ELECTROMAGNETIC DECAY AND ELECTROPRODUCTION OF A $3/2^+$-RESONANCE

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Abstract

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ELECTROMAGNETIC DECAY AND ELECTROPRODUCTION OF A $3/2^+$-RESONANCE

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The success of the theory of unitary symmetry of elementary particles increases interest in the study of electromagnetic decay and electroproduction of baryon resonances. This is due to the fact that, by studying these processes, one can, with the aid of one or another symmetry scheme, judge the structure of the electromagnetic form factors of baryons.

The aim of the present work is to give a general expression for the probability of electromagnetic decay and for the cross section of electroproduction of a resonance and, in particular, to compare the experimental data for these processes with the theoretical predictions following from the $U(12)$ symmetry scheme ([1]).

Let us write the general expression for the vector current for the transition $1/2^+ \to 3/2^+$:

$$V_\mu = \bar{\psi}_\nu(q)\left\{\frac{a_1}{m}(k_\nu\gamma_\mu - \delta_{\mu\nu}\hat{k}) + \frac{a_2}{m^2}k_\nu k_\lambda\sigma_{\mu\nu} + \frac{a_3}{m^2}(k_\nu k_\mu - \delta_{\mu\nu}k^2)\right\}\gamma_5\psi(p), \tag{1}$$

where a_1, a_2, a_3 are certain form factors depending on k^2; m is a quantity of the dimension of mass; p, q are the 4-momenta of the initial and final baryons, respectively; $k = q - p$.

In the $U(12)$ symmetry scheme the matrix element of the vector current for the transition between the states of $1/2^+$ and $3/2^+$ baryons belonging to the 364-plet has the form

$$V_\mu = \bar{D}^{abc}\varepsilon_{ade}Q^d_b N^e_c \mu_p \frac{f(k^2)}{m_0^2}\varepsilon_{\mu\nu\sigma\rho}\bar{\psi}_\nu\psi_p\gamma_\sigma k_\rho, \tag{2}$$

where D_{abc} and N^a_b are the unitary wave functions of the baryon decuplet and octet; Q is the charge operator; μ_p is the magnetic moment of the proton; $f(k^2)$ is the magnetic (Sachs) form factor of the proton; m_0 is the mass of the multiplet in the case of exact symmetry (see ([2],[3])).

Let us first consider the electromagnetic decay

$$\mathrm{B}^* \to \mathrm{B} + \gamma,$$

whose matrix element has the form

$$M = \frac{1}{\sqrt{2\omega}}\,\bar{\psi}\left\{a_1\left(e_\mu\gamma_5 - \frac{ik_\mu e_\nu\gamma_5}{m_B + m_{B^*}}\right) + \frac{a_2}{m^2}\varepsilon_{\nu\mu\sigma\rho}e_\nu p_\sigma k_\rho\right\}\psi_\mu, \tag{3}$$

whence for the decay probability we obtain

$$W = \frac{e^2 m_{B^*}}{24\pi}\left(1 - \frac{m_B^2}{m_{B^*}^2}\right)\left\{|a_1|^2\left[\left(1 - \frac{m_B}{m_{B^*}}\right)^2 - \frac{1}{4}\left(1 - \frac{m_B}{m_{B^*}}\right)^3\left(1 + \frac{m_B}{m_{B^*}}\right)\right]\right.$$

$$\left. + \frac{|a_2|^2}{4}\left(\frac{m_{B^*}}{m}\right)^4\left(1 - \frac{m_B^2}{m_{B^*}^2}\right)^2\left(1 + \frac{m_B}{m_{B^*}}\right)^2 - \frac{\mathrm{Re}\,a_1 a_2^*}{4}\left(\frac{m_{B^*}}{m}\right)^2\left(1 - \frac{m_B^2}{m_{B^*}^2}\right)^2\left(3 + \frac{m_B}{m_{B^*}}\right)\right\}. \tag{4}$$

