Investigation of the Absorption Effects in Coulomb Excitation of Neutron-Rich Silicon-Isotopes

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Coulomb excitation is a process of inelastic scattering in which one of the interacting nuclei gets excited to higher energy level due to the time varying electromagnetic field of the other nucleus. Experimentally, the events of pure Coulomb excitation need to be ascertained for the reliable extraction of various structural observables. This goal is achieved automatically for the incident beam energy below the Coulomb barrier and at above barrier energies by rejecting the scattering events occurring at angles having values greater than that of certain maximum scattering angle ($\theta_{\max}$) [1]. This angle corresponds to a minimum value of impact parameter ($b_{\min}$) through $b_{\min} = a\cot(\theta_{\max}/2)$ with $a\left(=\frac{Z_P Z_T e^2}{m_0 v^2}\right)$ as half the distance of closest approach in a head-on collision and Z_P (Z_T) is the charge number of the projectile (target). The so obtained value of $b_{\min}$ must exceeds the sum of the projectile and the target radii $(R_P + R_T)$ by several femtometer and must be large enough to avoid the strong nuclear interaction between the projectile and the target. It is taken for granted that for $b \geq b_{\min}$, no nuclear interaction exists and for $b < b_{\min}$, the role of electromagnetic processes becomes negligible. However, in actual practice the process can never be so sharp thus the smoothness of the interaction process must be taken into account. The simplest way to consider the smoothness of the process is to include the absorption effects through the survival probability of the projectile [2].

In the present work we have analyzed the absorption effects in the Coulomb excitation of neutron rich $^{32,34,36,38}Si$ –isotopes at intermediate energies [3] within the framework of RCE theory of Winther and Alder [4] by taking into account the survival probability of the projectile. Within the framework of this theory the excitation cross section from the initial nuclear state $|\,i\,\rangle$ to some final nuclear state $|\,f\,\rangle$ is given by

$$\sigma_{i\to f} = \left(\frac{Z_T\, e^2}{\hbar\, c}\right)^2 \sum_{\Pi\lambda\mu}\left(\frac{\omega_{fi}}{c}\right)^{2(\lambda-1)} B(\Pi\lambda;\, I_i \to I_f\,)/e^2 \times \left|G_{\Pi\lambda\mu}\left(\frac{c}{v}\right)\right|^2 g_\mu(\xi)$$

where $B(\Pi\lambda\,;\,I_i \to I_f)$ is the reduced transition probability and I_i (I_f) is the spin quantum number of initial (final) nuclear state. The $G_{\Pi\lambda\mu}\left(\frac{c}{v}\right)$ are termed as relativistic Winther-Alder functions and the functions $g_\mu(\xi)$ are expressed in terms of the integration of the μ^{th} order modified Bessel functions, $K_\mu(\xi)$, by the following relation

$$g_\mu(\xi) = 2\pi\left(\frac{\omega_{fi}}{\gamma\, v}\right)^2 \int_{b_{\min}}^{\infty} b\, db\, |K_\mu(\xi)\,|^2$$

$\hbar\omega_{fi} = E_f - E_i$ is the excitation energy and the argument of modified Bessel functions, ξ represents the adiabaticity parameter and γ is Lorentz factor. In order to take into account the absorption effects the functions $g_\mu(\xi)$ are replaced by

$$g'_\mu(\xi) = 2\pi\left(\frac{\omega_{fi}}{\gamma\, v}\right)^2 \int_{b_{\min}}^{\infty} b\, db\, |K_\mu(\xi)\,|^2\, |\,S(b)\,|^2$$

where $|\,S(b)\,|^2$ is the survival probability. To calculate $S\,(b)$ the projectile-target interaction potential is needed which in turn require the nuclear matter density of the projectile. Here, we have used 2-parameter Fermi (2pF) density distribution [5]. We have calculated the Coulomb excitation cross sections of $^{32,34,36,38}Si$ isotopes on Au target at incident beam energies of 37.4, 42.6, 48.2 and 42.4 MeV/A [3] respectively by properly incorporating the effects of survival probability. In Fig. (1), we have plotted $|\,S(b)\,|^2$ as a function of impact parameter b. Values of $|S(b)|^2$ varies gradually from zero to one for different values of impact parameters, say from 10 to 20 fm. Below 10 fm projectile doesn't survive at all while it fully survives only at and above 16 fm.

