Relativistic five-quark equations and exotic pentaquarks

S.M.Gerasyuta

Department of Physics, LTA, 194021, St. Petersburg, Russia

E-mail: gerasyuta@sg6488.spb.edu

Abstract

The relativistic five-quark equations are found in the framework of the dispersion relation technique. The five-quark amplitudes for the low-lying pentaquarks including the u, d, s-quarks are calculated. The poles of these amplitudes determine the masses of nucleon and Ξ^{--} pentaquarks. The mass spectra of the lowest pentaquarks with $J^P = \frac{1}{2}^+, \frac{1}{2}^-, \frac{3}{2}^+$ are calculated. The mass values of the positive and negative parity pentaquarks are determined by the mixing of both 0^+ and 1^+ diquarks.

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Recently, a number of laboratories have announced observation of a strangeness $^+1$ baryon [1, 2, 3, 4, 5, 6, 7, 8, 9, 10] with a mass of 1540 MeV and a narrow decay width. Such state cannot be a 3-quark baryon made from known quarks, and it is natural to interpret it as a pentaquark state. This state is made from four quarks and one antiquark $q^4\bar{q}$.

Then the NA49 group at CERN announced evidence for an additional narrow "cascade" exotic ($Q = S = -2$) Ξ^{--} with mass close to 1860 MeV [11, 12].

The present paper is devoted to the construction of relativistic five-quark equations for the nucleon and Ξ^{--} pentaquaks. The five-quark amplitudes for the lowest pentaquaks (nucleon family) contain only u, d-quarks. The poles of these amplitudes determine the masses of the $udud\bar{u}$ pentaquarks. We considered two cases: 1) using only the diquark 0^+ (Table 1) and 2) including the 0^+ and 1^+ diquarks (Table 1). In the first case the negative parity state with $J^P = \frac{1}{2}^+$ is lower than positive parity state. In the second case we construct the nucleon using the 0^+ and 1^+ diquarks and receive the positive parity nucleon lighter than negative parity. The important result of this model is the mixing 0^+ and 1^+ diquarks. The mass values of the low-lying nucleon pentaquarks are shown in Table 1. The masses of Ξ^{--} pentaquark was also calculated (Table 2). The mass of Ξ^{--} with $J^P = \frac{1}{2}^+$ and positive parity is smaller than the mass with negative parity. In this case the important role plays the mixing 0^+ and 1^+ diquarks. Our calculation takes into account the contribution to the Ξ^{--} amplitude the 35-, 27-, 10-, 10^*-, 8-plots.

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Table 1. Low-lying nucleon pentaquark masses

	diquark with $J^P = 0^+$
J^P	Mass, MeV
$\frac{1}{2}^+$	1686
$\frac{1}{2}^-$	1583
	diquark with $J^P = 0^+$ and 1^+
J^P	Mass, MeV
$\frac{1}{2}^+$	1480
$\frac{1}{2}^-$	1515
$\frac{3}{2}^+$	1900

Parameters of model: quark masses

$m_{u,d}$=410 MeV, m_s=557 MeV, cut-off parameters: $\Lambda_{0^+} = 16.5$, $\Lambda_{1^+} = 20.1$[13]; gluon coupling constant $g = 0.417$

Table 2. Low-lying Ξ^{--} pentaquark masses

	diquark with $J^P = 0^+$ and 1^+
J^P	Mass, MeV
$\frac{1}{2}^+$	1673
$\frac{1}{2}^-$	1936
$\frac{3}{2}^+$	2200

Parameters of model: quark masses $m_{u,d}$=410 MeV, m_s=557 MeV, cut-off parameters: $\Lambda_{0^+} = 16.5$, $\Lambda_{1^+} = 20.1$[13]; gluon coupling constant $g = 0.456$[14].

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