In the case of $U(12)$, instead of (4) we obtain

$$W = \frac{e^2}{96\pi}\,m_{B^*}|g|^2\left(\frac{m_{B^*}}{m_0}\right)^4\left(1 - \frac{m_B^2}{m_{B^*}^2}\right)^3\left(1 + \frac{m_B}{m_{B^*}}\right)^2, \tag{4'}$$

where $g = 1/\sqrt{3}\,\mu_p$ for the decay $N^{*+} \to p + \gamma$. For the remaining decays we have the relation

$$g_{N^{*0},\,n\gamma} = -\frac{2}{\sqrt{3}}g_{Y^{*0},\,\Lambda\gamma} = -g_{Y^{*+},\,\Sigma^+\gamma}$$

$$= 2g_{Y^{*0},\,\Sigma^0\gamma} = -g_{\Xi^{*0},\,\Xi^0\gamma} = g_{N^{*+},\,p\gamma} = -\frac{1}{\sqrt{3}}\mu_p.$$

Using expression (4′) with m_0 equal to the mean mass of the multiplet, we obtain the following estimate for the decay probabilities:

$$\Gamma(N^{*+} \to p + \gamma) = 0.177 \text{ MeV},$$
$$\Gamma(Y^{*0} \to \Lambda + \gamma) = 0.144 \text{ MeV},$$
$$\Gamma(Y^{*+} \to \Sigma^+ + \gamma) = 0.083 \text{ MeV},$$
$$\Gamma(\Xi^{*0} \to \Xi^0 + \gamma) = 0.179 \text{ MeV}.$$

Fig. 1

Figure 1: Fig. 1

Let us now turn to the consideration of electroproduction of a $3/2^+$-baryon on a $1/2^+$-baryon:

$$e^- + B \to B^* + e^-.$$

The diagram of this process is shown in Fig. 1. It corresponds to a matrix element of the form

Fig. 1

$$M = \frac{1}{k^2} V_\mu \bar{u}(k_2) \gamma_\mu u(k_1), \tag{5}$$

where V_μ is given by expression (1).

Hence, for the differential cross section we obtain the expression

$$
\begin{aligned}
d\sigma = {} & \frac{2}{3}\left(\frac{e^2}{4\pi}\right)^2 \frac{1}{v_1 k^4 \varepsilon_1 \varepsilon_2 E_B E_{B^*}}\,\delta(E_B + \varepsilon_1 - E_{B^*} - \varepsilon_2)\,d\mathbf{k}_2 \\
& \times \left\{ \left|\frac{a_1}{m} - \frac{ia_2}{m^2}(m_{B^*} - m_B)\right|^2 2\left(k^2 + \frac{(kq)^2}{m_{B^*}^2}\right) \right. \\
& \times \left(\frac{1}{2} m_B m_{B^*} k^2 + k_1 p \cdot k_2 q + k_1 q \cdot k_2 p\right) \\
& + \left|\frac{a_2}{m^2}\right|^2 \left(k^2 + \frac{(kq)^2}{m_{B^*}^2}\right)(m_B m_{B^*} + pq) \\
& \times \left[-\frac{k^2}{2}(p+q)^2 - 2(pk_1 + qk_1)(pk_2 + qk_2)\right] \\
& + \left|\frac{ia_1}{m}(m_B + m_{B^*}) + \frac{a_3}{m^2}k^2\right|^2 (m_B m_{B^*} + pq)\left(-\frac{k^2}{2} - \frac{2qk_1 \cdot qk_2}{m_{B^*}^2}\right) \\
& + 2\,\mathrm{Im}\left(\frac{a_1}{m} - \frac{ia_2}{m^2}(m_{B^*} - m_B)\right)\frac{a_2^*}{m^2}\left(k^2 + \frac{(kq)^2}{m_{B^*}^2}\right) \\
& \times \Big[(m_{B^*} - m_B)(m_B m_{B^*} + pq)\frac{k^2}{2} + (m_{B^*} - m_B)(qk_1 \cdot pk_2 + qk_2 \cdot pk_1) \\
& \qquad + 2m_{B^*} pk_1 \cdot pk_2 - 2m_B qk_1 \cdot qk_2\Big] \\
& + 2\,\mathrm{Im}\left(\frac{a_1}{m} - \frac{ia_2}{m^2}(m_{B^*} - m_B)\right)\left(\frac{ia_1^*}{m}(m_B + m_{B^*}) - \frac{a_3^*}{m^2}k^2\right) \\
& \times \Big[\frac{m_{B^*}}{4}k^2(pk - k^2) + \frac{1}{m_{B^*}}\Big(\frac{3}{4}pq \cdot kq \cdot k^2 + \frac{1}{2}kq \cdot qk_2 \cdot pk_1 \\
& \qquad + \frac{1}{2}kq \cdot qk_1 \cdot pk_2 + kp \cdot qk_1 \cdot qk_2\Big) + \frac{m_B}{2}k^2 \cdot qk - \frac{2m_B}{m_{B^*}}kq \cdot qk_1 \cdot qk_2\Big] \\
& + 2\,\mathrm{Re}\,\frac{a_2}{m^2}\left(\frac{ia_1^*}{m}(m_B + m_{B^*}) - \frac{a_3^*}{m^2}k^2\right) \\
& \left. \times (m_B m_{B^*} + pq)\,qk\left[\frac{k^2}{2}\left(1 - \frac{pq}{m_{B^*}^2}\right) - \frac{1}{m_{B^*}^2}(2qk_1 \cdot qk_2 + qk_1 \cdot pk_2 + qk_2 \cdot pk_1)\right]\right\}.
\end{aligned} \tag{6}
$$

