Impact of double spin component within the energy density formalism

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Introduction

Rigorous amount of work has been done in the past to explore the importance of spin-orbit density dependent term, which seems to contribute significantly for nuclei away from the line of stability. The robustness of magic numbers near the neutron drip line will depend strongly on the parameterizations of the spin-orbit dependent term [1]. This effect has been investigated for a variety of nuclear systems lying near the neutron and proton drip line [2]. Recently, the effect of spin-orbit density term was tested via single spin-orbit potential (W_0) only [2], and now we intend to analyze the comparative impact of both spin-orbit parameters i.e. W_1 and W_2 in medium mass neutron rich nuclei.

The semi-classical approach of Skyrme Energy Density Formalism (SEDF) is used to study the relative influence of W_1 and W_2 on spin-orbit density term V_J. For the purpose, Al-based reactions are chosen forming various isotopes of $^{68-76}$Se*. Different Skyrme forces containing double spin-orbit parameters W_1 and W_2 are taken such as, SKI2, SKI3 and SKI4 [3]. In the present study, both spherical as well as deformed choice of nuclei are considered for the calculations. It may be noticed that, SKI4 force exhibit highest barrier height and lowest interaction radius, however lowest barrier height is observed for SKI2 Skyrme force which contains single spin-orbit parameter W_1=W_2=W_0. The contribution of W_1 and W_2 is further tested for ^{72}Se* compound nucleus by calculating preformation probability P_0 and penetrability P of light mass fragments ($A_2 \leq 4$), which are the only contributors towards fusion excitation functions.

Methodology

The Skyrme Energy Density Formalism, defines the nuclear interaction potential as the sum of spin density independent term V_P and spin density dependent term V_J

$$V_N(R) = V_P(R) + V_J(R) \tag{1}$$

with

$$\begin{aligned}
V_P(R) &= \frac{\hbar^2}{2m}\tau + \frac{1}{2}t_0\left[(1+\frac{1}{2}x_0)\rho^2 - (x_0+\frac{1}{2})(\rho_n^2+\rho_p^2)\right] \\
&+\frac{1}{12}t_3\rho^\alpha\left[(1+\frac{1}{2}x_3)\rho^2 - (x_3+\frac{1}{2})(\rho_n^2+\rho_p^2)\right] \\
&+\frac{1}{4}\left[t_1(1+\frac{1}{2}x_1)+t_2(1+\frac{1}{2}x_2)\right]\rho\tau \\
&-\frac{1}{4}\left[t_1(x_1+\frac{1}{2})-t_2(x_2+\frac{1}{2})\right](\rho_n\tau_n+\rho_p\tau_p) \\
&+\frac{1}{16}\left[3t_1(1+\frac{1}{2}x_1)-t_2(1+\frac{1}{2}x_2)\right](\vec{\nabla}\rho)^2 \\
&-\frac{1}{16}\left[3t_1(x_1+\frac{1}{2})+t_2(x_2+\frac{1}{2})\right] \\
&\times\left[(\vec{\nabla}\rho_n)^2+(\vec{\nabla}\rho_p)^2\right]
\end{aligned} \tag{2}$$

and

$$V_J(R) = \frac{1}{2}W_1\left[\rho\vec{\nabla}\cdot\vec{J}\right] + \frac{1}{2}W_2\left[\rho_n\vec{\nabla}\cdot\vec{J_n}+\rho_p\vec{\nabla}\cdot\vec{J_p}\right] \tag{3}$$

Where W_1 and W_2 are the double spin-orbit parameters.

Further, Schrödinger wave equation is solved in η-motion to calculate the preformation probability P_0, and for penetrability P, WKB approximation is applied within dynamical cluster-decay model (DCM) [5]

Calculations and Results

In the present work, the effect of including two parameters (W_1 and W_2) in spin-orbit potential is analyzed via semi-classical approach of SEDF at T=0 MeV for various Se isotopes having mass range 68-76. In order

TABLE I: The preformation probability P_0 and penetrability P of light fragments calculated at $\ell=\ell_{max}$ with and without the contribution of spin-orbit term using SKI4 Skyrme force.

