Analysis of Fusion Excitation Function of ^{11}Be+^{209}Bi System in Near Barrier Energy Region

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The fusion of weakly bound nuclei is of utmost importance in conjunction with the process of nucleosynthesis and energy production in stars [1]. The early experiments carried out using Radioactive Ion Beams have confirmed the existence of an extended halo structure among some of these weakly bound nuclei [2]. Owing to their exceptionally large size and very small binding energy of last nucleon(s) the fusion involving these nuclei differs fundamentally from those involving tightly bound nuclei. The nucleus ^{11}Be being a representative of well-established halo system has attracted a significant attention since from the beginning of the era of Radioactive Ion Beam facilities [3]. Since the fusion of ^{11}Be with heavy target offers a very good opportunity to study the peculiar behavior of fusion reactions involving loosely bound nuclei, we have studied the fusion of ^{11}Be+^{209}Bi system within the framework of quantum diffusion approach.

The quantum diffusion approach is based on the quantum master equation for the reduced density matrix [4]. Within this approach, the collision of nuclei is treated in terms of a single collective variable: the relative distance R between the colliding nuclei. The partial wave capture cross-section, the cross-section for the formation of dinuclear system, is given by

$$\sigma_c(E_{c.m.}) = \sum_L \sigma_c(E_{c.m.}, L) = \pi\lambda\!\!\!^{-2}\sum_L (2L+1) P_{cap}(E_{c.m}, L) \qquad (1)$$

where $\lambda\!\!\!^{-2} = \hbar^2/2\mu E_{c.m}$ is the reduced de Broglie wavelength.

Above, the partial capture probability P_{cap} which is defined as the passing probability of the potential barrier in the relative distance R between the colliding nuclei at a given L, is obtained by integrating an appropriate propagator from initial state at t = 0 to the final state at time t and is given by [4]

$$P_{cap} = \lim_{t\to\infty} \frac{1}{2} erfc\left[\frac{-r_{in} + \overline{R(t)}}{\sqrt{\Sigma_{RR}(t)}}\right] \qquad (2)$$

The first moment, $\overline{R(t)}$, and the variance, $\Sigma_{RR}(t)$, are obtained by constructing a suitable Hamiltonian for quantum nuclear system which results in integro-differential equations for Heisenberg operator R and P whose solutions give the following expressions for $\overline{R(t)}$ and $\Sigma_{RR}(t)$

$$\overline{R(t)} = A_t R_0 + B_t P_0$$

$$\sum\nolimits_{RR}(t) = \frac{2\hbar^2\lambda\gamma^2}{\pi}\int_0^t d\tau' B_{\tau'}\int_0^t d\tau'' B_{\tau''} \times \int_0^\infty d\Omega \frac{\Omega}{\Omega^2+\gamma^2} \times coth\left[\frac{\hbar\Omega}{2T}\right] cos[\Omega(\tau'-\tau'')]$$

with

$$B_t = \frac{1}{\mu}\sum_{i=1}^{3}\beta_i\,(s_i+\gamma)e^{s_i t}$$

$$A_t = \sum_{i=1}^{3}\beta_i[s_i(s_i+\gamma) + \hbar\lambda\gamma/\mu]e^{s_i t}$$

which when used in Eq. (2) leads to

$$P_{cap} = \frac{1}{2} erfc\left[\left(\frac{\pi s_1(\gamma - s_1)}{2\mu\hbar(\omega_0^2 - s_1^2)}\right)^{1/2} \frac{\mu\omega_0^2 R_0/s_1 + P_0}{[\gamma \ln(\gamma/s_1)]^{1/2}}\right]$$

For further details of the model see Ref. [4]. In the present work we have used this expression for calculating P_{cap} and hence the fusion excitation function for the system considered.

All the input parameters needed in the calculations are taken within the limits as prescribed in Ref. [4]. The parameter R_0 is very crucial and strongly depends on the separation of the region of pure Coulomb interaction and that of Coulomb nuclear interference, we here propose a very simple expression for its determination which takes into account the spatial extension of the nucleus through R_{int}. If the value of r_{ex}, the position of external turning point, is larger than the interaction radius R_{int}, we take $R_0 = R_{int}(\exp(-(E_{c.m.} - E_{int})/V_b))$ and $P_0 = 0$ while for $r_{ex} < R_{int}$ we take $R_0 = R_{int}$ and P_0 is equal to the kinetic energy at that point. The quantity E_{int} corresponds to the incident energy for which the r_{ex} and R_{int} coincides.

The comparison of the calculated fusion excitation function for ^{11}Be +^{209}Bi system in the near barrier energy region with the corresponding experimental data taken from Ref.[5] is shown in Fig.1. It is found that there is a reasonably good agreement between the data and predictions except in the deep sub barrier energy region. In deep sub barrier region there is a significant enhancement of the calculated cross section in comparison to the measured values. The mismatch between the data and predictions in the deep sub barrier region may be ascribed to various dynamical effects like coupling to continuum, coupling to neutron transfer channel etc. which are not accounted for here. Nevertheless these preliminary results are very encouraging in the energy region just below and just above the barrier.

In nutshell, we have proposed an energy dependent simple expression for determining the separation between the fusing nuclei at *t = 0*, an important ingredient needed in the quantum diffusion model, which when used along with appropriate set of other parameters explains the fusion excitation function data of ^{11}Be+^{209}Bi system reasonably well.

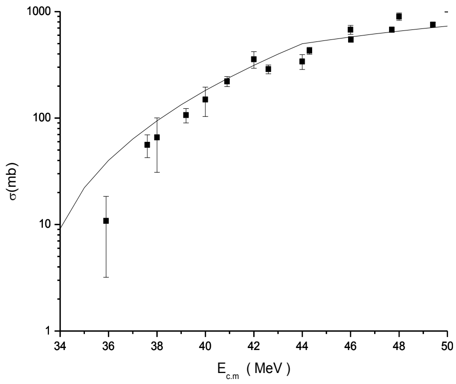

Fig.1 Comparison of the fusion excitation function of ^{11}Be+^{209}Bi system with the experimental data taken from Ref.[5].

References

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