Analysis of spontaneous fission using quantum phase transition

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Abstract

A systematic study of quantum phase (i.e., nuclear shape) transition has been carried out from the standpoint of spontaneous fission. The quantum phase transition is defined by the ratio of relative excitation energies of I^{Π}=4^{+} to I^{Π}=2^{+} states between heavier and lighter fission fragments and its extremum value fixes the most probable pair of fission fragments. This ratio provides an effective order parameter which is not only easy to measure, but also distinguishes between first and second order phase transitions and takes on a special value in the critical region. Its (i.e., the energy ratio) variation is mainly controlled by the relative inertia tensors of the correlated pair of fission fragment and is fully supported by our cranking mass parameter calculations based on the asymmetric two center shell model bases.

Once the fission fragment pair is governed by the quantum phase transition, its validity is tested by F-spin selection rule that is based on valence nucleons which are responsible for determining the nuclear shape transition. It implies that if a pair of conjugate fission fragments together with appropriate neutron emission have total F-spin equal to $\frac{1}{2}$ with projections $F_0 = \pm\frac{1}{2}$ then and only then the fission proceeds, provided both the valence shell nucleons in either of the fission fragments are treated as particles like and is valid for the even-even decay modes. The goodness of F-spin selection rule extends further to extract all the allowed pairs of neutron-rich fission fragments. The validity of F-spin selection rule has been tested in various decay modes of spontaneous fission and seems to be a milestone in deciding the appropriate decay channels. These findings have important consequences in the formation and discovery of drip-line exotic nuclei.

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