Dynamics of the Y_{05}^* (1815-MeV) $\bar{K}N$ Resonance

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An exact N/D calculation is done in $\bar{K}N$ scattering by taking ρ and ω exchanges in the t channel. The calculation shows a resonance (Y_{05}^*) at $\simeq 13\ m_\pi$ with a width of $\Gamma \simeq 100$ MeV in the $I=0$, $f_{5/2}$ state. No resonance occurs in the $I=0$, $d_{5/2}$ partial wave, suggesting the spin-parity assignment $\frac{5}{2}^+$.

I. INTRODUCTION

Recent experimental investigations[1–6] in $\bar{K}N$ scattering have shown a resonance Y_{05}^* at 1815 MeV in the state $I=0$. Sodickson *et al.*[6] have suggested its spin to be $\frac{5}{2}$, but have not been able to say anything about its parity. In our analysis, we have assumed its spin to be $\frac{5}{2}$ and have tried to ascertain the parity.

In the analysis of $\bar{K}N$ scattering, one normally faces a multichannel problem, namely

$$\bar{K}N \to \bar{K}N\,, \tag{1.1}$$

$$\bar{K}N \to \Lambda\pi\,, \tag{1.2}$$

$$\bar{K}N \to \Sigma\pi\,. \tag{1.3}$$

Of these $\bar{K}N \to \Lambda\pi$ is ruled out in our case, because it cannot contain a Y_{05}^* resonance on account of isotopic spin conservation. Also, the third channel can be neglected since Y_{05}^* decays mainly into K^-p. Rosenfeld *et al.*[7] have reported that 80% of the Y_{05}^* decay is $\bar{K}N$ and less than 10% is $\Sigma\pi$. This shows that Y_{05}^* is very weakly coupled to the $\Sigma\pi$ channel. There can be other inelastic channels like $\bar{K}N \to \Lambda\eta$ and $\bar{K}N \to \bar{K}^*N$ also, but we have not taken them into account for reasons of simplicity and have confined ourselves to one-channel elastic scattering.

The forces due to only one-particle exchanges were taken into account. No baryon exchange is possible. ρ and ω mesons were exchanged in the t channel and we tried to see if they could give sufficient force in the s channel to give rise to a resonance in the $J=\frac{5}{2}$, $T=0$ state. We made an exact N/D calculation and found that a resonance occurs at $12.99 m_\pi$ with a width of 100 MeV in f wave. This shows that a very likely spin-parity assignment for the resonance is $\frac{5}{2}^+$.

In Secs. II and III we give the description of the input forces and the method of calculation. The numerical results have been given in Sec. IV and have been compared with the available experimental data.

II. INPUT FORCES

The invariant amplitude for the $\bar{K}N$ process is written as

$$T=A(s,t,u)+\tfrac{1}{2}B(s,t,u)\gamma\cdot Q\,, \tag{2.1}$$

where Q is the sum of the momenta of the two $\bar{K}$ mesons.

The partial-wave amplitude is defined, as usual, as

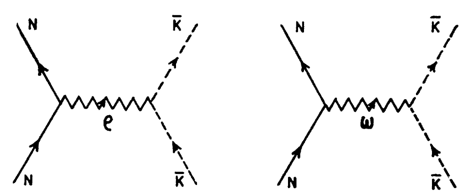
$$f_{l_\pm}=(1/q)\exp(i\delta_{l_\pm})\sin\delta_{l_\pm} \tag{2.2}$$

and is connected with $A(s,t,u)$ and $B(s,t,u)$ in the usual way.[8]

We confine ourselves to the forces arising because of one-particle-exchange Born graphs only. No baryon exchange is allowed in the u channel. The only one particle exchanges that we have taken in the t channel are ρ and ω mesons. There could be other exchanges like φ and f^0 also but we have not taken them into account because that would introduce unknown parameters in the calculation.[9]

The Born diagram for ρ exchange [Fig. 1(a)] gives

$$\begin{aligned} f_{l_\pm}{}^{\rho(I_s=0)}=(3/4\pi)(1/4Wq^2)[(E+M_N)&\\ \times\{A_l+(W-M_N)B_l\}+(E-M_N)&\\ \times\{-A_{l\pm1}+(W+M_N)B_{l\pm1}\}],&\end{aligned} \tag{2.3}$$



(a) (b)

Fig. 1. Exchange graphs for $\bar{K}N$ scattering. (a) ρ-meson exchange. (b) ω-meson exchange.

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[9] Apart from the unknown coupling constants $g_{KK\varphi}g_{NN\varphi}$ and $g_{KKf^0}g_{NNf^0}$ there are other undetermined parameters, since f^0, which is a particle of spin-2, does not have a unique propagator, see G. Mohan and S. C. Agarwal, Nuovo Cimento **37**, 470 (1965).

