Decay of Θ^+ in a quark model

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One of the distinguished features of the pentaquark particle Θ^+ is its very narrow width [1]. In this report we study the decay of Θ^+ in the non-relativistic quark model [3].

In the quark model, the decay of the pentaquark occurs through the fall apart process, in which the five quarks dissociate into a three-quark cluster, a nucleon, a quark-antiquark cluster, a meson, without pair creation of the quarks as shown in Fig. 1. The decay amplitude is then written as a product of the spectroscopic factor and the basic interaction matrix element. For the latter, we employ the standard meson-quark interaction of the Yukawa type: $\mathcal{L}_{\rm int} = -i\, g\bar{\psi}\gamma_5\Phi\psi \sim \frac{g}{2m}\chi^\dagger\vec{\sigma}\cdot\vec{\nabla}\Phi\chi$, where we have adopted the standard notation.

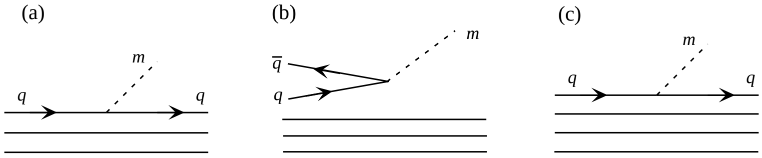

Figure 1: Meson-baron couplings involving an mqq coupling. (a) Transition of a three-quark baryon to another three-quark baryon. (b) A decay of pentaquark baryon into a three-quark baryon and a meson. (c) A diagram equivalent to (b).

The matrix element is then taken between the Θ^+ in the initial state and the kaon and nucleon in the final state:

$$\mathcal{M}_{\Theta^+\to K^+n} = -i\sqrt{2}\langle n_f(udd)|\int d^3x\, g\bar{\psi}\gamma_5\psi e^{-i\vec{q}\cdot\vec{x}}|\Theta^+(uudd\bar{s})\rangle, \qquad (1)$$

where the initial state Θ^+ can be expressed as a kaon-nucleon like state with a spectroscopic factor a: $|\Theta^+\rangle = a|(u(1)d(2)d(3))^n(u(4)\bar{s}(5))^{K^+}\rangle + \cdots$.

We have computed this matrix element for several J^P. The results are summarized in Table 1. From there, we see that the width of the negative parity Θ^+ is too wide for the state to be regarded as a sharp resonance.

For the positive parity Θ^+, the column SF (spin-flavor) shows the results for the Θ^+ configuration minimizing the spin-flavor interaction, where the spectroscopic factor is $\sqrt{5/96}$ [4]. The column SC (spin-color) is for the result for the configuration minimizing the spin-color interaction, which has a spectroscopic factor $\sqrt{5/192}$. We have also shown in the column JW the result for the case where the Jaffe-Wilzeck type of diquark correlation is developed [5]. In this case, the spectroscopic factor becomes $\sqrt{5/576}$ [4] instead of $\sqrt{5/96}$, which reduces the decay width by the factor 6 from the result of SF. Typically, the decay width of a positive parity Θ^+ is of order 10 MeV. To get an even narrower width ~ 1 MeV, we need further mechanism.

References

[1] For an overview of the recent status, see presentations at the international workshop PENTAQUARK04 held at SPring-8, Jul. 20-23 (2004): www.rcnp.osaka-u.ac.jp/∼penta04/

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Table 1: The $KN\Theta^+$ coupling constant $g_{KN\Theta^+}$ and decay width (in MeV) of Θ^+ for $J^P = 1/2^\pm$.

		$g_{KN\Theta}$			
		$J^P = 1/2^-$	$1/2^+$		
$\langle r^2\rangle^{1/2}$	α_0^2		SF	SC	JW $1/\sqrt{2}$ fm
3 fm^{-2}	4.1	7.7	5.5	3.2	
1 fm	1.5 fm^{-2}	3.2	8.4	5.9	3.4