Analysis of some Λ-nucleus potentials

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Introduction

For the analysis of the experimental data, the choice of a suitable Λ-nucleus potential and its parameters is important. For medium and heavy nuclei, the Woods-Saxon (W-S) form of density has been most extensively employed to calculate the potentials. However, there is sufficient flexibility in these potentials in terms of their size, their potential strengths as well as dependence on the linear or higher powers of density. Here, we compare these potentials with our phenomenological density-dependent potentials.

The Λ-nucleus potential [1] is obtained by folding Λ-nucleon (ΛN) force with the nucleon density of the core nucleus assuming point proton and point neutron densities to be same and the range of ΛN force to be equal to the proton size. The folded potential is given as :

$$V_\Lambda(r) = - D_\Lambda \rho_{ch}(r), \qquad (1)$$

where D_Λ is the potential depth and the charge density $\rho_{ch}(r)$ is given as:

$$\rho_{ch}(r) = 1/[1+\exp((r-R)/a)] .$$

The radius and diffuseness parameters [2] are expressed as functions of core mass number A_c :

$$R = C_0 + C_1 A_C^{1/3} + C_2 (N-Z) A_C^{-1},$$

$$a = A_0 + A_1 (N-Z) A_C^{-1} .$$

The coefficients C_0, C_1, C_2, A_0 and A_1 are fixed [1] from the radius and diffuseness parameters of experimental charge density covering a fairly large range of medium and heavy nuclei. Numerical fitting of Λ-binding energy (B_Λ) data was carried out for ground as well as excited states of $^{28}_{\Lambda}$Si, $^{40}_{\Lambda}$Ca, $^{51}_{\Lambda}$V and $^{89}_{\Lambda}$Y with a single parameter D_Λ. The Λ-nucleus potential so obtained is plotted for $^{89}_{\Lambda}$Y in Fig. 1, as V1.

Another numerical fitting [3] of B_Λ was carried out for ground as well as excited states of $^{28}_{\Lambda}$Si, $^{32}_{\Lambda}$S, $^{40}_{\Lambda}$Ca , $^{51}_{\Lambda}$V and $^{89}_{\Lambda}$Y using the point nucleon density $\rho_N(r)$ as the average of point proton density $\rho_p(r)$ and point neutron density $\rho_n(r)$ [2],

$$\rho_N(r) = \frac{Z}{A_C}\rho_p(r) + \frac{N}{A_C}\rho_n(r) \qquad (2)$$

Both point proton and point neutron densities, normalized to unity, are taken to be of the W-S form. Their radius and diffuseness are chosen to have the same parameterization as is done earlier [2]. The coefficients of 'R' and 'a' for point proton, point neutron and point nucleon densities are taken from ref. [2] and [3] respectively. The single particle Λ-nucleus potential [3] obtained by folding zero-range ΛN potential with the point nucleon density of the core nucleus is plotted for $^{89}_{\Lambda}$Y in Fig. 1, as V2.

Millener et al. [4] used a local density dependent Λ-nucleus potential of the form:

$$-V(r) = A\,\rho(r) - B\,\rho^{\gamma}(r) , \qquad (3)$$

with γ = 4/3, 5/3, 2 and 3. The values of A and B are obtained from the fit to the Λ-binding energies in the ground as well as excited states of $^{89}_{\Lambda}$Y . The density ρ(r) is chosen to have a form:

$$\rho(r) = \rho_0/[1+\exp((r-c)/a)] ,$$

where $c = r_0 A_c^{1/3}$ with r_0=1.08 fm and a=0.54 fm.

The Λ-nucleus potentials [4], with the best fit values of A and B given therein and γ = 4/3, 5/3, 2 and 3 are plotted for $^{89}_{\Lambda}$Y in Fig. 1 as V3A, V3B, V3C and V3D respectively.