$E_{c.m.}$ (MeV)	Fragment	P_0: V_P	P_0: $V_N=V_P+V_J$	P: V_P	P: $V_N=V_P+V_J$
31.74	1n	2.40×10^{-12}	1.28×10^{-11}	2.74×10^{-4}	5.05×10^{-4}
	2n	1.16×10^{-9}	4.71×10^{-9}	5.52×10^{-8}	3.96×10^{-7}
	3n	2.53×10^{-7}	5.86×10^{-7}	5.32×10^{-13}	6.71×10^{-11}
	4H	7.61×10^{-5}	1.31×10^{-4}	8.77×10^{-13}	1.66×10^{-10}
50.05	1n	1.98×10^{-13}	2.905×10^{-13}	0.825	0.861
	2n	1.55×10^{-11}	3.517×10^{-11}	0.618	0.665
	3n	6.95×10^{-9}	1.478×10^{-8}	0.221	0.279
	4He	8.17×10^{-6}	1.680×10^{-5}	0.384	0.475

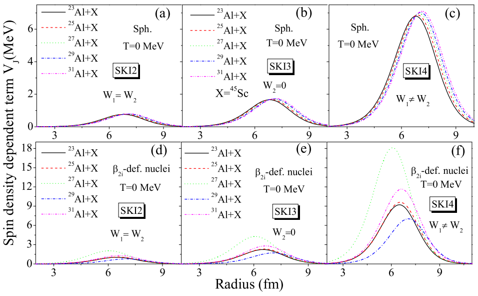

FIG. 1: The spin density dependent part V_J as a function of R(fm) using SKI2, SKI3 and SKI4 skyrme forces for $^{23-31}$Al+^{45}Sc channels. The upper and lower panels shows the case respectively for spherical and β_2-deformed nuclei.

to explore the specific role of spin-orbit parameter (W_1 and W_2), different Skyrme forces i.e. SKI2 (W_1 = W_2), SKI3 (W_2=0) and SKI4 ($W_1 \neq W_2$) are considered. In upper panel of Fig. 1, the various isotopes of Se* are chosen starting with the target-projectile combination of ^{23}Al + ^{45}Sc. Different isotopes of Se are formed by using stable ^{45}Sc target and adding two successive neutrons to the ^{23}Al projectile. One may notice from Fig. 1 that, the presence of double spin parameter in spin-orbit part of interaction potential significantly influence the magnitude of V_J, which becomes highest for SKI4 and least for SKI2 force. The upper panel of Fig. 1 shows that for spherical choice of colliding nuclei, the spin barrier height (V_{JB}) and barrier position (R_{JB}) remains almost constant for SKI2 Skyrme force and start increasing for SKI3 and SKI4 Skyrme forces, with increase in mass of projectile. However, on allowing deformation effects, enhancement in V_{JB} is higher specially for oblate shape nuclei followed sequentially by prolate and spherical choice of colliding partners. The results are depicted in the lower panel of Fig. 1

Furthermore, the impact of W_1 and W_2 is investigated in the decay analysis of ^{72}Se* compound system using SKI4 Skyrme force. Since in DCM [5], the decay primarily depends upon the preformation probability and penetrability of decaying fragments. Therefore, the effect of spin-orbit term is estimated through P_0 and P of decaying fragments calculated at extreme center of mass energies $E_{c.m.}$ as shown in Table I. It is clearly observed that, there is deviation in P_0 and P when double spin-orbit parameter is not included. This evidently prove the importance of double spin-orbit parameters in the reaction dynamics of ^{72}Se* system, which further affects the fusion-evaporation excitation functions (not shown here). Further investigations are in progress to see the effect of double spin-orbit parameter on fusion cross-section(s).

References

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