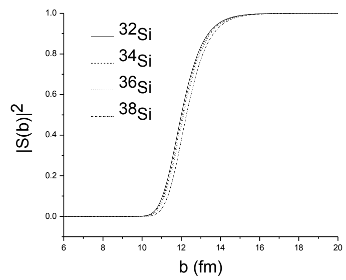

Fig. 1. The survival probability for $^{32,34,36,38}Si$ - isotopes for 2pF matter density distributions.

Clearly the 'corridor of uncertainty' extends from ~11 fm to ~15 fm wherein values of $|S(b)|^2$ varies from 0.1 to 0.95. Hence the inclusion of the survival probability affects the cross section when $b_{\min}$ is chosen within the range mentioned above. We have used $R_P + R_T$, R_{int}[6] and $a \cot(\theta_{\max}/2)$ as three different possible values of $b_{\min}$. The value of $R_P + R_T$, R_{int} and $a \cot(\theta_{\max}/2)$ come out to be 10.8, 12.9 and 20.5 fm for ^{32}Si, 10.9, 12.9 and 17.1 for ^{34}Si, 10.9, 13 and 14.1 fm for ^{36}Si and 11, 13, 15.2 for ^{38}Si respectively. As the values of $a \cot(\theta_{\max}/2)$ lie well outside the corridor of uncertainty the absorption effects are negligibly small when $b_{\min}$ is obtained by using experimental value of $\theta_{\max}$. On the other hand the value of $b_{\min}$ ~ 11 fm, obtained through $b_{\min} = R_P + R_T$, lies almost at the lower edge of corridor of uncertainty the absorption effects are expected to be more pronounced in this case. While in the case of $b_{\min} = R_{\text{int}}$ these effects may be observed but to a smaller extent. For the sake of clarity, it is convenient to express the absorption effects in terms of the quantity $\sigma^* = \left(\frac{\sigma - \sigma^{|S(b)|^2}}{\sigma}\right)\%$, here σ is the Coulomb excitation cross section without survival probability and $\sigma^{|S(b)|^2}$ is with survival probability. The subscript $i \to f$ has been dropped for brevity. The quantity σ^* versus $b\,(fm)$ for various Silicon isotopes has been plotted in Fig. 2.

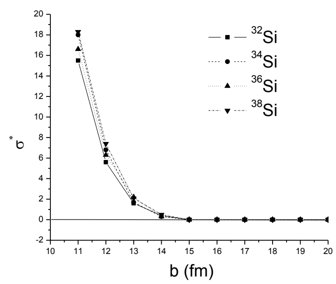

Fig. 2. A plot of σ^* vs. $b\,(fm)$ for various Si - isotopes corresponding to $|S(b)|^2$ as shown in Fig.1.

It is clear from this figure that σ^* lies within 15-18 % in case of $b_{\min} = R_P + R_T$ for $^{32,34,36,38}Si$ isotopes i.e. the values of σ decrease by 15-18 % due to absorption effects. In case of $b_{\min} = R_{\text{int}}$, the ratio σ^* reduces to almost 2 % which suggests that although the absorption effects are non-zero but are very small. Hence for $b_{\min} = R_{\text{int}}$, both sharp- and smooth-cutoff based models give almost equal values of Coulomb excitation cross sections. Hence, it becomes clear that $b_{\min} = R_{\text{int}}$ may be considered as reasonably "safe" lower limit of impact parameter b for the estimation of pure Coulomb excitation cross sections.

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