765)$ with $J^P = 5/2^-$. In support of this hypothesis we note that A_2 and A_4

are large and positive in the energy region where the total cross section peaks, whereas A_6 is insignificant. This observation suggests a $J = 5/2$ amplitude, since the square of an amplitude with spin J makes a positive contribution to A_m for all even m with $m < 2J$.

To obtain more quantitative information on the amplitudes present in the $\Lambda\pi$ channel, we made a computer search for the set of partial-wave amplitudes which best fitted the polarization and differential cross sections in Fig. 1.

Table I lists the sets of amplitudes assumed in different fits. In fits 1, 2 and 3 we assume four nonresonant amplitudes S_1, P_1, P_3, and D_3, since analyses of the $\Lambda\pi$ channel in the c.m. interval 1600 to 1700 MeV have established the presence of S_1, P_1 and at least one $J = 3/2$ background amplitudes.[7,1c,1d] The energy dependence of these amplitudes is not known, and we hypothesize that they are constant over the energy region. The magnitudes and phases of these amplitudes were allowed to vary in all the fits.

In order to test for the presence of $Y_1^*(1765)$ with $J = 5/2$ in the $\Lambda\pi$ channel, the four nonresonant amplitudes were combined with a single $5/2^-$ (D-wave) resonant amplitude in fit 1a, and with a single $5/2^+$ (F-wave) resonant amplitude in fit 1b.

The resonant amplitudes had the Breit-Wigner form

$T = \frac{1}{2} (\Gamma_{\bar{K}N} \Gamma_{\Lambda\pi})^{1/2}/(E_R - E - i\,\Gamma/2)$ with $\Gamma_i \propto [q_i^2/(q_i^2 + X^2)]^{\ell_i}(q_i/E)$ and $\Gamma = \sum_i \Gamma_i$. The summation is over all decay channels of the resonance; X is fixed at 350 MeV, and q_i and ℓ_i are the momentum and orbital angular momentum of the decay products of the resonance of energy E in channel i.[8] In fit 1 and succeeding fits, the mass E_R, width Γ, and the magnitude at the resonant energy $x_{\overline{K}N} \cdot x_{\Lambda\pi}$ ($= \Gamma_{\overline{K}N} \quad \Gamma_{\Lambda\pi}/\Gamma^2$) of the $J = 5/2$ resonant amplitude were allowed to vary.

The differential cross sections and polarizations predicted by each set of amplitudes 1a and 1b were compared with the experimental data and the χ^2 function computed. The χ^2 was a function of 11 variables --the magnitudes and phases of the four nonresonant amplitudes, and the mass, width, and magnitude of the resonant amplitude. One phase is arbitrary, and this was fixed by making the $J = 5/2$ resonant amplitude purely imaginary at $E = E_R$ (this convention was used in all fits). The program VARMIT[9] was used to search through the hyperspace of 11 variables for the minimum in χ^2.

The solutions that minimize χ^2 for the 1a[10] and 1b hypotheses are shown in Fig. 3, a and b, and the final χ^2 is listed in Table I. The resonant D_5 amplitude is clearly favored over the resonant F_5 amplitude, but both solutions are highly improbable. Although both sets of amplitudes in fit 1 are inadequate to fit the data, it is instructive to examine the A and B coefficients generated by each solution; these are drawn in on Fig. 2. The manner in which the experimental data discriminates between the F_5 and D_5 hypotheses is clearly illustrated by the A_2 and B_2 coefficients. In terms of the partial-wave amplitude A_2 and B_2 are expressed as:

$$A_2 = \mathrm{Re}\left[2(|P_3|^2 + |D_3|^2) + (24/7)(|D_5|^2 + |F_5|^2) + 4(S_1^* D_3 + P_1^* P_3) + 6(S_1^* D_5 + P_1^* F_5) + (12/7)(P_3^* F_5 + D_3^* D_5)\right]$$

$$B_2 = \mathrm{Im}\,[2(S_1^* D_3 - P_1^* P_3) - 2(S_1^* D_5 - P_1^* F_5) + (10/7)$$
$$(P_3^* F_5 - D_3^* D_5)].$$

The terms in A_2 are the scalar products of the corresponding vectors in Fig. 3; the terms in B_2 are the vector products. The energy dependence of A_2 is equally well reproduced by the S_1 and D_5 amplitudes in Fig. 3a or by the P_1 and F_5 amplitudes in Fig. 3b. But only the S_1, D_5 interference gives the correct sign for the B_2 coefficient.

