Energy dependence of the absorption effects in Coulomb excitation process

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The inelastic scattering process in which the interacting nuclei get excited through the electromagnetic field only is known as Coulomb excitation. Because of very well known reaction mechanism the process has been serving as one of the oldest and best-established experimental tools in nuclear structure physics since 1950's [1]. Events of pure Coulomb excitation have to be ensured for precise and reliable extraction of various nuclear structural observables. In the intermediate energy Coulomb excitation experiments the dominance of Coulomb excitation is ascertained by taking measurements below some very small angle. This angle corresponds to a minimum value of impact parameter ($b_{\min}$). The so obtained value of $b_{\min}$ must exceed the sum of the projectile and the target radii $(R_P + R_T)$ by several femtometers and must be large enough to avoid the strong nuclear interaction between the projectile and the target. It is generally accepted that for impact parameters greater than or equal to $b_{\min}$, no nuclear interaction exists while for impact parameters smaller than $b_{\min}$, the strong nuclear interactions dominate over weak electromagnetic processes. However, in actual practice the process can never be so sharp thus the smoothness of the process needs to be accounted for. The simplest way to consider the smoothness of the process is to include the absorption effects through the survival probability of the projectile [2-4].

The $b_{\min}$, apart from playing a crucial role in the calculations of the Coulomb excitation cross section, is the only quantity which decides the purity of the Coulomb excitation process. For determination of the hypersensitive parameter $b_{\min}$, out of a large number of indirect parameterization schemes some commonly used are due to Benesh, Cook and Vary (BCV) [5], W.W. Wilcke et al. (WWW) [6] and S Kox et al. (KOX) [7]. We have checked the adequacy of these indirect as well as the recently proposed direct scheme [4] with the intent of ascertaining the purity of Coulomb excitation process. For this purpose we have studied the Coulomb excitation of a number of neutron rich isotopes ^{26}Ne, ^{32}Mg, ^{36}Si, ^{42}S, ^{46}Ar, ^{52}Fe, ^{78}Kr at 40-80 MeV/nucleon [4] within the framework of RCE theory of Winther and Alder [8]. According to 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

$$B(\Pi\lambda\,;\, I_i \to I_f\,) = \frac{1}{(2I_i+1)} \left|\left\langle I_i \left\| m(\Pi\lambda) \right\| I_f \right\rangle\right|^2$$

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. 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. Now in order to take into account the absorption effects the functions $g_\mu(\xi)$ are replaced by

$$g'_\mu(\xi) = 2\pi \left(\frac{\omega_{fi}}{\gamma\, v}\right)^2 \int_{0}^{\infty} b\, db\, |K_\mu(\xi)|^2\, |S(b)|^2$$

where $|S(b)|^2$ is the survival probability and generally, in realistic form it is taken in terms of the integrals of the projectile-target interaction along the straight-line trajectories [9]. For all the isotopes

^{26}Ne, ^{32}Mg, ^{36}Si, ^{42}S, ^{46}Ar, ^{52}Fe, ^{78}Kr the values of $|S(b)|^2$ varies gradually from zero to one for different values of impact parameters, e.g. from 10 to 20 fm [4]. In between these b values there lies a region termed as the 'corridor of uncertainty (CU)' where it is uncertain whether projectile survives or not [3]. In Fig. 1, we have plotted $|S(b)|^2$ as a function of impact parameter b for $^{32}Mg + ^{197}Au$ system at different beam energies. With increase in incident beam energy the value of $|S(b)|^2$ increases for a particular value of b say it increase from ~50% at 30 MeV/nucleon to ~ 80% at 500 MeV/nucleon in case of ^{32}Mg. The same trend has also been observed for other isotopes being discussed here. In other words the corridor of uncertainty is shifting towards lower value of impact parameter with increasing beam energy.

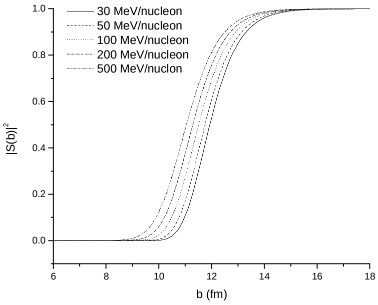

Fig.1 The survival probability of ^{32}Mg for different beam energies ranging from 30MeV/nucleon to 500 MeV/nucleon.

However, the inclusion of the survival probability or absorption effects affects the cross section when $b_{\min}$ is chosen within the range lying in the region of uncertainty. The absorption effects are conveniently expressed by $\left(\frac{\sigma-\sigma^{|S(b)|^2}}{\sigma}\right)\%$ [3, 4] where σ ($\sigma^{|S(b)|^2}$) is the Coulomb excitation cross section calculated by neglecting (by considering) survival probability. It is found that at experimental mid target beam energies which are being considered here, the absorption effects are relevant at the level of as much as ten percent for BCV, three percent for WWW and KOX [4]. Although for WWW and KOX these effects are less significant but are still non-zero. While at experimental beam energies for all the isotopes these effects vanish altogether in case of recently proposed scheme [4].

The variation of the absorption effects with incident beam energy for BCV, WWW and KOX as well as for the recently suggested parameterization scheme is depicted in Fig. 2. As per the expectations, from the trend shown in Fig. 1 and following Ref. [3], these effects are found to be decreasing with increasing beam energy for all the parameterization schemes. In case of BCV scheme, the absorption effects reduce to three percent at 500 MeV/nucleon as compared to those of ten percent at 30 MeV/nucleon. While in case of WWW and KOX schemes these effects are important only at the level of one to two percent.

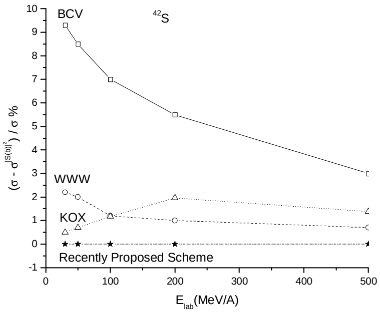

Fig. 2 The variation of the absorption effects in Coulomb excitation of ^{42}S on *Au* target with beam energy for BCV (□) , KOX (Δ), WWW (o) and recently proposed parameterization scheme (*).

Thus it becomes clear, from Fig. 2, that for beam energies less than 200 MeV/nucleon the BCV, KOX and WWW parameterization schemes are not valid. On the other hand the recently proposed scheme is applicable for entire beam energies ranging from 30-500 MeV/nucleon as it excludes the every possibility of nuclear interaction in the Coulomb excitation experiments.

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