The Λ-nucleus potential chosen by G. A. Lalazissis [5] has the form :

$$V_{\Lambda A_c}(r) = -V_1 f(r) + V_2 f^2(r) , \qquad (4)$$

where the form factor f(r) is given as :

$$f(r) = \frac{\sinh(R/a)}{\left[\cosh(r/a) + \cosh(R/a)\right]}$$

The potential depth and the radius parameter is obtained [5] from the best fit B_Λ values, for the 1s-state of ${}^{16}_{\Lambda}O$, ${}^{28}_{\Lambda}Si$, ${}^{40}_{\Lambda}Ca$, ${}^{51}_{\Lambda}V$ and ${}^{89}_{\Lambda}Y$. The diffusivity 'a' is assumed to be a constant equal to 0.6 fm. The Λ-nucleus potential so obtained [5] is plotted as V4 in Fig. 1.

Result and Discussion

From Fig. 1, we see that the potentials obtained for ${}^{89}_{\Lambda}Y$ in ref.[1] and [2], referred to as V1 and V2 respectively, differ only slightly in their depths and radius. The potential V1 obtained using charge density distribution [1] has slightly larger depth and smaller radius compared to the potential V2 obtained using average nucleon density distribution [2]. The radius and diffuseness parameters of the potential V1 are fixed [1] from the radius and diffuseness parameters of the experimental charge density while for potential V2 these parameters are determined [2] by least square fitting of eq.(2). Both these potentials, however, are found to give fairly good agreement with the available experimental B_Λ data in various states for medium and heavy hypernuclei.

The potentials obtained by Millener et al.[4] for ${}^{89}_{\Lambda}Y$, with γ = 4/3, 5/3 and 2, referred to here as V3A, V3B and V3C respectively, have small variations in their potential strengths but the size of the potentials is almost same. They have fitted the Λ-binding energy spectra of ${}^{89}_{\Lambda}Y$. While their potential with γ = 3, referred to here as V3D has a shallower depth in the interior which increases by ~ 3- 4 MeV near the surface. This potential is found to develop a pocket at the surface due to an increase in the repulsive term of the potential V3D.

The potential of ref. [5] is plotted for ${}^{89}_{\Lambda}Y$ as V4 in Fig. 1. The potential can be seen to have a large radius and smaller potential depth. The potential depth and the radius parameter is obtained from the fitting of ground state B_Λ of ${}^{16}_{\Lambda}O$, ${}^{28}_{\Lambda}Si$, ${}^{40}_{\Lambda}Ca$, ${}^{51}_{\Lambda}V$ and ${}^{89}_{\Lambda}Y$.

It can be seen from Fig. 1 that size of the potential well is smaller when the depth is large and vice-versa. Hence, the size of the potential well can be controlled by the strength of the potential. The slight difference in the potentials V1 and V2 are due to difference in their charge and nucleon densities. The local Λ-nucleus potential of Millener et al [4], with γ = 4/3, 5/3 and 2, are nearly same in the surface region with small variations in the interior. The potential with repulsive ρ^3-term has a shallow potential well in the interior which becomes more attractive near the surface region. While the potential V4 has an increased central radius and smaller potential depth.

For each type of density dependence, the interplay between the ρ and ρ^γ- terms simply gives potential well of a certain depth and size to fit the B_Λ data. The binding energies can be seen to be relatively insensitive to the finer details of the radial shape. Thus, we may conclude that the potentials chosen by us (V1,V2) seem quite appropriate for predicting B_Λ data for a wide range of hypernuclei, the parameters of which are adjusted by an overall fit to all the available data of given states, which leads to more reliable potentials and hence results.

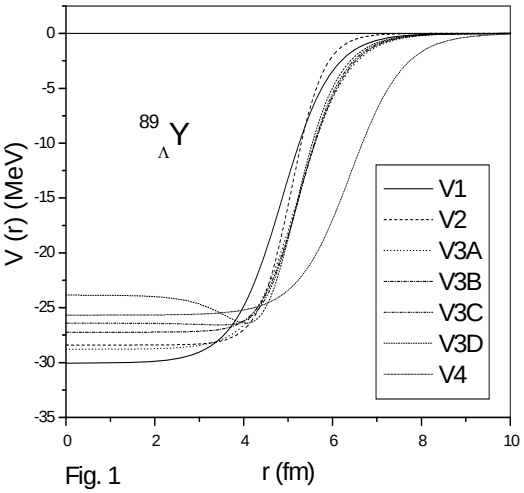

Fig. 1

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