The expansion for A_4 is

$$A_4 = \mathrm{Re}\,[(18/7)(|D_5|^2 + |F_5|^2) + (72/7)(P_3^* F_5 + D_3^* D_5)]. \quad (4)$$

The energy dependence of A_4 is well described by the D_3 and D_5 amplitudes in Fig. 3a, but not by the P_3 and F_5 amplitudes in Fig. 3b.

In fit 2 we added to the amplitudes in fit 1 the J = 7/2 resonant amplitude due to $Y_1^*(2030)$. According to references 4 and 5, we fixed the mass and width at 2035 MeV and 160 MeV, respectively; our data are insensitive to these parameters since the resonant energy is far removed from the energy region under study. The data are sensitive, however, to the parity of $Y_1^*(2030)$, and this was checked by trying both the $J^P = 7/2^+$ (F-wave) and $7/2^-$ (G-wave) hypothesis. The magnitude and phase of $Y^*(2030)$ were allowed to vary, thus increasing the number of variables from 11 to 13. The only acceptable solution is 2a, which requires negative parity for the J = 5/2 resonant amplitude and positive parity for the J = 7/2 resonant amplitude. Solution 2a gives 1777 ± 6 and 135 ± 16 MeV respectively for the mass and width of the $5/2^-$ resonance. Therefore, we identify this resonance with $Y_1^*(1765)$ and confirm the previous determination of I, $J^P = 1,\ 5/2^-$. This parity solution for $Y_1^*(2030)$ agrees with the recent measurement of Wohl, Solmitz, and Stevenson.[5]

Solution 2a is shown in Fig. 3c. This set of amplitudes cannot generate the negative A_6 coefficient observed at 1855 MeV. The interference terms D_5, G_7 and F_5, F_7 are responsible for a negative A_6 coefficient. Since the single $J = 7/2$ amplitude present has been identified as F_7, an F_5 amplitude is indicated; a G_7 amplitude would generate an A_7 coefficient which is not required to fit the data. The negative A_6 coefficient is most marked at 1855 MeV; A_4 is negative at this energy, showing that $|F_5|^2$ in Eq. (4) is small. The fact that F_5 is relatively weak makes it impossible to determine whether or not this amplitude is resonant. However, we speculate that this amplitude may correspond to the recently discovered $Y_1^*(1915)$.[4] In fit 3 an F_5 amplitude of mass 1915 MeV and width 65 MeV was added to the D_5 and F_7 resonant amplitudes. The solution is shown in Fig. 3d. The χ^2/N value for this fit is (226/196); the equivalent probability is 0.07.

Table II summarizes the parameters of $Y_1^*(1765)$, $Y_1^*(2030)$, and $Y_1^*(1915)$ determined with varying degrees of certainty in fits 2 and 3. Fit 3 gives 1776 and 129 MeV respectively for the mass and the width of $Y_1^*(1765)$, together with the value of $(x_{\overline{K}N}\, x_{\Lambda\pi})$ for the three states. Using the published values of $x_{\overline{K}N}$, we determine the branching ratio $x_{\Lambda\pi}$ for $Y_1^*(1765)$ and $Y_1^*(1915)$ into the $\Lambda\pi$ channel. The branching ratio $x_{\Lambda\pi}$ for $Y_1^*(2030)$ is 0.55 ± 0.20, in disagreement with reference 5. The disagreement is not surprising, since it is not known whether the energy dependence assumed for Γ is valid for energies about 2Γ below the resonant energy.[8, 11]

The errors quoted in Table II are the statistical errors calculated in our fitting program, increased by a factor of two. The statistical errors have been doubled in an attempt to include uncertainties arising from the assumptions (a) that there are no nonresonant amplitudes present with the same spin and parity as the resonances, (b) that the background amplitudes are constant, and (c) that the energy dependence used for Γ may not be exactly correct.

