Knockout of an isobar from a deuteron

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It is shown that the probability of observing the configuration Δ–Δ(1236) when an isobar is knocked out from a deuteron is larger than the probability that determines the contribution of the Δ component to the magnetic moment of the deuteron. Theoretical predictions are obtained for the momentum and energy distributions of the Δ isobars knocked out from a deuteron.

Isobaric components in a deuteron on the order of several percent lead to noticeable effects in the electromagnetic form factors, *p-d* backward scattering, and other processes, particularly with large transfer of momentum to the deuteron,[1,2] and can be observed when an isobar is knocked out from the deuteron.[3] It was assumed by various workers[2,4] that in the nonrelativistic approximation the properties of the isobar component are determined by its wave function $\psi(\mathbf{p})$, which depends on the relative momentum $\mathbf{p}$ in the deuteron rest system, i.e., on one invariant variable p^2, and the instability of the isobar was neglected.

It is shown in this paper that when account is taken of the instability of the isobar, the isobar component is described by a function of two invariant variables, which we choose to be p^2 and E—the energy of one of the isobars in the rest system of the deuteron.

Let us compare the diagrams for the electromagnetic form factor (Fig. 1a) and the knockout process (Fig. 1b) in the case when the particles x and y are stable and unstable, for example NN and ΔΔ (the baryons are assumed to be nonrelativistic). When calculating the triangle diagrams, the particle y is taken to the mass shell (we neglect the singularities of the vertex functions in the energy of particle y). For a stable particle y, both diagrams are expressed in terms of

$$\Gamma^{0}_{xy}(\mathbf{p}) = \Gamma_{xy}(\mathbf{p}, E)\Big|_{E = m_y + p^2/2m_y}$$

which is a function of one invariant variable p^2, connected with the nonrelativistic wave function via the relation

$$\psi(\mathbf{p}) = (2\pi)^{-3/2}\,\frac{2m_{xy}}{p^2 + 2m_{xy}\epsilon}\,\Gamma(\mathbf{p}), \tag{1}$$

where m_{xy} is the reduced mass and ϵ is the binding energy.

If the particle y is unstable, then the vertex $\Gamma_{xy}(\mathbf{p}, E)$ enters the triangle diagram with a complex value of the energy $E = m_y - i\Gamma/2 + p^2/2m_y$ (Γ is the width), and enters the pole diagram at different real values of E.

We consider the isobar component Δ—Δ(1236). The

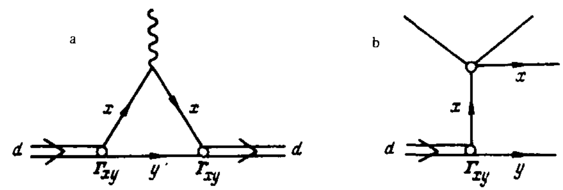

FIG. 1.

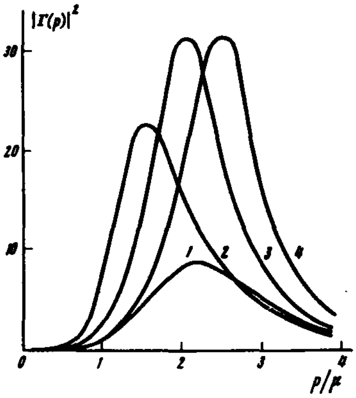

FIG. 2.

c	p_i^{LS}	Δ isobar component				
		$^3S_1$	$^3D_1$	$^7D_1$	$^7G_1$	Total
3μ	p_1^{LS}	0.66	0.08	1.64	0.14	2.52
	p_2^{LS}	1.96	0.23	3.51	0.26	5.96
2μ	p_1^{LS}	0.50	0.05	0.84	0.07	1.46
	p_2^{LS}	1.55	0.17	2.10	0.15	3.97

vertex $\Gamma_{\Delta\Delta}(\mathbf{p},E)$ in the first approximation in the smallness of the Δ component is expressed in terms of the nucleon wave function $\phi(\mathbf{k})$ and the potential $U(\mathbf{k},\mathbf{p},E)$ connecting the channels NN and ΔΔ:

$$\Gamma_{\Delta\Delta}(\mathbf{p},E) = -(2\pi)^{-3/2}\int U(\mathbf{k},\mathbf{p},E)\phi(\mathbf{k})d^3\mathbf{k}. \qquad (2)$$

