A study of hypernuclei with isovector scalar meson

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Introduction

A hypernucleus is formed by injecting at least one hyperon. The injected hyperons formed a new kinds of species in nuclear medium where strange baryons are treated as an impurity and used as a probe to reveal many of the interesting nuclear phenomenon in the dimension of strangeness. A very limited information on YN scattering data is available which is a major consequence of experimental difficulties [1]. In this connection, significant efforts on theoretical basis have been made to enrich the knowledge about YN interaction using various theoretical approaches either relativistic or non-relativistic. Here, the relativistic mean field (RMF) formalism with isovector-scalar $\delta-$meson interaction in addition of meson-hyperon is applied to describe the structure of asymmetric hypernuclei. Specifically, we evaluate the contribution of $\delta-$meson in all physical observables of asymmetric hypernucleus and compared with their counter parts.

Essentials of RMF formalism

The RMF Lagrangian for hyperon-nucleon-meson many-body system [2] including the $\delta-$ meson is written as the sum of nucleon and hyperon lagrangian

$$\mathcal{L} = \mathcal{L}_N + \mathcal{L}_\Lambda,$$

$$\begin{aligned}
\mathcal{L}_N &= \bar{\psi}_i\{i\gamma^\mu\partial_\mu - M\}\psi_i + \frac{1}{2}(\partial^\mu\sigma\partial_\mu\sigma - m_\sigma^2\sigma^2) \\
&- \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 + \frac{1}{2}(\partial^\mu\delta\partial_\mu\delta - m_\delta^2\delta^2) \\
&- g_s\bar{\psi}_i\psi_i\sigma - g_\delta\bar{\psi}_i\vec{\tau}\psi_i\vec{\delta} - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} \\
&+ \frac{1}{2}m_w^2V^\mu V_\mu - g_w\bar{\psi}_i\gamma^\mu\psi_iV_\mu - \frac{1}{4}B^{\mu\nu}B_{\mu\nu} \\
&+ \frac{1}{2}m_\rho^2\vec{R}^\mu\vec{R}_\mu - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - g_\rho\bar{\psi}_i\gamma^\mu\vec{\tau}\psi_i\vec{R}^\mu \\
&- e\bar{\psi}_i\gamma^\mu\frac{(1-\tau_{3i})}{2}\psi_iA_\mu , \\
\mathcal{L}_\Lambda &= \bar{\psi}_\Lambda\{i\gamma^\mu\partial_\mu - m_\Lambda\}\psi_\Lambda - g_{\omega\Lambda}\bar{\psi}_\Lambda\gamma^\mu\psi_\Lambda V_\mu \\
&- g_{\sigma\Lambda}\bar{\psi}_\Lambda\psi_\Lambda\sigma ,
\end{aligned}$$

where ψ and ψ_Λ denote the Dirac spinors for nucleon and Λ particle, whose masses are M and m_Λ respectively, and $g_{\sigma\Lambda}$, $g_{\omega\Lambda}$ are Λ-meson coupling constants. All the symbols have their usual meaning.

Results and Discussions

To analyze the effects of $\delta-$meson on bulk properties of considered hypernucleus, we calculate the binding energy (BE), root mean square neutron (r_n), proton (r_p), charge (r_{ch}) and matter radius (r_t), and energy of first and last filled orbitals of $^{90}_{\Lambda}$Zr with various combinations of g_ρ and g_δ. In Fig. 1 (a and c), we have shown the binding energy difference ΔBE of ^{90}Zr and $^{90}_{\Lambda}$Zr between the two solutions obtained with (g_ρ, g_δ=0) and (g_ρ, g_δ), i.e.

$$\Delta BE = BE(g_\rho, g_\delta = 0) - BE(g_\rho, g_\delta), \quad (1)$$

here $BE(g_\rho, g_\delta = 0)$ is the binding energy at $g_\delta = 0$ in the adjusted combination of (g_ρ, g_δ) and $BE(g_\rho, g_\delta)$ is the binding energy with non-zero value of g_δ in the adjusted combination which reproduce the same binding as

