Quantum calculations of Coulomb reorientation for sub-barrier fusion

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Tunneling, the slow "quantum leak" through a classical barrier, is an intriguing phenomenon in nature. In 1928, Gamow discovered this effect looking for an explanation of the α radioactivity. However, the tunneling of complex systems remains to be understood. As in the Gamow times nuclear physics is providing one of the most challenging field to understand tunneling. In particular, fusion cross sections involving massive nuclei around the Coulomb barrier can be orders of magnitude over one dimensional quantum tunneling predictions. Couplings between the internal degrees of freedom and the relative motion deeply modifies tunneling. Neutron transfer, excitation of low-lying vibrational and rotational states, neck formation, zero-point motion and polarization of collective surface vibration as well as static deformation have been identified as key inputs in the understanding of this sub-barrier fusion enhancement.

For nuclei with a significant static quadrupole deformation, the main effects are i) on the barrier height (geometrical effect) since it is lower in the elongated direction and ii) on the reorientation of the deformed nucleus (rotational effect) under the torque produced by the long-range Coulomb force.

In the past, fusion excitation functions were measured for ^{16}O (spherical) + $^{144-154}$Sm reactions. ^{144}Sm is spherical whereas ^{154}Sm is prolate ($\beta_2 \approx 0.3$). The data near the barrier were interpreted as arising from the different orientations of the prolate nucleus. An enhancement of the fusion probability is observed when the deformation axis is parallel to the collision axis and a hindrance when the two axis are nearly perpendicular. In these studies, however, the assumption of an *isotropic orientation distribution* of the deformed nucleus at contact was made. This contradicts semi-classical calculations which show partial reorientation. From the quantum mechanics point of view, the reorientation is a consequence of the excitation of rotational states, which may affect near barrier fusion specially for light deformed nuclei. Computational techniques have been developed in the past to solve coupled channel (CC) equations for Coulomb excitation but a good understanding of the Coulomb reorientation dynamics during the approach phase is still required.

In this work we obtain a deeper insight in the Coulomb reorientation. We focus on the reorientation effect of a deformed projectile on a spherical target. Analytical results for the classical dynamics of a rigid body, confirmed by exact simulations, show that, in contrast to a naive expectation, the Coulomb reorientation depends neither on charges nor on relative energy. The relevant observables are the deformation parameter and the inertias. Those conclusions have been extended to quantum dynamics using the Time-Dependent Hartree-Fock (TDHF) theory. These calculations show that the nuclear contribution are negligible and they exhibit a sizeable increase of the reorientation as compared to classical calculations, interpreted in terms of a smaller moment of inertia for the quantum system as compared to the rigid body approximation. In fact, the TDHF calculations predict an increase by 30% of the induced rotation interpreted in terms of quantum effects. The reorientation is expected to be maximum when the deformed nucleus is light and its collision partner heavy. For these systems, long range Coulomb couplings have to be included in fusion cross section calcilations. Indeed, CC calculations of barrier distributions which show that sub-barrier fusion is partially hindered by the reorientation process. The induced effects give an helpful interpretation of full CC calculations. We also suggest experiments to measure the effect of the reorientation on excitation functions.