Until now we have neglected $Y_1^*(1660)$ because its amplitude in the $\Lambda\pi$ channel is weak.[2] In fits 4a and 4b we took the experimental data below 1800 MeV, where the $Y_1^*(1660)$ amplitude is more important, and we made the assumption that one of the $J = 3/2$ amplitudes was due to a resonance of mass 1660 MeV and width 44 MeV. The magnitude and phase of the $J = 3/2$ resonance were allowed to vary. Only the $3/2^-$ resonant hypothesis led to a satisfactory fit; the corresponding $x_{\overline{K}N} \; x_{\Lambda\pi}$ value is given in Table II. However, the data below 1800 MeV is almost equally well described by constant $3/2^-$ and $3/2^+$ amplitudes as shown by fit 4c, so that the $J^P = 3/2^-$ assignment is not conclusive.[12]

COUPLING CONSTANTS $g_{\overline{K}NY^*}$ AND $g_{\Lambda\pi Y^*}$

The resonant D_5 amplitude was defined to be purely imaginary at $E = E_R$. The phase angles ϕ of the other resonant amplitudes at the resonant energies, relative to D_5 are shown in Table II. In the elastic channel ϕ is always zero; in the inelastic channel it may be zero or 180 deg because the sign of the off-diagonal T matrix elements is undefined. The resonant amplitude in the elastic channel is proportional to $g^2_{\overline{K}NY^*}/(E_R - E - i\,\Gamma/2)$ and in the $\Lambda\pi$ channel to $g_{\overline{K}NY^*}\, g_{\Lambda\pi Y^*}/(E_R - E - i\,\Gamma/2)$. For the elastic amplitude the numerator is always positive; in the inelastic channel the sign of the numerator depends on the relative sign of the coupling constants $g_{\bar{K}NY^*}$ and $g_{\Lambda\pi Y^*}$. The values of ϕ in Table II are consistent with $\phi = 180$ deg for $Y_1^*(2035)$ and $Y_1^*(1660)$, and $\phi = 0$ for $Y_1^*(1915)$. This shows that the product of the coupling constants $g_{\bar{K}NY^*}\, g_{\Lambda\pi Y^*}$ is of one sign for $Y_1^*(1765)$ and $Y_1^*(1915)$ and of the opposite sign for $Y_1^*(1660)$ and $Y_1^*(2030)$.[13] The ambiguity arises because the overall orientation of the amplitudes in the $\Lambda\pi$ channel relative to the $\bar{K}N$ channel cannot be determined by this analysis.

We note that the phase of the conjectured $Y_1^*(1915)$, $J^P = 5/2^+$, amplitude in fit 3 is 6 ± 18 deg, in agreement with the requirement that the phase ϕ be 0 or 180 deg. The resonant nature of the F_5 amplitude is supported by this observation.

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Footnotes and References

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9. The program VARMIT was written at Lawrence Radiation Laboratory by E. R. Beals. The input to the program is the χ^2 function and the analytic partial derivatives of χ^2 with respect to all the variables. The minimum is found by the Variable Metric method of W. C. Davidson, Argonne National Laboratory, 5990 (Rev. 1959). Approximately two minutes of time is required on the CDC 6600 computer to find the minimum of a function of 15 variables.

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10. To check the uniqueness of solution 1(a) we used the search mode of the program MINFUN, written by W. E. Humphrey, to look for low regions in the 11-variable hypersurface. A total of 25 low points were used as starting values for the program VARMIT. In all cases the same solution (Fig. 3a) was obtained.

11. The value of X = 175 MeV in the expression $\Gamma_i \propto [q_i^2/(q_i^2 + X^2)]^{\ell_i} (q_i/E)$ gives a better fit to the data than X = 350 MeV and brings the value of $x_{\Lambda\pi}$ for $Y_1^*(2030)$ into closer agreement with the measurement of Wohl et al.