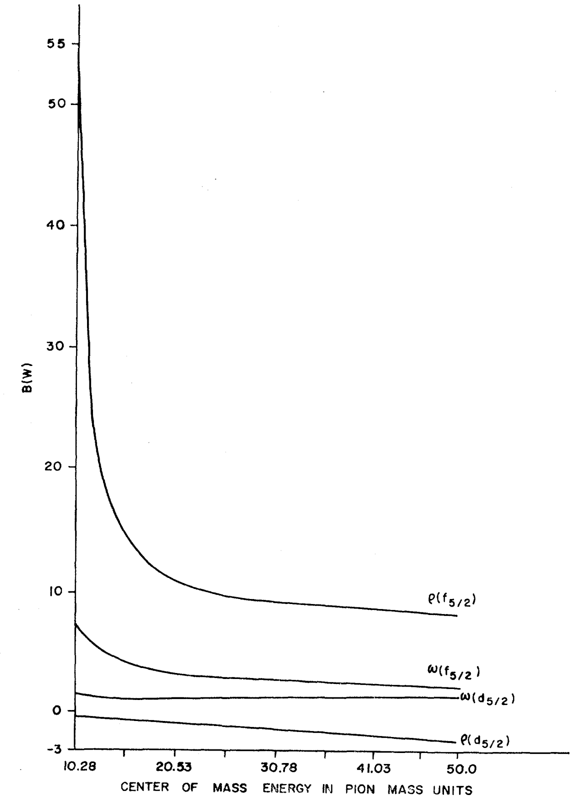

FIG. 2. The ρ and ω contributions to the Born function $B(W)$ for the $d_{5/2}$ and $f_{5/2}$ partial waves, shown separately.

where

$$A_l = g_{KK\rho}g_{NN\rho}'\left(\frac{2M_N^2+2M_K^2-2W^2-M_\rho^2}{2M_N}\right)\times Q_l\left(1+\frac{M_\rho^2}{2q^2}\right)$$

and

$$B_l = 2(g_{KK\rho}g_{NN\rho}+g_{KK\rho}g_{NN\rho}')Q_l(1+M_\rho^2/2q^2).$$

g and g' here refer to the rationalized charge and magnetic-moment coupling strengths, respectively, and E refers to the energy of the nucleon. W and q are the total center-of-mass energy and momentum, respectively, and the masses of the various particles are identified by adding a suffix to M.

The ω contribution [Fig. 1(b)] is trivially obtained by replacing ρ by ω everywhere in the above expression and dividing the expression by 3.

The coupling constants were found by using the known decay widths and unitary symmetry.[10,11] The values are

$$\begin{aligned} g_{KK\rho}g_{NN\rho}/4\pi &= 0.56\,, \\ g_{KK\rho}g_{NN\rho}'/4\pi &= 2.25\,, \\ g_{KK\omega}g_{NN\omega}/4\pi &= 1.68\,, \\ g_{KK\omega}g_{NN\omega}'/4\pi &= 0\,. \end{aligned} \tag{2.4}$$

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III. CHOICE OF THE AMPLITUDE AND THE METHOD OF CALCULATION

As indicated earlier, we shall make use of the familiar N/D method, which is based on the analyticity and the unitarity properties of the amplitude. The details in the case of πN scattering have been worked out by several authors.[12,13] We shall follow the arguments given by these authors to choose our amplitude as

$$h = \rho f\,,$$

where ρ is a kinematic factor which takes care of the threshold behavior and the behavior at infinity of the amplitude. Thus h is a smoothly varying function and contains only the dynamical singularities. Following Ball and Wong[13,14] we write

$$h_J(W) = (W^{2J}/(E+M_N)q^{2J-1})f_{l=J-\frac{1}{2}}(W)\,, \tag{3.1}$$

which is again written as

$$h_J(W) = N(W)/D(W)\,, \tag{3.2}$$

where $D(W)$ and $N(W)$ satisfy the dispersion relations

$$D(W) = 1 - \frac{W}{\pi}\left[\int_{-\infty}^{-(M_N+M_K)} + \int_{(M_N+M_K)}^{\infty} dW'\left(\frac{E'+M_N}{(W')^{2J+1}}\right)\frac{|q'|^{2J}N(W')}{W'-W}\right] \tag{3.3}$$

and

$$N(W) = h_J^L(W) + \frac{1}{\pi}\left[\int_{-\infty}^{-(M_N+M_K)} + \int_{(M_N+M_K)}^{\infty} dW'\left\{\frac{W'h_J^L(W')-Wh_J^L(W)}{W'-W}\right\}\times\left(\frac{E'+M_N}{(W')^{2J+1}}\right)|q'|^{2J}N(W')\right]. \tag{3.4}$$

Here $h_J^L(W)$, the discontinuity across the left-hand cut, is the sum of the contributions from the one-particle-exchange Born diagrams multiplied by the appropriate kinematic factor ρ.

