Resonances below pion-nucleon threshold and their consequences for nuclear systems

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The experimental search for exotic states in one-baryon and two-baryon spectra has a long history. Enthusiasm has been recently revived in the field after two experimental reports [1, 2]. In ref. [1] the reaction $pp \to p\pi^+ X$ was investigated and three narrow peaks (width ~ 5 MeV) in the missing mass M_X spectrum were seen at 1004, 1044 and 1094 MeV with high statistical significance. Ref. [2] reported about the study of the reaction $pd \to p\,p\,X_1$. Three peaks of the width of 5 MeV were clearly observed in the missing mass M_{pX_1} spectrum at 1904, 1926 and 1942 MeV. In the missing mass M_{X_1} spectrum the peaks are located at 966, 986 and 1003 MeV. The evident regularity of the observed peaks is in contrast with previous experimental data which were limited by a lower resolution in energy and lower statistics.

Three interpretations of these peaks were suggested in the literature: (i) The peaks can be assigned to supernarrow dibaryon resonances (D') [2]; (ii) The peaks can be interpreted as new nucleon resonances (N') [1]; (iii) They are bound states of one or two nucleons with several light pseudoscalar particles ($\widetilde{\pi}$) having mass of about 20 MeV [3]. These interpretations imply that the new particles should have an exotic internal quark structure, having only a small overlap with usual nucleon and pion states. Nevertheless they could be produced with a detectable probability in particle-nucleus and nucleus-nucleus collisions as well as other rare probes (photons, di-leptons, strange particles, etc). The small probalility of an elementary reaction is enhanced in latter case due to a large number of interactions.

Being motivated by recent experimental studies and their interpretations, we have investigated [5] how the existence of exotic light dibaryons, nucleon resonances and pions, would manifest itself in nuclear systems. As an example we have considered the lightest state in the dibaryon spectrum (spin and isospin 0), $m_{D'} = 1904$ MeV, and the two lightest states in the nucleon spectrum (spin and isospin $\frac{1}{2}$) $m_{N'_1} = 966$ MeV and 986 MeV. For "light pions" we take $m_{\widetilde{\pi}} = 22$ MeV. We vary the unknown D', N'–nucleon interaction within a broad interval.

We found that dibaryons and N' resonances are absent in nuclei, if their interactions with nucleons are indeed sufficiently small as it has been suggested. We show also that light pions cannot be accumulated in atomic nuclei, the size of the nucleus and the value of the Coulomb potential being to small for that.

The new exotic states, if exist, can be accumulated in the neutron star (NS) matter filling new Fermi seas and/or forming a $\widetilde{\pi}$ condensate, in the same way as hyperons and other fermion resonances and pion condensate do. However, due to their abnormally small masses this happens already at rather small densities $\sim \rho_0$, with $\rho_0 = 0.16\,\mathrm{fm}^{-3}$ being a normal nuclear matter density. Their presence drastically changes the composition of a NS and makes the equation of state very soft. In the presence of dibaryons the pressure is typically smaller by an order of magnitude compared to the one without dibaryons. The maximum mass of NS in the presence of D', N' is less then the observational limit $1.4M_\odot$ ($M_\odot$ being the solar mass).

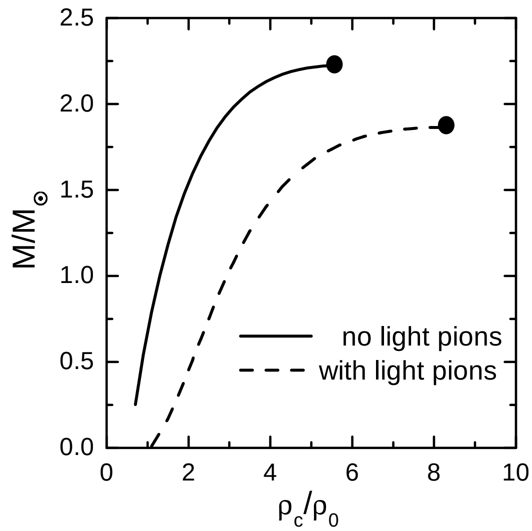

Figure 1: The NS mass as a function of the central baryon density without (solid line) and with (dashed line) the presence of light pions $\widetilde{\pi}$. In absence of $\widetilde{\pi}$ the optimal equation of state of the Urbana-Argonne group is used.

The existence of light pions, althogh softens the equation of state too, would not lead to a contradiction with observed NS masses, see Figure 1. However, it would allow for the existence of abnormal nuclei ($A \gtrsim 10^3$) and "nuclei-stars" of arbitrary size, bound by strong and electromagnetic interactions. In heavy-ion collisions $\widetilde{\pi}$ mesons would contribute to dilepton spectra and could be seen there as a peak at ~ 20 MeV energy.

The importance of consequences of the low-mass resonance states should strongly motivate further experimental investigations, as well as a search for new theoretical interpretations.

References

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