Excited hyperonic states in some odd and even mass single-Λ hypernuclei

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Various properties of hypernuclei have been extensively studied in several experiments and are the objects of a rich experimental program. The first experiments were aimed at identifying the hypernuclei and at determining the energy of their ground states. Now-a-days, with the improvement in experimental techniques, measurements of high-quality excitation spectra have been possible in (π^+, K^+), (K^-, π^-) or $(e, e'K^+)$ reactions. In future, further advancements may be possible by means of γ-ray spectroscopy, which may become a standard investigation tool [1].

Among other approaches, single-Λ hypernuclei have been theoretically studied within the Relativistic mean field (RMF) approximation. The RMF model, when applied to various medium-heavy and heavy nuclei, has been quite successful in reproducing the single hyperon energies, a feature of the single particle properties of the system.

We have calculated the excitation energy of lambda hyperon in single-Λ hypernuclei that are formed by adding a Λ to different even-even and odd mass normal nucleus. In the first case since both the neutrons and the protons in the hypernucleus are paired, the angular momentum, parity etc. of the final nucleus is determined solely by the hyperon. In the latter case the unpaired nucleon couples to the hyperon to produce the spin-parity of the nucleus. The odd particles (nucleon and/or hyperon) may occupy different single particle states. In a mean field approach, the potential depends on the occupancy of the single particle states. Thus the excited states, generated in such a way, is significantly dependent on the single particle state occupied by the odd nucleon and the hyperon.

In our calculation, we have employed the FSUGold Lagrangian density[2] that have been devised for normal nuclei. The hyperon part of the Lagrangian density is given by

$$\mathcal{L}_\Lambda = \bar{\psi}_\Lambda(i\gamma_\mu\partial^\mu - M_\Lambda - g_{\sigma\Lambda}\sigma - g_{\omega\Lambda}\gamma_\mu\omega^\mu)\psi_\Lambda$$

The nucleon-meson coupling constants are the standard ones as given in [2]. The Hyperon-meson coupling constants have been varied in the present work to reproduce the experimental hyperon separation energy. Since the mean field approximation does not work very well in very light nuclei, hypernuclei with $A \geq 16$ are chosen for the fitting procedure. We assume that the non-strange sector of the Lagrangian is completely determined by the Lagrangian for normal nuclei (in the present case FSUGold) and the only task that remains is fixing the two hyperon-meson coupling constants.

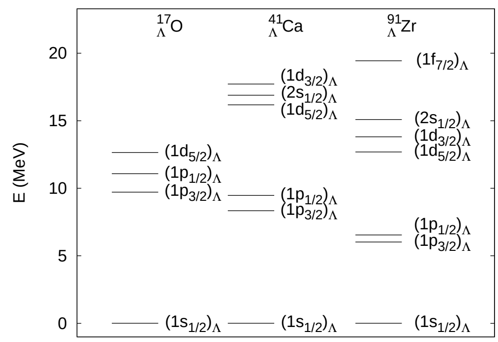

FIG. 1: Calculated single-Λ excitation energy for $^{17}_{\Lambda}$O, $^{41}_{\Lambda}$Ca, $^{91}_{\Lambda}$Zr .

We have calculated the excitation spectra of single Λ hypernuclei arising out of hyper-

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onic or hyperon-nucleon coupling in some representative nuclei. Specifically, we have investigated the ${}^{12}_{\Lambda}$C, ${}^{16}_{\Lambda}$O, ${}^{90}_{\Lambda}$Zr, ${}^{208}_{\Lambda}$Pb hypernuclei since there are experimental data available for these nuclei [3–5], [6], [7], [8].We also investigate the ${}^{40}_{\Lambda}$Ca as this was investigated in a shell model approach in [9].

One interesting feature that has been observed in the hypernuclei that have a close shell structure for normal nucleons is the single particle structure for the hyperon. As is evident from FIG. 1, in ${}^{17}_{\Lambda}$O, the shell gap expected between $1p_{\frac{3}{2}}$ and $1d_{\frac{5}{2}}$ is missing while in heavier nuclei, the gap appears as in the case of normal nucleons, It will be interesting to verify experimentally such a phenomena which may throw light on the hyperon-nucleon interaction inside the nucleus.

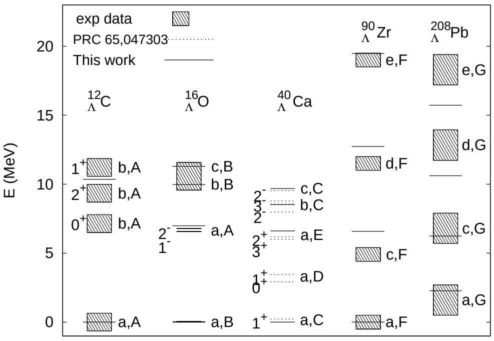

FIG. 2: Calculated and experimental single-Λ excitation energy. Theoretical results for one Λ excitation energies are represented by solid lines while experimental values are indicated by hatched rectangles. The height of the rectangles represent the uncertainty in the experimental resolution. The dashed lines represent the results of shell model calculations taken from [9]. Notations are described in TABLE I.

We see that some of the MF states are degenerate as the calculation is in the mean field level and no residual interaction has been assumed. In some cases the theoretical energy does not match with the experimental ones. This may be an indication of the effects coming from the Λ-nucleon interaction, and possibly of collective excitation.

TABLE I: Notations used in FIG. 2

Symbol	hyperon state	Symbol	nucleon state
a	$(1s_{\frac{1}{2}})_{\Lambda}$	A	$(1p_{\frac{3}{2}})_n^{-1}$
b	$(1p_{\frac{3}{2}})_{\Lambda}$	B	$(1p_{\frac{1}{2}})_n^{-1}$
c	$(1p_{\frac{1}{2}})_{\Lambda}$	C	$(1d_{\frac{3}{2}})_n^{-1}$
d	$(1d_{\frac{5}{2}})_{\Lambda}$	D	$(2s_{\frac{1}{2}})_n^{-1}$
e	$(1f_{\frac{7}{2}})_{\Lambda}$	E	$(1d_{\frac{5}{2}})_n^{-1}$
-	-	F	$(1g_{\frac{9}{2}})_n^{-1}$
-	-	G	$(1i_{\frac{13}{2}})_n^{-1}$

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