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Abstract

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ON THE ROLE OF BOUND STATES IN PHOTOPRODUCTION PROCESSES*

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The purpose of the present note is to consider the role of bound states in the dispersion relations of photoproduction processes. The study of this question is essential, since it is connected with the analysis of the unobservable energy region in the dispersion relations. The photoproduction threshold in the coordinate system $(\mathbf{p}+\mathbf{p}')_\perp = 0$ is equal to $\left(1+\frac{\mu^2}{4\mathbf{p}^2}\right)|\mathbf{p}|$**. Let us consider the energy region E in which $E < |\mathbf{p}| + \frac{\mu^2}{4|\mathbf{p}|}$ and where, consequently, the formation of "bound" states is possible.

The anti-Hermitian part of the amplitude of the photoproduction reaction may be represented in the form

$$\begin{aligned} A_{\xi,\omega}(E,\lambda\mathbf{e}) = \pi \sum_n &\langle \dot\Psi^*_{-\mathbf{p},s} J_\rho(0) \dot\Psi_{n,\lambda\mathbf{e}-\varepsilon\mathbf{p}}\rangle \langle \dot\Psi^*_{n,\lambda\mathbf{e}-\varepsilon\mathbf{p}} I_m(0) \dot\Psi_{p,s}\rangle \times \\ &\times \delta\Big(E - \sqrt{M_n^2+\lambda^2+\varepsilon^2\mathbf{p}^2} + \sqrt{M^2+\mathbf{p}^2}\Big) - \\ &- \pi \sum_n \langle \dot\Psi^*_{-\mathbf{p},s} I_m(0) \dot\Psi_{n,-\lambda\mathbf{e}+\varepsilon\mathbf{p}}\rangle \langle \dot\Psi^*_{n,-\lambda\mathbf{e}+\varepsilon\mathbf{p}} J_\rho(0) \dot\Psi_{p,s}\rangle \times \\ &\times \delta\Big(E + \sqrt{M_n^2+\lambda^2+\varepsilon^2\mathbf{p}^2} - \sqrt{M^2+\mathbf{p}^2}\Big). \end{aligned} \quad (1)$$

Let us assume that between M and $M+\mu$ there are no bound states of the meson–nucleon system. In other words, $M_n \geqslant M+\mu$ for $n \geqslant 1$ ($n=0$ corresponds to the one-nucleon state of the system). Let us consider the region of recoil momenta $\mathbf{p}^2 < M\mu/2$. Then it is easy to show that the region of integration in the dispersion relations (10) of work (1) splits into two parts:

$$0 < E' < \frac{M\mu + \frac{1}{4}\mu^2 - \mathbf{p}^2}{\sqrt{M^2+\mathbf{p}^2}} < E' < \infty. \quad (2)$$

In the first region, only one-nucleon states give a contribution different from zero to the integral. States with $n \geqslant 1$ contribute only to the integral over the second region. Strictly speaking, the second region also contains part of the unobservable energy region. However, the contribution from it can be made sufficiently small if we fix the recoil momentum in a suitable way.

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** We adhere to the notation and terminology adopted in (1).

The expression for $A_{\xi,\omega}$ in the first energy region can be written in the form:

$$A_{\xi,\omega}(E,\lambda e) =$$

$$= -\pi \frac{M^2 - \frac{1}{4}\mu^2}{M^2 + \mathbf{p}^2} \sum_{s''} \left\langle \Psi_{-\mathbf{p},s'} I_m(0) \Psi_{-\lambda e+\varepsilon \mathbf{p},s''} \right\rangle \left\langle \Psi_{-\lambda e+\varepsilon \mathbf{p},s''} J_{\rho'}(0) \Psi_{p,s} \right\rangle$$

$$\delta\left(E - \frac{\mathbf{p}^2 + \frac{1}{4}\mu^2}{\sqrt{M^2 + \mathbf{p}^2}}\right). \qquad (3)$$

Let us consider the matrix elements of the currents that occur here. As an example, we shall calculate the matrix element of the meson current $I_{\rho'}(0)$. The matrix element of the electromagnetic current is calculated analogously.

We have:

$$\left\langle \Psi^*_{p',s'} I_{\rho'}(x) \Psi_{p,s} \right\rangle = e^{i(p'-p)x} \left\langle \Psi^*_{p',s'} I_{\rho'}(0) \Psi_{p,s} \right\rangle;$$

on the other hand:

$$\left\langle \Psi^*_{p',s'} I_{\rho'}(x) \Psi_{p,s} \right\rangle = i \left\langle \Phi^*_{p',s'} \frac{\delta S}{\delta \varphi_{\rho'}(x)} \Phi_{p,s} \right\rangle.$$

Introducing the Fourier transform

$$\varphi_{\rho'}(x) = \frac{1}{(2\pi)^4} \int e^{iqx} \varphi_{\rho'}(q)\, dq,$$

we obtain

$$\delta(p' - p + q) \left\langle \Psi^*_{p',s'} I_{\rho'}(0) \Psi_{p,s} \right\rangle = i \left\langle \Phi^*_{p',s'} \frac{\delta S}{\delta \varphi_{\rho'}(q)} \Phi_{p,s} \right\rangle.$$

The last expression can symbolically be represented in the form of the following sum of graphs:

symbolic sum of graphs: a vertex Γ_5 with external lines ρ', ρ, and q, plus a second graph with an internal loop attached to an external q line

Figure 1: symbolic sum of graphs: a vertex Γ_5 with external lines ρ', ρ, and q, plus a second graph with an internal loop attached to an external q line

Here Γ_5 is the strongly bound part. If, instead of the symbol Λ, there were free meson lines here, the sum under consideration would be equal to

$$e_5^{\rho'}(p, p', q)\Delta_c^{\rho'}(q).$$

Since in our case there is no free meson line, the expression obtained must additionally be multiplied by $(\mu^2 - q^2)$.

Using the normalization condition for the Green functions at ${p'}^2 = M^2$, $p^2 = M^2$, $q^2 = \mu^2$, and also the energy-momentum conservation law, we find the final expression:

$$\left\langle \Psi^*_{p's'} J_{\rho'}(0) \Psi_{p,s} \right\rangle = g \left\langle \bar{u}_{s'}(p') \gamma^5 \tau^{\rho'} u_s(p) \right\rangle . \tag{4}$$

As is easy to see, g is the renormalized pseudoscalar coupling constant of the meson and nucleon fields.

In the case of the electromagnetic current

$$\left\langle \Psi^*_{p',s'} I_m(0) \Psi_{p,s} \right\rangle =$$

$$= \left\langle u_{s'}(p') \left\{ e \frac{1+\tau_3}{2} \gamma^m + \frac{1}{2} \widehat{\mathfrak{M}} [(k\gamma), \gamma^m] \right\} u_s(p) \right\rangle , \tag{5}$$

where $\widehat{\mathfrak{M}} = \mu_p \dfrac{1+\tau_3}{2} + \mu_n \dfrac{1-\tau_3}{2}$; e is the renormalized electron charge; μ_p and μ_n are the anomalous magnetic moments of the proton and neutron.

With the aid of the obtained formulas (4) and (5), it is not difficult to write, in final form, the dispersion relations for photoproduction, in which the "bound" states are taken into account and the unobservable energy region is separated out. A complete analysis of the dispersion relations in the fixed-source approximation gives results equivalent to those obtained by Low and Chew [(2)].

In conclusion, we express our deep gratitude to Academician N. N. Bogolyubov, under whose direction this work was carried out.

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Note: Figure translations are in progress. See original paper for figures.