The potential $U(\mathbf{k},\mathbf{p},E)=U(\mathbf{q},E)$ $(\mathbf{q}=\mathbf{p}-\mathbf{k})$ will be taken in the one-pion exchange model

$$U(\mathbf{q},E) = -\frac{\Gamma_{\Delta N\pi}(\mathbf{q})\Gamma_{\Delta N\pi}(\mathbf{q})}{q^2+\mu^2-(E-m)^2-i\delta}. \qquad (3)$$

Here μ and m are the masses of the pion and nucleon. The vertex $\Gamma_{\Delta N\pi}$ corresponding to the process $\Delta\to N+\pi$ is of the form

$$\Gamma_{\Delta N\pi}(\mathbf{q}) = \frac{g}{\mu}\sqrt{\frac{4\pi}{3}}\, q\, C^{3/2\, t_\Delta}_{1/2\, t_N\, 1\, t_\pi} C^{3/2\, \nu_\Delta}_{1/2\, \nu_N\, 1\, m} \times Y_{1m}\left(\frac{\mathbf{q}}{q}\right)\left(\frac{c^2+q_0^2}{c^2+q^2}\right), \qquad (4)$$

where $g=2$ is the dimensionless coupling constant, t and ν are the isospin and spin indices, q is the momentum of the pion in the Δ rest system, $q_0\approx\sqrt{(E-m)^2-\mu^2}$ is the momentum corresponding to the real decay $\Delta\to N+\pi$, and c is a parameter of the form factor and takes into account the departure of the pion from the mass shell.

From the data on the Δ-isobar production[5] we conclude that c is close to 3μ. Bearing in mind the uncertainty in the value of c, we investigate the sensitivity of the results to its variations.

Figure 2 shows plots of the squares of the moduli of the vertex functions corresponding to the partial wave $^7D_1$ of the Δ component (this wave makes the main contribution). The calculation was performed for a nucleon wave function $\phi(\mathbf{k})$ in a Hamada-Johnson potential at $c=3\mu$. Curves 1, 2, 3, and 4 correspond to energy E values $M-i\Gamma/2$, $M-\Gamma/2$, M, and $M+\Gamma/2$, respectively (M and Γ are the mass and width of the Δ(1236) isobar). A similar picture is obtained also for the remaining waves of the Δ component. The vertex function that determines the amplitude of the isobar knockout (curves 2, 3, 4) is much larger than the vertex function that enters in the electromagnetic form factors (curve 1), and its maximum shifts towards increasing momentum with increasing isobar energy. Therefore the wave function connected with the vertex $d\Delta\Delta$, for which one of the isobars is on the mass shell $(E\approx M-i\Gamma/2)$, is insufficient to describe the isobaric impurity, unlike the case of stable particles.

We set the vertex $\Gamma_{\Delta\Delta}(\mathbf{p},E)$ in correspondence, in accordance with formula (1), with "wave functions" $\psi_E(p)$ that depend on the energy. At $E=M-i\Gamma/2$, the square of the norm of the partial wave

$$p_1^{LS} = \langle\psi_E^{LS}|\psi_E^{LS}\rangle\Big|_{E=M-i\Gamma/2}$$

represents the probability of observing the isobaric impurity in a state with relative orbital and spin momenta L and S when the magnetic moment is measured. The probability p_2^{LS} of observing the isobar following the knockout is given by the formula

$$p_2^{LS} = \int_{\mu+m}^{\infty}\frac{\Gamma/2\pi}{(E-M)^2+\Gamma^2/4}\langle\psi_E^{LS}|\psi_E^{LS}\rangle dE. \qquad (5)$$

The table lists the values of p_1^{LS} and p_2^{LS} calculated for $c=3\mu$ and $c=2\mu$. The energy spectrum of the isobar knocked out from the deuteron differs in form from the Breit-Wigner spectrum:

$$f(E) = \frac{\Gamma/2\pi}{(E-M)^2+\Gamma^2/4}\left(\sum_{LS}\langle\psi_E^{LS}|\psi_E^{LS}\rangle\right)/\left(\sum_{LS}p_2^{LS}\right). \qquad (6)$$

The maximum of the spectrum $f(E)$ is located at $E=M+\delta E$, where $\delta E=15$ MeV for $c=3\mu$.

Although the results do contain a certain quantitative uncertainty, owing to the departure of the isobar from the mass shell, the noted singularities of the Δ component, namely, the strong dependence of the momentum distribution on the isobar energy, the shift of the maximum of the energy spectrum of the knocked-out isobars, the different probability of the appearance of isobar as a function of the reaction mechanism, are all the consequence of one-pion exchange, which couples the NN and ΔΔ channels. An investigation of the knockout of an isobar from the deuteron, from this point of view, would be quite useful as a check on the dominance of the OPE mechanism of Δ-component production.

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