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Electromagnetic Transition Amplitudes of Nucleon Negative-parity Resonance by OPE and OGE Quark Models*

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Abstract: Electromagnetic transition amplitudes of negative-parity resonances are calculated based on one-pion exchange (OPE) model and one-gluon exchange (OGE) model, respectively. The configuration mixing caused by the hyperfine interactions of the two models is discussed. Calculated results for the amplitudes indicate that baryon wave functions of OGE are more reasonable than those of OPE.

Key words: constituent quark model; configuration mixing; transition amplitude

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Constituent quark models have been employed to study hadron structures for a long time. They are promising approaches to deal with the physics in nonperturbative QCD region. There are two kinds of the constituent quark models. One is one-gluon exchange model[1] and the other is one-pion exchange model[2]. The two models have their own advantages in different aspects. So far, it is not clear which one is better than the other.

It is believed that the configuration mixing angles in the baryon wave functions are different in the two models because of different hyperfine interactions[3]. The hyperfine interaction between quarks 1 and 2, from the one-gluon exchange is

$$H^{\rm hyp}_{\rm OGE} = A\left\{\frac{8\pi}{3}\boldsymbol{S}_1 \cdot \boldsymbol{S}_2\delta^3(\rho)+ (3\boldsymbol{S}_1 \cdot \hat{\rho}\,\boldsymbol{S}_2 \cdot \hat{\rho} - \boldsymbol{S}_1 \cdot \boldsymbol{S}_2)\rho^{-3}\right\} . \quad (1)$$

The interaction from one-pion exchange is

$$H^{\rm hyp}_{\rm OPE} = B\left\{-\frac{4\pi}{3}\boldsymbol{S}_1 \cdot \boldsymbol{S}_2\delta^3(\rho)+ (3\boldsymbol{S}_1 \cdot \hat{\rho}\,\boldsymbol{S}_1 \cdot \hat{\rho} - \boldsymbol{S}_1 \cdot \boldsymbol{S}_2)\rho^{-3}\right\}\lambda_1^f \cdot \lambda_2^f. \quad (2)$$

In the equations, $\hat{\rho}=\frac{\boldsymbol{\rho}}{|\rho|}$ and A and B are constant which are determined by the strength of the interactions. $\lambda^f_{1,2}$ are the eight 3×3 Gell-Mann $SU(3)$ flavor matrices for quarks 1 and 2.

To obtain reliable baryon wave functions, one need to consider the configuration mixing caused by the hyperfine interactions. For the four negative-parity nucleon resonances, we have

$$\begin{aligned}
&|N(1\ 700)\rangle 3^-/2 \\
&= \cos\theta_{3/2}\ |^4P_{3/2}\rangle + \sin\theta_{3/2}\ |^2P_{3/2}\rangle, \\
&|N(1\ 520)\rangle 3^-/2 \\
&= -\sin\theta_{3/2}\ |^4P_{3/2}\rangle + \cos\theta_{3/2}\ |^2P_{3/2}\rangle, \\
&|N(1\ 650)\rangle 1^-/2 \\
&= \cos\theta_{1/2}\ |^4P_{1/2}\rangle + \sin\theta_{1/2}\ |^2P_{1/2}\rangle, \\
&|N(1\ 535)\rangle 1^-/2 \\
&= -\sin\theta_{1/2}\ |^4P_{1/2}\rangle + \cos\theta_{1/2}\ |^2P_{1/2}\rangle, \quad (3)
\end{aligned}$$

where the mixing angles are

$$\theta_{3/2} = -52.7^\circ, \quad \theta_{1/2} = 25.5^\circ \quad (4)$$

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for OPE and

$$\theta_{3/2} = 6°, \quad \theta_{1/2} = -32°$$

for OGE. Clearly, the mixing angles of the two models are remarkably different.

Table 1 Calculated transition amplitudes of negative-parity resonances with OPE and OGE (in unit of 10^{-3} $GeV^{-1/2}$), respectively.

States	A_λ^N	OPE	χ^2_{OPE}	OGE	χ^2_{OGE}	Exp.[6]
$N_{3^-/2}$	$A^p_{1/2}$	29	3.9	−26	0.1	−18±3
(1 700)	$A^n_{1/2}$	33	0.4	17	0.1	0±50
	$A^p_{3/2}$	−131	17.2	−21	0.4	−1±24
	$A^n_{3/2}$	89	3.6	−27	0.2	−3±44
$N_{3^-/2}$	$A^p_{1/2}$	−31	0.1	−21	0.0	−24±9
(1 520)	$A^n_{1/2}$	−5	6.2	−40	0.8	−59±9
	$A^p_{3/2}$	55	29.0	142	1.4	−166±5
	$A^n_{3/2}$	−74	8.1	−124	0.4	−139±11
$N_{1^-/2}$	$A^p_{1/2}$	−35	11.9	81	1.2	53±16
(1 650)	$A^n_{1/2}$	36	3.1	−46	1.1	−15±21
$N_{1^-/2}$	$A^p_{1/2}$	106	0.2	82	0.0	90±30
(1 530)	$A^n_{1/2}$	−75	0.8	−66	0.4	−46±27

It is expected that the differences of the two models in the baryon wave functions can be seen in some physical observable, such as the baryon resonance electromagnetic transition amplitudes. In this work, those transition amplitudes are calculated with the usual electromagnetic interactions between photons and quarks[4]. Comparing to the available data, we want to identify which model is better. In table 1, the calculated results are displayed, where a useful measure of the quality of fit χ^2 is shown as well for the two models[5], respectively .

We see from the table that the admixture by OGE gives better agreement with the present data. In other word, OGE gives consistent mixing angles to explain baryon spectrum, strong decays and the electromagnetic transition amplitudes. On the other hand, the admixture by OPE is not favored by the data. Thus, one may conclude that OGE is better than OPE in fit with the photo-production amplitudes, at least, for the negative-parity resonances.

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单胶子交换和单 π 交换夸克模型中核子负宇称共振态的电磁跃迁振幅*

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摘 要：分别利用单胶子交换和单 π 交换夸克模型计算了核子负宇称激发态的电磁跃迁振幅，讨论了两个模型所给出的不同的组态混合角. 结果表明，单胶子交换模型所给出的重子波函数比单 π 交换夸克模型的波函数更为合理.

关键词：组份夸克模型；组态混合；跃迁振幅

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