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(Received March 15, 1972)

We use a phenomenological model to make comparisons with the experimental data for the process $\gamma p \rightarrow \eta p$ and calculate the radiative width for the S_{11} (1550) resonant state. We obtain $\Gamma_\gamma(S_{11} \rightarrow \gamma p) = 0.42 \pm 0.14$ MeV. In addition, we are able to give ranges for the radiative widths of the S_{11} (1700) and P_{11} (1750) states.

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It has been known for some time that the S_{11} (1550) resonance makes one of the major contributions to the amplitude for the process $\gamma p \rightarrow \eta p$ near threshold. Following recent measurements of the differential cross section [1,2] and a measurement of the polarization of the final proton [3] it is now clear that some improvement of early (before 1969) phenomenological models for this process is necessary. We have developed a model that includes direct-channel resonances with a phase rotation with respect to the background and nonresonant terms for S and P waves, which can be used to determine the important resonant state contributions to the reaction $\gamma p \rightarrow \eta p$. In addition, we are able to obtain a value for the radiative width of the S_{11} (1550) which seems to reflect to a great extent the data rather than the phenomenological model.

For the resonant part of an electric $E_\ell \pm$ or magnetic $M_\ell \pm$ multipole amplitude we assume

$$E_\ell \pm (\mathrm{res}) = \frac{-ie^{i\phi}(\Gamma^E_{\gamma p}\,\Gamma_{\eta p})^{1/2}}{2[qkj_\gamma\,(j_\gamma+1)]^{1/2}\,(W_r - W - i\frac{\Gamma}{2})} \quad , \tag{1}$$

and a similar expression for $M_\ell \pm$(res), where ℓ is the orbital angular momentum in the final state and the total angular momentum is given by $J = \ell \pm 1/2$. Here k and q are the c.m. momenta of the γ and η respectively, W is the total c.m. energy. W_r is the mass of the resonant state, ϕ is the rotation angle and $j_\gamma = \ell \pm 1$ for $E_\ell\pm$ and $j_\gamma = \ell$ for $M_\ell\pm$. The product of the partial widths is given by

$$(\Gamma^E_{\gamma p}\Gamma_{\eta p})^{1/2} = [2kRv_L\,(kR)]^{1/2}\,[2qRv_\ell(qR)]^{1/2}\gamma^E \tag{2}$$

and similarly for $E \to M$, where R is an interaction radius chosen to be 1 Fermi $\simeq \frac{1}{200}$ MeV^{-1}, the v's are barrier factors [4], γ^E (or γ^M) is a constant which depends upon the strength of the interaction, $L = \ell$ except for $E_{\ell-}$ when $L = \ell$-2. The energy dependent total width is given by the sum of the partial widths for a given resonant state.

For the S_{11} state we write

$$\Gamma = \Gamma_{\eta N} + \Gamma_{\pi N} + \Gamma_{other} \tag{3}$$

or

$$\Gamma = \frac{aq_{\eta N}}{q^r_{\eta N}}\Gamma_r + \frac{bq_{\pi N}}{q^r_{\pi N}}\Gamma_r + c\Gamma_r \tag{4}$$

where the index r means evaluated at the resonant energy, and the branching ratios a,b, and c sum to unity. In the current work we have used the approximations a = 0.6, b = 0.4, c = 0, and Γ_r = 130 MeV. We approximate the energy dependence of the widths of all other resonant states by the relation

$$\Gamma = \frac{q_{\pi N}\,v_\ell\,(Rq_{\pi N})}{q^r_{\pi N}\,v_\ell\,(Rq^r_{\pi N})}\Gamma_r \tag{5}$$

so Γ reduces to the total width Γ_r at the resonant energy.

For the nonresonant background in S and P waves we use the method of Orito [5] and Schorsch *et al.* [6], retaining only the first term in the series.

