Octupole deformation in nuclear fusion

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Introduction

There is a great interest recently in octupole deformation since it can contribute to the atomic electric dipole moment, thus meaning a time-reversal violation. This interest has turn into large experimental efforts on searching for octupole deformations on the regions where different theoretical approaches predict strong octupole correlations with the help of continuous development of the radioactive beam facilities. In [1, 2], Coulomb excitation has been used to measure the different electric transition probabilities. This tool provides quadrupole and octupole transition probabilities with good accuracy. However large octupole transitions can be found for octupole vibrators, and also large dipole ones when this vibration is coupled to a quadrupole deformations [3].

Nuclear fusion has been shown to be a useful tool to study the nuclear shapes. However, the possibility of testing octupole deformation of a nucleus with this tool has not been fully explored yet. It is well known that fusion at energies around the Coulomb barrier is driven by the dynamical couplings to the internal degrees of freedom of the fusing counterparts [4]. The presence of octupole and dipole moments in one of the fusing partners will have a certain impact in the final subbarrier fusion cross section. This fact could suggest, if the minimum accuracy is reached, the possibility of distinguishing between static octupole deformation and the corresponding dynamical vibration.

The Model

Fusion probabilities are calculated by solving the corresponding coupled-channel equations under ingoing-wave boundary conditions (IWBC). In our case we will consider one of the two ions to be a quadrupole deformed rotor. We will also look at cases where the deformed nuclei has an octupole vibration or a static octupole deformation together with the quadrupole one. We modify the original spherical Woods-Saxon to have a radius with a dependence on the angle. The distance from the two surfaces (one spherical and the other one deformed) can be characterized by a function of the angle as $R(\theta') = R_0[1+\sum_\lambda \beta_\lambda Y^*_{\lambda 0}(\theta')]$. If one assumes that the potential is still a function of the distance between projectile and target, the potential can be expanded in multipoles as

$$V(R,\Omega) = \sum_{\lambda\mu} V_\lambda(R)\mathcal{D}^\lambda_{\mu 0}(\alpha,\beta,\gamma)Y^*_{\lambda\mu}(\hat{R}), \quad (1)$$

where $\mathcal{D}$ is the so called rotation matrix. Finally, evaluating the matrix elements of this potential between the states of the rotor, it is possible to obtain the coupling potentials [4].

For the vibration case of one of the nucleus, it is characterized as a variation on the surface as $R(\xi) = R_0[1+\sum_{\lambda,\mu} \alpha_{\lambda\mu} Y^*_{\lambda\mu}(\hat{R})]$, where $\alpha_{\lambda\mu}$ are to be understood as dynamical variables, given in terms of phonon creation ($b^\dagger_{\lambda\mu}$) and annihilation ($b_{\lambda\mu}$) operators.

The nuclear coupling between the ground state and the first one phonon state of multipolarity reads

$$V_{coup} = -\frac{\beta_\lambda}{\hat{\lambda}} R_0 \frac{\partial V}{\partial R} Y^*_{\lambda\mu}(\hat{R}). \quad (2)$$

The derivative of the potential has a certain dependence of the orientation. We can express this dependence as

$$V_{coup}(R,\xi) = -\frac{\beta_3}{\hat{3}} R_0 \frac{\partial V}{\partial R}\left(R - R_0\left[1+\beta_2 Y_{20}\right]\right) Y_{30}. \quad (3)$$

Together with these vibrational couplings, the traditional quadrupole deformed potential will

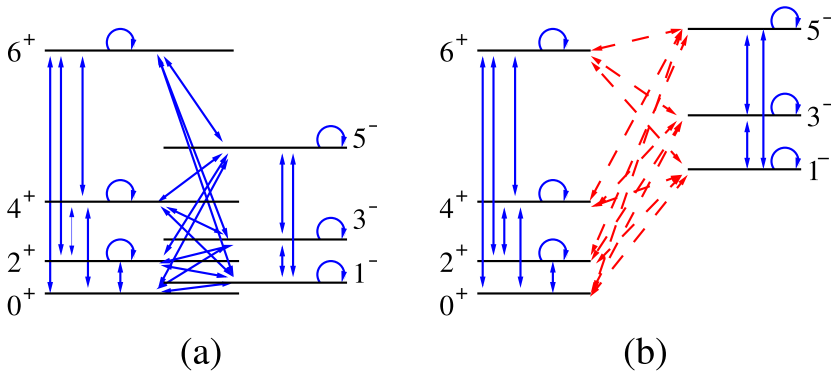

FIG. 1: Level schemes considered for a quadrupole octupole deformed nucleus (left panel) and for a quadrupole deformed nuleus with an octupole vibration (right panel). Each arrow can be related to transitions with more than one possible multipolarity λ.

only act between states with the same number of phonons. It is to be noted that this potential is only coupling zero octupole phonon states with one octupole phonon states. For further details see Ref. [5].

Calculations and Discussion

Fig. 1 (a) shows the scheme of a single octupole-quadrupole deformed band. We can couple all the levels in this scheme (blue solid arrows), with a deformed potential considering the nucleus both octupole and quadrupole deformed. The scheme (b) in Fig. 1 shows a ground state quadrupole deformed rotor band and a one octupole phonon quadrupole deformed band. Different one phonon bands may result from the coupling of one octupole phonon and a quadrupole deformation. For big enough values of β_2 and β_3 the lowest energy band is the $K = 0^-$ band with associated levels $I = 1^-, 3^-, 5^-...$ [6], so that this case coincides with the octupole quadrupole deformed level scheme.

We have done calculations for two systems ^{16}O+^{144}Ba and ^{16}O+^{224}Ra. Both targets have an octupole deformation with a considerable β_3. Excitations of the projectile are not considered. Differences between the form factors of two systems for both schemes are small but significant. The presence of an octupole deformation affects to the quadrupole strength and viceversa.

We find that the barrier distributions for both cases show some differences, but probably not enough to open the possibility of clearly distinguishing the two situations. It would depend on the strength of the octupole deformation and the experimental accuracy available on each case. However, it will be quite interesting to extend the present analysis to other mass regions with large octupole deformations.

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