Magnetic moments of the $\Lambda(1405)$ and $\Lambda(1670)$ resonances

D. Jido[a], A. Hosaka[a], J.C. Nacher[b], E. Oset[b] and A. Ramos[c]

[a] *Research Center for Nuclear Physics (RCNP), Ibaraki, Osaka 567-0047, Japan*
[b] *Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Ap. Correos 22085, E-46071 Valencia, Spain*
[c] *Departament d'Estructura i Constituents de la Matèria, Universitat de Barcelona, Diagonal 647, 08028 Barcelona, Spain*

Various models for investigating baryon resonances have been proposed based on different physical motivations. Generally, these models are so established as to reproduce masses of the baryon resonances at least. Now these models are in the stage to discuss the details of baryon properties, such as their magnetic moments.

Construction of the baryon resonances with $J^P = 1/2^-$ is quite different in the quark model and in the unitrized chiral perturbation theory ($U\chi\mathcal{PT}$). In the quark model, three quarks are constituents of the baryon and excitation of one of the quarks gives negative parity to the baryon resonances. On the other hand, in $U\chi\mathcal{PT}$ baryon resonances are generated dynamically from meson-baryon scattering. Thus, in order to understand the structure of the baryon resonance, it is interesting to compare physical consequences of these models, especially, quantities which have much information of the wave function of the resonance, such as the magnetic moment. Here we consider the magnetic moments of the $\Lambda(1405)$ and $\Lambda(1670)$ as well as the transition magnetic moment of these resonances [1].

In $U\chi\mathcal{PT}$ the $\Lambda(1405)$ resonance is shown as a resonance in meson-baryon scatterings in $S = -1$ channel [2] by using the Bethe-Salpeter equation for the T-matrix of meson-baryon scatterings, which is given by

$$T = V + VGT \ , \tag{1}$$

where G is the meson-baryon propagator and V is a kernel potential, which is taken from the lowest order of the chiral Lagrangian. The Feynman diagrams summed by eq. (1) are given in Fig.1.

To extract the magnetic moments of these resonances, we compute amplitudes for the process $MB \to M'B'\gamma$, inserting the elementary couplings of the photon to the components of the meson-baryon amplitude at lowest order of the chiral expansion, and we take a summation over the Feynman diagrams which generate the resonance both on the left and on the right of the photon coupling, as shown in Fig.2. The amplitudes obtained in this way are compared to a resonance description of the Breit-Wigner form.

The results obtained in $U\chi\mathcal{PT}$ are summarized in Table.1. For the transition magnetic moment we obtain a value $|\mu_{\Lambda(1670)\to\Lambda(1405)}| \sim 0.023\mu_N$, which leads to a branching ratio of the $\Lambda(1670)$ to $\Lambda(1405)\gamma$ channel of the order of 2×10^{-6}.

In the SU(6) quark model, $\Lambda(1405)$ and $\Lambda(1670)$ are described as p-wave excitations of the 70-dimensional representation, whose SU(2) $\times$ SU(3) decomposition is given by $70 = {}^28 + {}^48 + {}^21 + {}^210$, in which the notation on r.h.s., ${}^{2j+1}D$, j represents the resonance spin and D the dimension of the flavor SU(3) representation. A Λ state is written as a linear combination of the ${}^{2j+1}D$ basis:

$$|\Lambda\rangle = a_1|{}^28\rangle + a_2|{}^48\rangle + a_3|{}^21\rangle \, . \tag{2}$$

The coefficients are determined by assuming suitable interactions between quarks [3].

In the non-relativistic formulation, the magnetic moment operator is given by the sum of twice spin and orbital angular momentum. With eq.(2), we find the corresponding matrix element $\langle\Lambda|\mu_3|\Lambda\rangle = \sum_{nm} a_n a_m \langle n|\mu_3|m\rangle$. The results for the magnetic moments is also summarized in Table 1.

In summary, the comparison between the two models offers an evidence that the nature of these states as dynamically generated from multiple scattering of coupled channels of mesons and baryons differs from an ordinary quark model description. One of the interesting results obtained in this work is the abnormally small decay width for the $\Lambda(1670) \to \Lambda(1405)\gamma$ transition, which differs in two order of magnitude from the quark model predictions. Short of a difficult measurement of the transition, given the small numbers predicted, even the determination of upper bound would provide interesting information about the nature of there resonances.

References

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Model	$\Lambda(1405)$	$\Lambda(1670)$	transition
$U\chi\mathcal{PT}$	$+0.24 \sim 0.45$	-0.29 ± 0.01	0.023 ± 0.009
QM	0.04	0.28	0.31

Table 1: Magnetic moments obtained by the chiral unitary approach ($U\chi\mathcal{PT}$) and the quark model (QM) in units of the nuclear magneton. The sign of the transition magnetic moment is not determined.

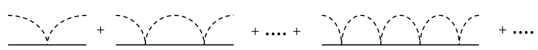

Figure 1: Diagrammatic representation of the Bethe-Salpeter equation in eq. (1). Dashed and solid lines denote the meson and the baryon, respectively

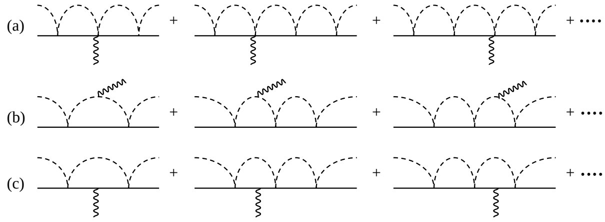

Figure 2: Diagrams for the coupling of the photon to the resonance dynamically generated in meson-baryon scattering.