Electric quadrupole photoexcitation of Δ_{33} and experimental confirmation of the tensor interaction of quarks

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An energy-independent multipole analysis based on experimental data exclusively on the photoproduction of pions at protons demonstrates a resonant electric quadrupole transition $\gamma_p \rightarrow \Delta_{33}^{+}$. This result confirms that the nucleon and the isobar have a *d*-wave admixture due to a tensor interaction between quarks.

Whether the resonant electric quadrupole transition $\gamma N \rightarrow \Delta_{33}$ occurs has remained unresolved for many years (see Ref. 1, for example). The question has resurfaced in connection with the interest in the problem of the tensor interaction of quarks. Quark models were used in Refs. 2–4 to calculate the effects of tensor forces and the effects stemming from a *d*-wave admixture in the nucleon and the Δ_{33} isobar. In particular, measurements of the resonant electric quadrupole amplitude for the photoproduction of pions at nucleons at energies near the Δ_{33} resonance, $E_{1+}^{(3/2)R}$, can provide an experimental test of the existence of a *d*-state admixture and thereby cast light on the problem of the tensor interaction of quarks. According to the theoretical models, the ratio of the resonant parts of the electric quadrupole and magnetic dipole amplitudes, $\xi = E_{1+}^{(3/2)R}/M_{1+}^{(3/2)R}$, is extremely small, $-(0.3-0.5)\%$ (Refs. 2 and 3) or -0.92% (Ref. 4).

We have recently carried out an energy-independent multipole analysis[5] of a set of experimental data which essentially constitute a comprehensive experiment on the processes $\gamma p \rightarrow \pi^{+} n$, $n^{0} p$ over the energy range 300–420 MeV. We derived the first estimates of the complex *s*- and *p*-wave amplitudes for photoproduction at the proton. In contrast with earlier analyses, we did not appeal to the πN scattering phase shifts;

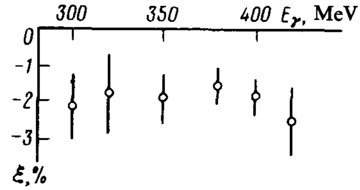

FIG. 1.

i.e., these new estimates of the amplitudes are based exclusively on experimental data on photoproduction.

The resonant parts of the amplitudes $E_{1+}^{(3/2)}$ and $M_{1+}^{(3/2)}$, in which we are interested, can be distinguished by the parametrization of the total amplitude from Ref. 6:

$$E_{1+}^{(3/2)},\ M_{1+}^{(3/2)} = (B^{E,M}\cos\phi_{33} + R^{E,M}\sin\ \phi_R)e^{i\phi_{33}}, \tag{1}$$

where ϕ_{33} and ϕ_R are respectively the observable and resonant phase shifts, $B^{E,M}$ are the background (Born) parts of the photoproduction amplitudes, and $R^{E,M}$ are the resonant parts of the corresponding photoproduction amplitudes (R^2 is the relative width of the radiative decay of the Δ_{33} isobar). In scattering theory, expression (1) is known as the "unitarized" form of a total amplitude which contains a resonance and a background. In this case the ratio ξ is equal to the ratio R^E/R^M, which can be found with the help of (1):

$$\xi = R^E/R^M = \left(\frac{|E_{1+}^{(3/2)}|^2}{\mathrm{Re}\,E_{1+}^{(3/2)}} - B^E\right)\Bigg/\left(\frac{|M_{1+}^{(3/2)}|^2}{\mathrm{Re}\,M_{1+}^{(3/2)}} - B^M\right). \tag{2}$$

Figure 1 shows results calculated on ξ from this expression and the data of the analysis of Ref. 5 for each energy. In complete accordance with the theoretical predictions, ξ has no significant energy dependence within the resonance. This result is evidence that this method for distinguishing the resonant parts of the amplitudes is reliable, and it allows us to refine the experimental estimate of ξ by means of the weighted-average value $\langle\xi\rangle = -1.83 \pm 0.22\%$.

In summary, the data of the multipole analysis of Ref. 5 lead to the conclusion that the resonant part of the electric quadrupole amplitude is significantly different from zero and agrees qualitatively with these model-based calculations. This result demonstrates that there is a d-state admixture in the nucleon and in Δ_{33} and thereby demonstrates the existence of a tensor interaction between quarks.

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