The radiative width Γ_γ is given by [7]

$$\Gamma_\gamma = \frac{k^2}{4\pi}\frac{M_N}{W_r}\frac{8}{2J+1}\left\{|A_{1/2}|^2 + |A_{3/2}|^2\right\} \tag{6}$$

where M_N is the mass of the nucleon and $A_{1/2}$ and $A_{3/2}$ are the helicity amplitudes for the excitation of the nucleon into resonant states of helicity ½ and 3/2 respectively. In terms of the partial widths $\Gamma^E_{\gamma p}$ and $\Gamma^M_{\gamma p}$ Eq. (6) reduces to

$$\Gamma_\gamma = \Gamma^E_{\gamma p} + \Gamma^M_{\gamma p} , \tag{7}$$

For the S_{11} state the radiative width is simpler since $A_{3/2}$ and $\Gamma^M_{\gamma p}$ vanish.

We use the available data below 2 GeV c.m. energy [1-3, 8-14] for the process $\gamma p \rightarrow \eta p$ to obtain optimum values for the resonance parameters γ^E, γ^M, and the phase parameter ϕ for each resonance, and the background parameters in the S and P waves. The minimization method is the usual one, the parameters are allowed to vary until a minimum is found for χ^2/N, where N = number of data points minus number of variable parameters. Altogether we have done well over a thousand minimizations (using two independently written computer programs) with random initial values for the variable parameters.

Various combinations of isospin-½ nucleon resonant states have been included, and while we agree with previous studies [15,16] in regard to the most important resonance contributions [S_{11} (1550) and P_{11} (1750)], we are unable to obtain an acceptable fit to the data without including additional states. In particular, the S_{11} (1700) appears to be needed although it is difficult to separate it from the background, and contributions from additonal P_{11}, P_{13}, D_{13}, and F_{15} states are very helpful. Without these additional states, $\chi^2/N > 3.5$ and we obtain $\chi^2/N <$ 1.8 with them included. A detailed quantitative discussion along with a graphical description of these results will be presented in a more lengthy future publication.

In all of the combinations there is one number which seems to be consistently stable within rather narrow limits. That is the value of the radiative width for the S_{11} (1550), which we find to be

$$\Gamma_\gamma = 0.42 \pm 0.14 \text{ MeV}, \tag{8}$$

or in terms of $A_{1/2}$ we have

$$A_{1/2} = 0.095 \pm 0.016 \text{ GeV}^{-1/2} . \tag{9}$$

The errors are not only statistical, but also represent the fluctuation due to various combinations of resonant states.

Our value of Γ_γ agrees with the value predicted by Minami [17] with much less data. It is also in agreement with Walker's result [18,19] which was obtained by studying a different process–single pion photoproduction. Therefore, it appears that the situation is rather clear in regard to the radiative width of the S_{11} (1550).

Our results are consistent with a mixing of S_{11} (1550) and S_{11} (1700) states in a harmonic oscillator model [20-23] with a mixing angle around 35°; however, we are not able to fix the radiative width of the S_{11} (1700) with great precision. We find the following range,

$$0.2 \text{ MeV} < \Gamma_\gamma [S_{11}(1700)] < 1.5 \text{ MeV}, \tag{10}$$

which includes the value $\Gamma_\gamma = 0.26$ MeV predicted by the relativistic harmonic oscillator model of Lipes [23,24], with a mixing angle of 35° assumed.

In addition, we are able to give a range for the radiative width of the P_{11} (1750) state,

$$0.1 \text{ MeV} < \Gamma_\gamma [P_{11}(1750)] < 0.4 \text{ MeV}, \tag{11}$$

with a value somewhere near the middle of the range favored. In obtaining (10) and (11) we have assumed the partial widths [25] $\Gamma_{\eta N}$ [S_{11} (1700)] = 10 MeV and $\Gamma_{\eta N}$ [P_{11} (1750)] = 60 MeV. Work is currently in progress to narrow the ranges given by equations (10) and (11).

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