In solving these equations exactly, one is faced with the well-known problem of dealing with divergent integrals which is an essential feature of the forces arising due to the exchange of particles of spins, greater than or equal to one. We use a cutoff parameter to overcome this difficulty, as is usually done, and solve the equations exactly by the method of matrix inversion. A resonance occurs at $W=M^*$ when $\mathrm{Re}D(M^*)$

[12] E. Abers and C. Zemach, Phys. Rev. **131**, 2305 (1963).
[13] J. S. Ball and D. Y. Wong, Phys. Rev. **133**, B185 (1964).
[14] The amplitude defined in this way has the disadvantage that h has a zero of the order s^{2J} at $s=0$ which implies that f may have unwanted poles at this point. However, since we are interested only in the resonance which occurs at quite a high energy, we expect that this pole will not affect our results very much.

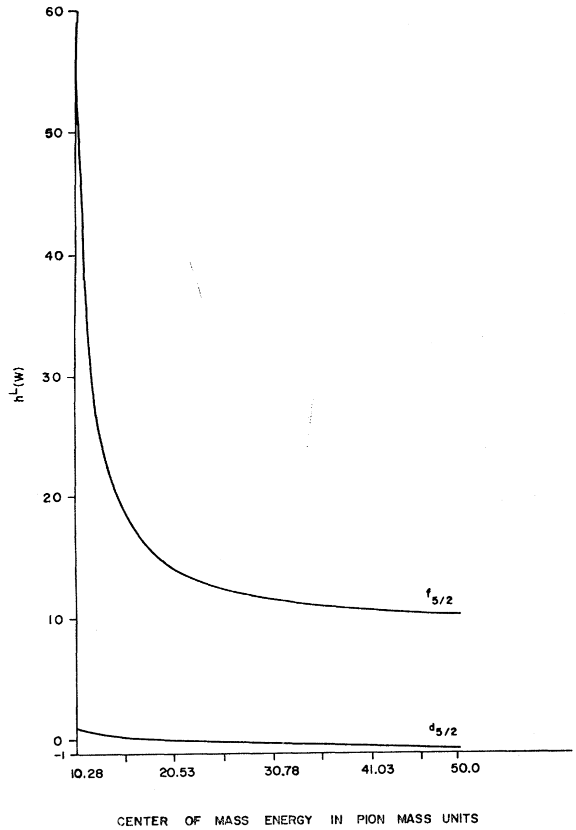

FIG. 3. The total contribution to $h_{5/2}^L$ for the $d_{5/2}$ and $f_{5/2}$ partial waves.

$=0$. The width Γ is given by the formula

$$\Gamma = -\frac{2q^*}{\rho(M^*)} \frac{N(M^*)}{\mathrm{Re}D'(M^*)}, \tag{3.5}$$

where q^* is the center-of-mass momentum at the energy where the resonance occurs.

IV. RESULTS AND DISCUSSIONS

The values of all the masses of the particles were taken from the experimental data. In the $I=0$, $d_{5/2}$ state the ρ and ω exchanges give a repulsion (Figs. 2 and 3) and we do not get a resonance for any value of the cutoff parameter. This shows that Y_{05}^* is not a d-wave resonance. However, in the $I=0$, $f_{5/2}$ state we get a resonance at the correct mass ($12.99m_\pi$) and with slightly higher width ($\Gamma=101.60$ MeV) with the value of the cutoff parameter $=48.5m_\pi$. The experimental values are $12m_\pi$ and 70 MeV, respectively.[7] This suggests that the resonance has even parity. The variation in the value of the width and the position of the resonance as the cutoff parameter is varied has been shown in Table I.

TABLE I. Position and width of the Y_{05}^* resonance for different values of the cutoff parameter.

Cutoff (pion mass)	Mass (M^*) (pion mass)	Width (Γ) (MeV)
45.5	13.68	167.44
47.0	13.30	138.90
48.5	12.99	101.60
50.0	12.65	73.83

V. CONCLUSION

In conclusion it may be pointed out that the very simple model proposed here is adequate for understanding the Y_{05}^* resonance. Although the model is an approximate one in the sense that the other inelastic channels may be important, and that no strong justification exists for neglecting the exchanges like φ and f^0, except that this would introduce unknown coupling constants (unknown to the extent that even their signs cannot be fixed by any existing theory), the present approach is in keeping with the spirit of attempting to understand the phenomena in simplest possible terms as a first step.

A necessary conclusion of this model is that the parity of Y_{05}^* is even. No adjustable parameters were used except the cutoff and we did not get a resonance in the $I=0$, $d_{5/2}$ state for any value of the cutoff parameter. This is not a surprising result if we note that the exchanges considered here give a repulsion in the $I=0$, $d_{5/2}$ state and there just cannot occur a resonance with odd parity. Hence the model suggests that the Y_{05}^* is an f-wave resonance.

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