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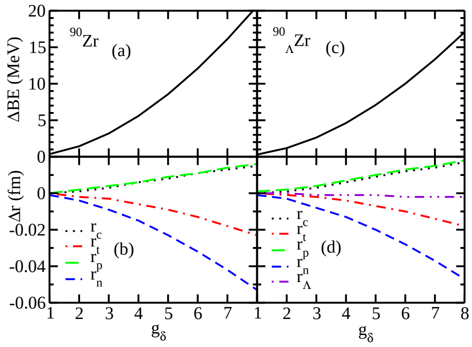

FIG. 1: Binding energy (BE) and root mean square radius for ^{90}Zr and $^{90}_{\Lambda}$Zr using various combination of g_ρ and g_δ.

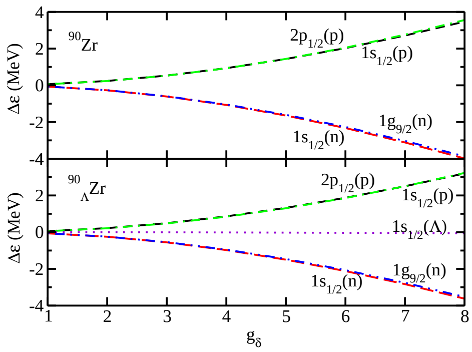

FIG. 2: First ($1s^{n,p}$) and last ($1g^n$, $2p^p$) occupied orbits for ^{90}Zr and $^{90}_{\Lambda}$Zr using various (g_ρ, g_δ) combinations.

pure NL3*. In this way, ΔBE represents the contribution of $\delta-$ meson in binding energy. Similarly, the effect of $\delta-$meson in radius for both nucleus and hypernucleus is calculated from:

$$\Delta r = r(g_\rho, g_\delta = 0) - r(g_\rho, g_\delta), \qquad (2)$$

where $r(g_\rho, g_\delta = 0)$ is the radius at $g_\delta = 0$ in the adjusted combination (g_ρ, g_δ) and $r(g_\rho, g_\delta)$ is the radius in adjusted combination of g_ρ and g_δ with non zero value of g_δ. The same procedure has adopted to estimate the contribution of $\delta-$meson on single particle energy for considered hypernucleus and their nonstrange counter part. The difference in single particle energy ($\Delta\epsilon$) for a particular level is expressed as

$$\Delta\epsilon = \epsilon(g_\rho, g_\delta = 0) - \epsilon(g_\rho, g_\delta), \qquad (3)$$

where $\epsilon(g_\rho, g_\delta = 0)$ is the single-particle energy for adjusted combination (g_ρ, g_δ) with $g_\delta = 0$, and $\epsilon(g_\rho, g_\delta)$ is energy of the occupied level with non zero value of g_δ. Because of the presence of Λ hyperon, the contribution of $\delta-$meson in binding energy, radii and single particle energy are less on hypernucleus compared to the normal nucleus. On contrary to this, the proton and charge radii are affected more in hypernucleus than their normal counter part. In Fig. 2, the change in first occupied ($1s^{n,p}$) and last occupied levels ($1g^n$ and $2p^p$) for $^{90}_{\Lambda}$Zr and ^{90}Zr is presented. Owing to zero isospin of Λ hyperon, the lambda orbit ($1s^{\Lambda}_{1/2}$) is unaffected with the strength of g_δ.

Summary

It is concluded that g_δ affects the binding energy, radii and single particle energies significantly. It is also observed that the contribution of delta-meson interaction in strange nucleus is less compare to nonstrange nucleus. Contrary to this, the proton and charge radii are affected relatively more than normal counter part. It is worthy to mention that $\delta-$meson has indispensable contribution not only in asymmetric nuclei but in hypernuclei also.

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References

[1] O. Hashimoto and H. Tamura, Prog. Part. Nucl. Phys. **57**, 564 (2006).

[2] D. Vretenar, W. Pöschl, G. A. Lalazissis and P. Ring, Phys. Rev. C **57**, R1060 (1998); N. K. Glendenning, D. Von-Eiff, M. Haft, H. Lenske and M. K. Weigel, Phys. Rev. C **48**, 889 (1993); M. T. Win and K. Hagino, Phys. Rev. C **78**, 054311 (2008).