12. An analysis of about 20 events in the reaction $\pi^+ p \rightarrow \Sigma^\pm \pi^\mp \pi^+ K^+$ at 3.23 BeV/c favors $J^P = 3/2^-$ for $Y_1^*(1660)$, Y. Y. Lee, D. D. Reeder, and R. W. Hartung, Phys. Rev. Letters 17, 45 (1966).

13. The connection between the signs of the coupling constants and the SU3 classification of the Y_1^* resonances will be examined in a forthcoming publication.

Table I. Partial-wave amplitudes used for a least-squares fit to the experimental distributions in Fig. 1. The χ^2 for each fit and the corresponding probability are also listed.

Fit	Constant amplitudes	Resonant amplitudes	χ^2	Degrees of freedom	Probability
1a	S_1, P_1, P_3, D_3	D_5	359	200	4×10^{-12}
1b	S_1, P_1, P_3, D_3	F_5	724	200	$<< 10^{-20}$
2a	S_1, P_1, P_3, D_3	D_5, F_7	240	198	0.02
2b	S_1, P_1, P_3, D_3	D_5, G_7	353	198	10^{-11}
2c	S_1, P_1, P_3, D_3	F_5, F_7	717	198	$<< 10^{-20}$
2d	S_1, P_1, P_3, D_3	F_5, G_7	581	198	$<< 10^{-20}$
3	S_1, P_1, P_3, D_3	D_5, F_5, F_7	226	196	0.07
4a	S_1, P_1, P_3	D_3, D_5, F_7	148	120	0.04
4b	S_1, P_1, D_3	P_3, D_5, F_7	172	120	10^{-3}
4c	S_1, P_1, P_3, D_3	D_5, F_7	150	120	0.03

Table II. Parameters and quantum numbers of $Y_1^*(1660)$, $Y_1^*(1765)$, $Y_1^*(1915)$, and $Y_1^*(2030)$. The quantities measured or verified in this experiment are underlined with a solid line; quantities suggested by this experiment are indicated by a broken line.

Mass E_R (MeV)	Width Γ (MeV)	Spin J	Parity P	$x_{\overline{K}N}\, x_{\Lambda\pi}$	$x_{\overline{K}N}$	$x_{\Lambda\pi}$	ϕ (deg)
1660	44	3/2	-	0.009 ± .010	0.15	0.06 ± .06	207 ± 23
1776 ± 6	129 ± 16	5/2	-	0.071 ± .008	0.5	0.14 ± .02	0
1915	65	5/2	+	0.012 ± .008	0.10	0.12 ± .08	6 ± 18
2035	160	7/2	+	0.137 ± .050	0.25	0.55 ± .20	162 ± 9

Figure Legends

Fig. 1. The differential cross section, $d\sigma/d\Omega$, and the lambda polarization, P_Λ, in the reaction $K^- + n \rightarrow \Lambda + \pi^-$ in the c. m. energy region 1660 to 1900 MeV. The differential cross section is displayed in the lower portion of each figure, the lambda polarization in the upper portion.

Fig. 2. Coefficients A_i/A_0 and B_i/A_0 obtained by fitting the angular and polarization distributions in Fig. 1 with the expansion $d\sigma/d\Omega = \lambda^2 \; \Sigma A_m P_m (\hat{K} \cdot \hat{\pi})$ and $(d\sigma/d\Omega) \cdot \vec{P} = \hat{n} \lambda^2 \sum_m B_m P_m{}^1 (\hat{K} \cdot \hat{\pi})$. The lower portion of each figure shows A_i/A_0, and the upper portion B_i/A_0, plotted against c. m. energy. The continuous curves are calculated from solution 1a, with resonant D_5 amplitude; the dashed curves correspond to solution 1b, with resonant F_5 amplitude.

Fig. 3. Magnitude and phases of the amplitudes which best fit the experimental data in Fig. 1 for the assumption of constant S_1, P_1, P_3, D_3 amplitudes and (a) a resonant D_5 amplitude (b) a resonant F_5 amplitude (c) resonant D_5 and $Y_1^*(2030)$ with $J^P = 7/2^+$ or (d) resonant D_5, $Y_1^*(2030)$ with $J^P = 7/2^+$, and $Y_1^*(1915)$ with $J^P = 5/2^+$. The resonant amplitude traces a circle counterclockwise as the energy increases; c. m. energies are indicated on the periphery of the circle.

