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D^*N and B^*N molecules: the $\Lambda_c(2940)^+$ and the possible existence of the $\Lambda_b(6248)^0$

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An explanation of the $\Lambda_c(2940)^+$ baryon as a $D^{*0}N$ molecular state in the framework of a constituent quark model is proposed. A bound state with quantum numbers $J^\pi = \frac{3}{2}^-$ is found with the right binding energy. The measured partial widths to D^0p, D^+n, $\Sigma_c^{++}\pi^-$, $\Sigma_c^+\pi^0$ and $\Sigma_c^0\pi^+$ are calculated, with results consistent with the experimental data. The possibility of a partner of the $\Lambda_c(2940)^+$ in the bottom sector is explored, obtaining a candidate in the $J^\pi = \frac{3}{2}^-$ channel with a predicted mass of $6248\,MeV/c^2$ and a relatively small width of $\Gamma = 7.5\,MeV$, which is suitable to be discovered in the LHCb in the future.

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In the last decade, new exciting discoveries of charmed baryons at BaBar [1], Belle [2] and Cleo [3] Collaborations allowed to complete the description of the charmed lambda spectrum. Among such states, the zero isospin baryon $\Lambda_c(2940)^+$ is a challenge for the different models. BaBar [1] measured its mass and width, finding respectively $M = 2939.8 \pm 1.3 \pm 1.0 MeV/c^2$ and $\Gamma = 17.5 \pm 5.2 \pm 5.9 MeV$. It was later confirmed by Belle [2] as a resonant structure in the $\Sigma_c(2455)\pi$ decay with mass and width compatible with the BaBar measurement. The mass of the resonance is just $6 MeV/c^2$ below the $D^{*0}p$ threshold, suggesting that it can be interpreted as a molecular state.

Many attempts have been carried out to determine the nature of the $\Lambda_c(2940)^+$. In this work, a theoretical explanation of the $\Lambda_c^+(2940)$ as a D^*N molecular state is proposed [4], in the framework of a constituent quark model that has been extensively used to describe the hadron phenomenology [5, 6, 7].

The model is based on the assumption that the spontaneous breaking of the chiral symmetry is responsible for generating the constituent mass. Goldstone boson fields must be included in the Lagrangian to compensate such mass term, which mediate the interaction between quarks. In this model, baryons (mesons) are described as clusters of three quark (one pair of quark and antiquark). All the parameters of the model are taken from ref [5] and [7], gaining confidence on the final conclusions.

The most probable scenarios for the formation of a bound state are the $J^P = \frac{1}{2}^-$ and $J^P = \frac{3}{2}^-$ channels, where the meson-baryon system is in a relative S wave, as positive parity states are disfavored due to the P-wave nature of the molecule. We focus on the $J^P = \frac{3}{2}^-$ channel, as this channel is significantly more attractive due to the π tensor component.

The meson baryon interaction is obtained from the qq one using the Resonating Group Method (RGM). The meson wave functions are determined solving the Schrödinger equation using the Gaussian Expansion Method. For the baryon wave function we use a gaussian form with a suitable parameter. The possible bound states are obtained through the poles of the t matrix of the Lippmann-Schwinger equation.

To obtain the allowed decays, assuming a D^*N structure for the Λ_c, the amplitude to the final states are calculated in the constituent quark model framework. For DN final state this is achieved with a direct potential, but $\Sigma_c\pi$ final states require an exchange potential by simple quark rearrangement diagrams.

Finally, the possible existence of a partner of the $\Lambda_c(2940)^+$ in the bottom sector is also analyzed.

$M\,(MeV)$	$\mathscr{P}_{^4S_{3/2}}$	$\mathscr{P}_{^2D_{3/2}}$	$\mathscr{P}_{^4D_{3/2}}$	$\mathscr{P}_{D^{*0}p}$	$\mathscr{P}_{D^{*+}n}$	$\mathscr{P}_{I=0}$	$\mathscr{P}_{I=1}$
2938.80	96.22	0.86	2.92	63.93	36.07	97.52	2.48

Table 1: Mass of the $\Lambda_c^+(2940)$ and contributions for the different channels.

Decay channel	D^0p	D^+n	$\Sigma_c^{++}\pi^-$	$\Sigma_c^+\pi^0$	$\Sigma_c^0\pi^+$	$\Gamma(total)$	$\Gamma(experimental)$
Width (MeV)	9.40	10.73	0.00419	0.00435	0.00451	20.1	17^{+8}_{-6}

Table 2: Widths of the $\Lambda_c^+(2940)$ for different decay channels.

$M\,(MeV)$	$\mathscr{P}_{^4S_{3/2}}$	$\mathscr{P}_{^2D_{3/2}}$	$\mathscr{P}_{^4D_{3/2}}$	$\mathscr{P}_{B^{*-}p}$	$\mathscr{P}_{\bar{B}^{*0}n}$	$\mathscr{P}_{I=0}$	$\mathscr{P}_{I=1}$
6248.34	95.15	1.08	3.77	52.56	47.44	99.91	0.09

Table 3: Mass of the $\Lambda_b(6248)^0$ and contributions for the different channels.

As stated before, analyzing the two negative-parity channels $J^P = \frac{1}{2}^-$ and $J^P = \frac{3}{2}^-$, a molecular state is found per sector, with $\frac{3}{2}^-$ quantum numbers, at a mass of $2938.68\,MeV/c^2$ for the charm and $6248\,MeV/c^2$ for the bottom sector. The molecules are basically a $^4S_{3/2}$ state with a small mixture of $D_{3/2}$ states (see table 1 for Λ_c and table 3 for Λ_b). The Λ_c (Λ_b) state is basically a $D^{0*}p$ ($B^{*-}p$) molecule with a sizable $D^{+*}n$ ($\bar{B}^{*0}n$) component, with an almost pure $I = 0$ component, as measured by the experimental data for the charmed lambda. The results for the different decay widths are presented in table 2 (charm) and table 4 (bottom). For the Λ_c state, the results for DN final states are of the order of the experimental values, whereas the $\Sigma_c\pi$ channel contributions are negligible, as expected for a process occurring through a rearrangement diagram.

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Decay channel	B^-p	$\bar{B}^0n$	$\Sigma_b^+\pi^-$	$\Sigma_b^0\pi^0$	$\Sigma_b^-\pi^+$	$\Gamma(total)$
Width (MeV)	3.69	3.76	0.00630	0.00634	0.00638	7.47

Table 4: Widths of the $\Lambda_b(6248)^0$ for different decay channels.

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