In the case of the $\tilde{U}$ symmetry (12), formula (6) reduces to the simpler expression

$$
\frac{d\sigma}{d\varepsilon_2\,d\Omega} = \frac{1}{3}\left(\frac{e^2}{4\pi}\right)^2 |gf(k^2)|^2 \frac{m_B}{E_{B^*}}\frac{\varepsilon_2}{\varepsilon_1}\left[1 + \frac{(m_B + m_{B^*})^2}{k^2}\right] \times \frac{\varepsilon_1^2 + \varepsilon_2^2 + k^2/2}{m_0^4}\,\frac{\delta(\varepsilon_2 - \varepsilon_2^0)}{1 + (\varepsilon_2^0 - \varepsilon_1\cos\theta)/E_{B^*}}, \tag{7}
$$

where ε_1, E_B and ε_2^0, E_{B^*} are the energies of the electron and baryon, respectively, in the initial and final states.

Since $f(k^2)$ has been measured* in a fairly wide range of transferred momenta, one can compare expression (7) with the available experiments on electroproduction of π-mesons. It is clear that expression (7) must be compared with experiment in the region of resonant produc-

Table 1

$\theta = 90°$, i	$\theta = 90°$, ε_1, MeV	$\theta = 90°$, ε_2^i, MeV	$\theta = 90°$, $E^i_{B^*}$, MeV	$\theta = 90°$, k_i^2, MeV$^2 \cdot 10^4$	$\theta = 90°$, $\sigma_i \cdot 10^{-35}$, cm^2/sr	$\theta = 135°$, i	$\theta = 135°$, ε_1, MeV	$\theta = 135°$, ε_2^i, MeV	$\theta = 135°$, $E^i_{B^*}$, MeV	$\theta = 135°$, k_i^2, MeV$^2 \cdot 10^4$	$\theta = 135°$, $\sigma_i \cdot 10^{-35}$, cm^2/sr
1	523	169	1170	17.7	9.79± 1.00	1	563	130	1202	25.0	5.79± 0.32
2	523	146	1198	15.3	17.4± 1.3	2	563	103	1244	19.8	7.08± 0.81
3	523	122	1227	12.8	19.1± 1.7	3	607	146	1202	30.3	4.50± 0.26
4	523	96	1258	10.0	18.5± 2.1	4	607	122	1240	25.3	5.23± 0.42
5	550	159	1200	17.5	13.2± 0.8	5	645	159	1201	35.0	3.76± 0.27
6	550	154	1206	16.9	13.1± 0.8	6	645	139	1235	30.6	4.16± 0.48
7	550	144	1219	15.8	12.3± 0.8	7	645	114	1275	25.1	3.03± 0.59
8	550	137	1227	15.1	12.6± 0.9	8	684	171	1202	39.9	2.48± 0.22
9	550	113	1256	12.4	9.71± 1.05	9	684	128	1275	29.9	2.92± 0.49
10	576	174	1198	20.0	12.0± 0.7						
11	576	131	1251	15.1	13.2± 1.2						