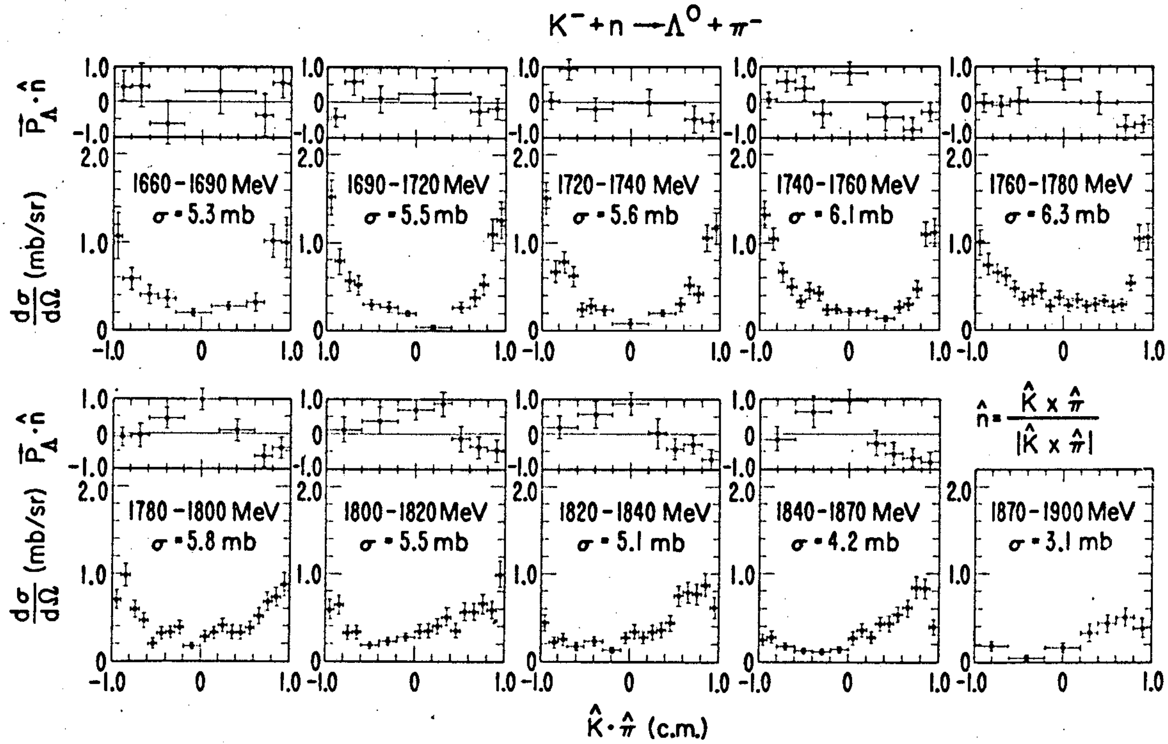
$K^- + n \longrightarrow \Lambda^0 + \pi^-$
$\bar{P}_\Lambda \cdot \hat{n}$
$\frac{d\sigma}{d\Omega}$ (mb/sr)
1660-1690 MeV
σ = 5.3 mb
1690-1720 MeV
σ = 5.5 mb
1720-1740 MeV
σ = 5.6 mb
1740-1760 MeV
σ = 6.1 mb
1760-1780 MeV
σ = 6.3 mb
1780-1800 MeV
σ = 5.8 mb
1800-1820 MeV
σ = 5.5 mb
1820-1840 MeV
σ = 5.1 mb
1840-1870 MeV
σ = 4.2 mb
1870-1900 MeV
σ = 3.1 mb
$\hat{n} = \frac{\hat{K} \times \hat{\pi}}{|\hat{K} \times \hat{\pi}|}$
$\hat{K} \cdot \hat{\pi}$ (c.m.)

