Possibility of existence of exotic baryon resonances with isospins $I \geq 5/2$

A. A. Grigoryan and A. B. Kaĭdalov

Institute of Theoretical and Experimental Physics

(Submitted 14 July 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **28**, No. 5., 318–322 (5 September 1978)

It is shown that the superconverging sum rules for the amplitudes of reggeon-baryon scattering lead to the possible existence of baryon resonances with isospins $I \geq 5/2$.

PACS numbers: 14.20. – c, 11.50.Li, 11.60. + c

We wish to call attention in this article to the possible existence of exotic baryon resonances with isospins $I \geqslant 5/2$ and discuss the characteristics of the formation and decay of such resonances. The conclusion that exotic baryons exist follows from an analysis of the superconvergent dispersion sum rules (SSR) for the amplitudes of reggeon scattering by particles.

Dispersion sum rules play an important role in the theory of elementary particles. Particular interest attaches to the SSR, which hold when the scattering amplitudes decrease sufficiently rapidly with increasing energy $T(s,t) < 1/s$ as $s \to \infty$. Saturation of the SSR with contribution of low-lying resonances makes it possible to establish the connections between the vertices of various transitions. Unfortunately, the number of superconvergent amplitudes for the scattering amplitudes of the known elementary particles (π,K,N,γ) is quite limited. More opportunities for finding SSR arise in investigations of the amplitudes of scattering of reggeons by particles $\alpha_i a \to \alpha_k b$.[1-5] These amplitudes have the usual analytic properties with respect to the variable s, and as $s \to \infty$ they become proportional to $s^{\alpha_l - \alpha_i - \alpha_k}$ (where α_l is the extreme right sigularity in j-plane with given quantum numbers in the t channel).

It was shown by us earlier[4] that in addition to the SSR that hold when $\alpha_l - \alpha_i - \alpha_k < -1$, additional SSR arise in the scattering of reggeons by particles with nonzero spins, and are valid under weaker restrictions $\alpha_l - \alpha_i - \alpha_k - n < -1$ (where $n = 1,2...$).

The SSR for scattering of reggeons with $I = 1(\rho,A_2,\pi,B,A_1)$ by the nucleon $N(938)$ and by the isobar $\Delta_{33}(1232)$ were analyzed in Ref. 5. The reactions $\alpha_i N \to \alpha_k N$ and $\alpha_i N \to \alpha_k \Delta$ were considered, and the intermediate states were taken to be N and Δ. The system of equations obtained for the helicity vertices $G^{a\alpha_i b}_{\lambda_a \lambda_b}(a,b = N,\Delta)$ turned out to be fully self-consistent[1)] with a unique solution

$$G^{a\alpha_i b}_{\lambda_a \lambda_b} = 0 \qquad \text{at} \quad \lambda_b = \lambda_a (\, i = \rho,\, A_2,\, \pi,\, B), \tag{1}$$

 0021-3640/78/170293-04$00.60

$$G^{1\Delta a\rho\Delta}_{\frac{1}{2}\,-\frac{1}{2}} = -2\sqrt{\frac{2}{5}}\,; \quad G^{1\Delta a\rho\Delta}_{\frac{1}{2}\,\frac{3}{2}} = \frac{\sqrt{3}}{2}\,G^{1\Delta a\rho\Delta}_{\frac{1}{2}\,-\frac{1}{2}}\,, \tag{2}$$

$$G^{1Na\rho\Delta}_{\frac{1}{2}\,-\frac{1}{2}} = \pm\sqrt{\frac{1}{2}}\,; \quad G^{1Na\rho\Delta}_{\frac{1}{2}\,\frac{3}{2}} = \sqrt{3}\,G^{1Na\rho\Delta}_{\frac{1}{2}\,-\frac{1}{2}}\,,$$

$$G^{1aa_j\Delta}_{\lambda_a\lambda_a\pm 1} = (\mp 1)\frac{\sigma_j P_j - 1}{2}\,G^{1aa\rho\Delta}_{\lambda_a\lambda_a\pm 1}\;(j = A_2,\pi), \tag{3}$$

where

$$G^{1aa_i\Delta}_{\lambda_a\lambda_\Delta} \equiv G^{aa_i\Delta}_{\lambda_a\lambda_\Delta} \Big/ G^{Na_iN}_{\frac{1}{2}\,-\frac{1}{2}}\,,$$

and $\sigma_j(P_j)$ is the signature (inner parity) of the reggeon j.[2)] These results agree well[5] with the experimental data.