Table 2

$\theta = 90°$, i,k	$\theta = 90°$, $\left(\frac{\sigma_i}{\sigma_k}\right)_{\text{theor}}$	$\theta = 90°$, $\left(\frac{\sigma_i}{\sigma_k}\right)^{\text{min}}_{\text{exp}}$	$\theta = 90°$, $\left(\frac{\sigma_i}{\sigma_k}\right)^{\text{max}}_{\text{exp}}$	$\theta = 135°$, i,k	$\theta = 135°$, $\left(\frac{\sigma_i}{\sigma_k}\right)_{\text{theor}}$	$\theta = 135°$, $\left(\frac{\sigma_i}{\sigma_k}\right)^{\text{min}}_{\text{exp}}$	$\theta = 135°$, $\left(\frac{\sigma_i}{\sigma_k}\right)^{\text{max}}_{\text{exp}}$
1,2	0.86	0.47	0.67	1,2	0.83	0.70	0.98
2,3	0.95	0.72	1.08	2,3	1.57	1.32	1.86
3,4	0.88	0.85	1.27	3,4	0.83	0.75	0.99
5,6	0.99	0.89	1.14	3,5	1.40	1.05	1.36

$\theta =$ 90°, i, k	$\theta =$ 90°, $\left(\frac{\sigma_i}{\sigma_k}\right)_{\text{theor}}$	$\theta =$ 90°, $\left(\frac{\sigma_i}{\sigma_k}\right)^{\text{min}}_{\text{exp}}$	$\theta =$ 90°, $\left(\frac{\sigma_i}{\sigma_k}\right)^{\text{max}}_{\text{exp}}$	$\theta =$ 135°, i, k	$\theta =$ 135°, $\left(\frac{\sigma_i}{\sigma_k}\right)_{\text{theor}}$	$\theta =$ 135°, $\left(\frac{\sigma_i}{\sigma_k}\right)^{\text{min}}_{\text{exp}}$	$\theta =$ 135°, $\left(\frac{\sigma_i}{\sigma_k}\right)^{\text{max}}_{\text{exp}}$
6,7	0.92	0.94	1.21	5,6	1.03	0.75	1.10
7,8	0.93	0.86	1.14	6,7	1.13	1.02	1.90
8,9	0.91	1.09	1.58	8,9	1.04	0.66	1.11
10,11	0.79	0.79	1.06	7,8	1.47	1.36	2.05

tion of the π-meson. For convenience, Table 1 gives experimental data taken from Ref. ([5]) on electroproduction of π-mesons. Table 2 gives the values of the ratios of cross sections at different energies, as well as

* The values of $f(k^2)$ are given in Ref. ([4]).

corresponding theoretical values. From this table it is seen that the theoretical values for the ratios of cross sections, obtained on the basis of the symmetry $\widetilde{U}(12)$ using the experimental data on the proton form factor, do not contradict experiment. It should be noted, however, that formula (7) gives the correct absolute values only for the value $m_0 \approx 1900(1 \pm 0.2)$ MeV.

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Note added in proof. It should be noted that the electroproduction of an isobar in the SU_6 scheme was considered in the recently published work of Geshkenbein (6).

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