Fig. 1

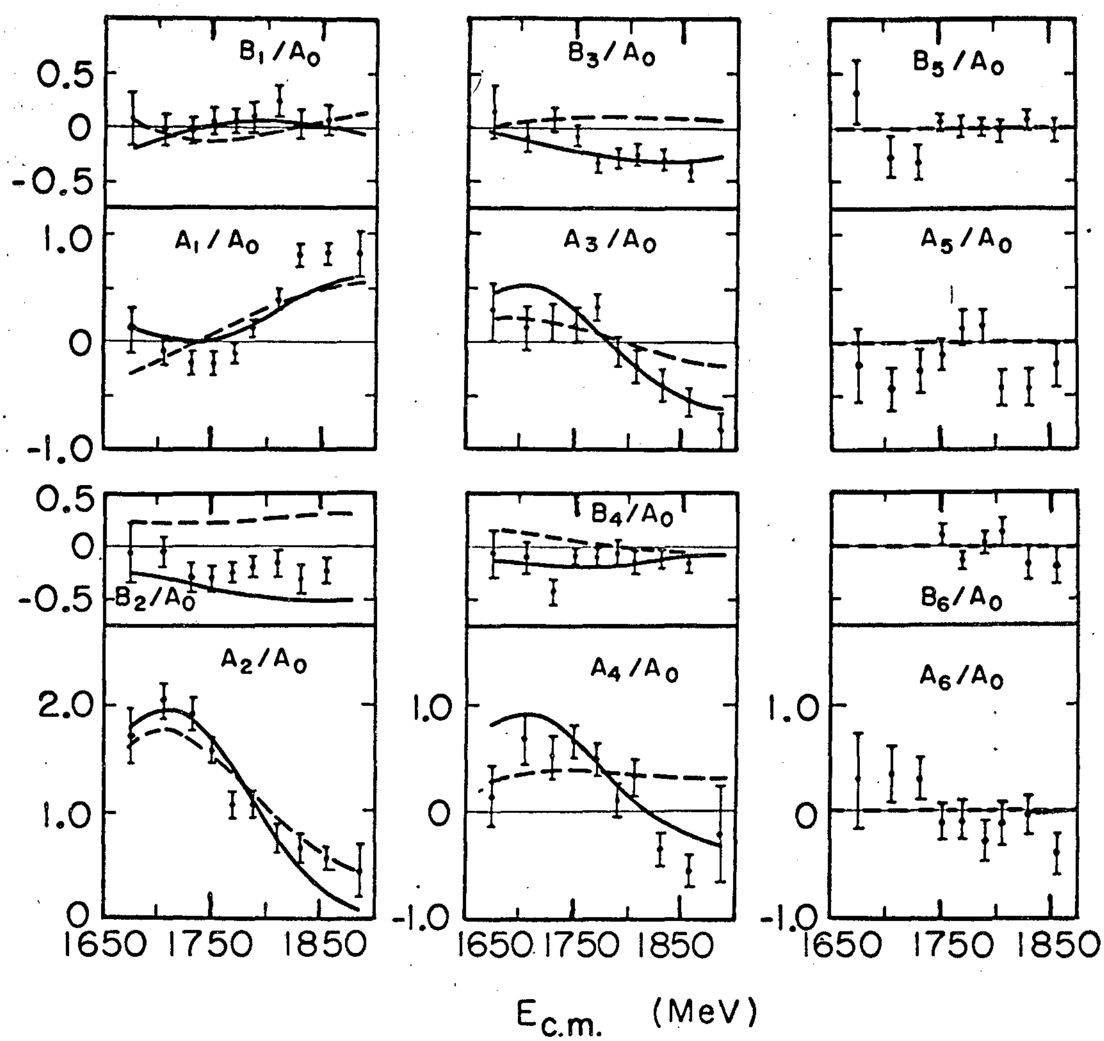

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Fig. 2

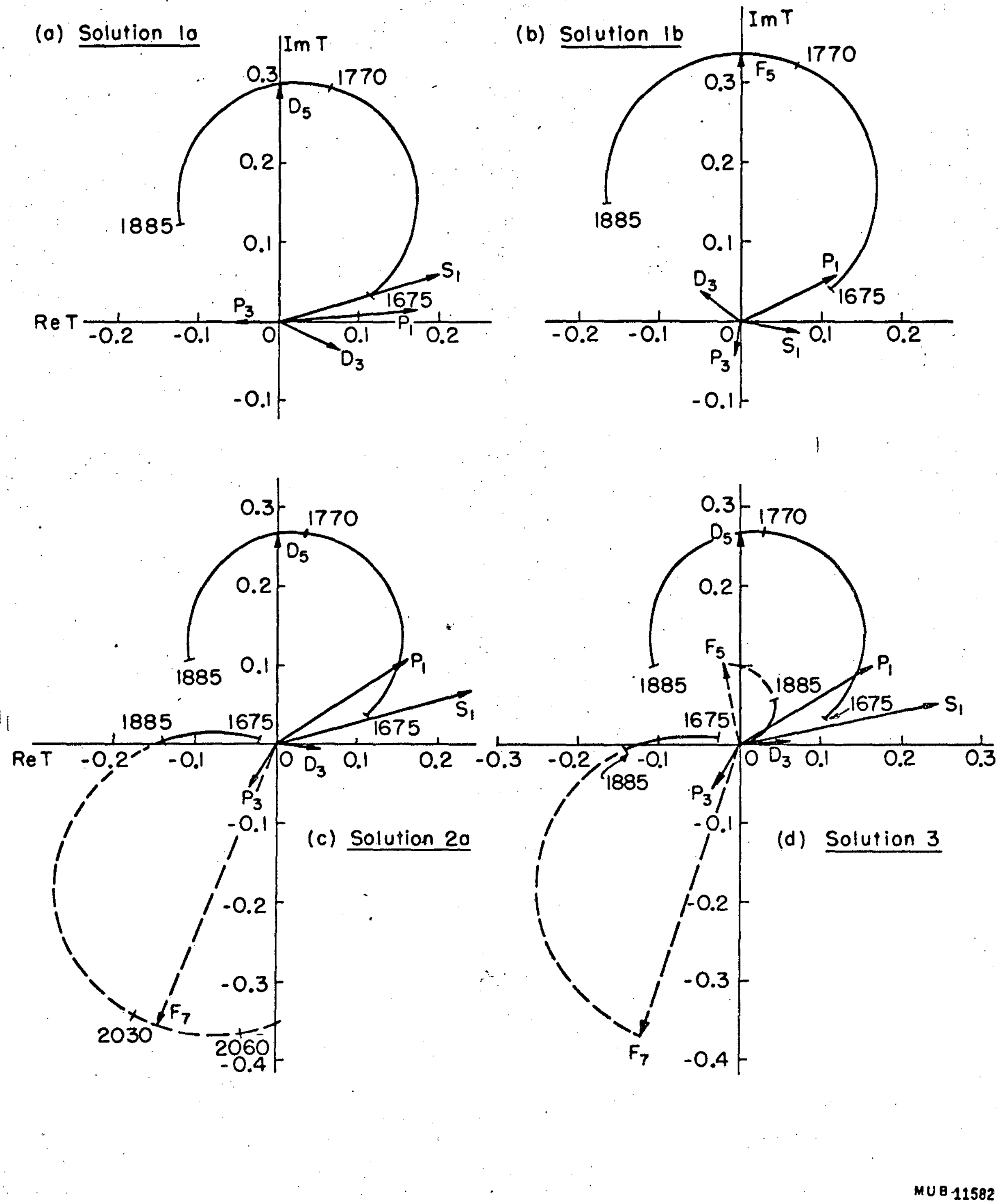
(a) Solution 1a
Im T
Re T
1770
1885
1675
D_5
S_1
P_1
P_3
D_3
(b) Solution 1b
Im T
1770
1885
1675
F_5
P_1
D_3
S_1
P_3
(c) Solution 2a
Re T
1770
1885
1675
2030
2060
D_5
P_1
S_1
P_3
D_3
F_7
(d) Solution 3
1770
1885
1675
D_5
F_5
P_1
S_1
P_3
D_3
F_7
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Fig. 3