We proceed now to the reaction $\alpha_i\Delta\to\alpha_k\Delta$. An analysis similar to that of Ref. 5 shows that the SSR in this case cannot be satisfied with allowance for only N and Δ, which are contributions with vertices of the transitions (1)–(3). In contrast to the reactions $\alpha_iN\to\alpha_kN$ and $\alpha_iN\to\alpha_k\Delta$, exchange of states with isospin $I=5/2$ in the $s(u)$ channel is possible in the processes $\alpha_i\Delta\to\alpha_k\Delta$, and a self-consistent solution of the SSR can be obtained if in addition to N and Δ there exists a baryon resonance with isospin $I=5/2-E_{55}$. We consider next the SSR that follow from the reactions $\alpha_i\Delta\to\alpha_kE_{55}$ and $\alpha_iN\to\alpha_kE_{55}$, and saturate the $s(u)$-channel isotopic relations $I=3/2$ and $5/2$ with contributions Δ and E_{55}, respectively. An investigation of the equations that follow from these SSR shows that the spin of E_{55} is also equal to 5/2, the parity is positive, and the helicity vertices $G^{a\alpha_iE}_{\lambda_a\lambda_E}(a=\Delta,E_{55})$ satisfy the relations

$$G^{aa_jE}_{\lambda\lambda} = 0 \quad (j = \rho, A_2, \pi, B), \tag{4}$$

$$G^{1\Delta a_jE}_{\lambda\lambda\pm 1} = \beta\left[\pm(\mp 1)\,\frac{1+\sigma_jP_j}{2}\,\sqrt{3}\,C^{5/2\;\lambda\pm 1}_{1\pm 1\;3/2\lambda}\right], \tag{5}$$

$$G^{1Ea_jE}_{\lambda\lambda\pm 1} = 3\sqrt{\frac{5}{7}}\,(\mp 1)\,\frac{1+\sigma_jP_j}{2}\,C^{5/2\;\lambda}_{2\lambda\pm\frac{1}{2}\;\frac{1}{2}\mp\frac{1}{2}}\;C^{5/2\;\lambda\pm 1}_{2\lambda\pm\frac{1}{2}\;\frac{1}{2}\pm\frac{1}{2}}\,. \tag{6}$$

In formulas (5) and (6), $j=\rho,A_2,\pi$; $\beta=\pm 1$, $C^{jm}_{j_1m_1j_2m_2}$ are Clebsch-Gordan coefficients, and the primes denote the same as in formulas (2) and (3). We note that the system of equations for the coupling vertices of the new resonance is greatly overdefined, but the solution (4)–(6) satisfies all the equations.

It is easy to verify that when the SSR in the reaction $\alpha_i E_{55} \to \alpha_k E_{55}$ are considered it becomes necessary to introduce a resonance with isospin $I = 7/2$ and $S = 7/2$. This process can be continued further and it can be deduced that there exists an entire sequence of baryon resonances[3)] with increasing isospins and with spins $I = S$, which decay in accordance with the scheme $(I,S) \to (I-1, S-1) + \pi$.

We examine now in greater detail the properties of the (5/2,5/2) resonance. An important difference between this resonance and the exotic systems that can be made up of $N\bar{N}\Delta$ within the framework of the "quasinuclear" approach,[6] as well as the dual and string models,[7] is the relatively small value of its mass. In first-order approximation it is degenerate with respect to mass with the Δ isobar. It is natural to assume that $M_{E_{55}} - M_\Delta \sim M_\Delta - M_N \approx 300$ MeV. We can then expect the mass of this resonance to lie in the interval 1.4–1.7 GeV.

Since the vertices of the $E_{55} \to \Delta + \pi$ transition are connected with the constants of the $\Delta \to N\pi$ decay by relations (2)–(5), we can express the width of the resonance E_{55} in terms of $\Gamma\Delta$:

$$\Gamma_{E_{55}} = \frac{4}{3} \frac{k^{*3}}{k^3} \Gamma_\Delta , \tag{7}$$

where k and k^* are the momenta in the decays of Δ and E_{55}, respectively.

Let us discuss the processes of formation of the resonance E_{55}. The most favorable for the experimental observation of exotic baryon resonances is their production in backward-scattering processes. For example, in the reaction $\pi^+ p \to \pi^+\pi^-\pi^+ p$ it is necessary to register the system $p\pi^+\pi^+$, which is emitted in the direction of the initial π^+ meson $\pi^+ p \to E_{55}^{+++}\pi^- \to (\Delta^{++}\pi^+)\pi^-$, while in the reaction $\pi^- p \to \pi^-\pi^-\pi^+\pi^+ n$ it is necessary to register the system $\pi^-\pi^- n$, which moves forward. The cross section for the production of E_{55} in backward scattering should be of the same order as the cross section of elastic $\pi^- p$ backward scattering, which, just as the process $\pi^+ p \to E_{55}\pi^-$, is due to exchange of the Regge Δ^{++} pole. There are practically no experimental data at present on the production of multiparticle baryon resonances in backward scattering processes. An experimental check on the possible existence of exotic baryon resonances in these processes with cross sections of the order of several microbarns is perfectly realistic and is of great interest from our point of view.

[1)] Saturation of the SSR by only N and Δ states is self-consistent within the limit $(M_\Delta - M_N)/\bar{M} \ll 1$. Allowance for the differences between the masses M_Δ and M_N calls of necessity for the introduction of higher-lying resonances.

[2)] The residues in (2) differ from those given in Ref. 5 by normalization factors.

[3)] Strictly speaking, it follows from the SSR that the imaginary part of the amplitude is quite large. However, the factorized character of the amplitude gives grounds for regarding the corresponding states as resonances.

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