Critical-Point Structure in Finite Nuclei *

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The study of shape changes in nuclei, as a prototype of quantum phase transitions in a finite system, is at present a frontier in nuclear structure research. Recently, it has been recognized that such shape-phase transitions are amenable to analytic descriptions at the critical points [1,2]. The importance of these analytic benchmarks of criticality lies in the fact that they provide a classification of states and analytic expressions for observables in regions where the structure changes most rapidly. For nuclei these benchmarks were obtained in the geometric framework of a Bohr Hamiltonian for macroscopic quadrupole shapes. In particular, the E(5) [1] (X(5) [2]) benchmark is applicable to a second- (first-) order shape-phase transition between spherical and deformed γ-unstable (axially-symmetric) nuclei. Empirical evidence of these benchmarks have been presented [3,4]. An important issue concerning phase transitions in real nuclei is the role of a finite number of nucleons. This aspect can be addressed in the algebraic framework of the interacting boson model (IBM) [5] which describes low-lying quadrupole collective states in nuclei in terms of a system of N monopole and quadrupole bosons representing valence nucleon pairs. The three dynamical symmetry limits of the model: U(5), SU(3), and O(6), describe the dynamics of stable nuclear shapes: spherical, axially-deformed, and γ-unstable deformed. Phase transitions for finite N are studied by an IBM Hamiltonian involving terms from different dynamical symmetry chains [6]. Many such studies (*e.g.* [7-10]) show that although in finite systems the discontinuities at the critical point are smoothed out, features of the phase transition persist even at moderate values of N. The finite-N critical Hamiltonian is determined by the structure of an intrinsic energy surface, $E(\beta, \gamma)$, obtained by the method of coherent (intrinsic) states [6,11]. Normally, the quadrupole shape parameters in the intrinsic state, characterizing the equilibrium shape of a given Hamiltonian, are chosen as the global minimum of $E(\beta, \gamma)$. This is a standard variational procedure for a Hamiltonian describing nuclei with rigid shapes, for which the global minimum is deep and well localized. However, as we show in the present contribution, near the critical point of a phase transition an alternative procedure is required. For an $E(5)$-like second-order phase transition, the relevant energy surface is γ-independent and flat-bottomed. The large fluctuations in β can be taken into account, in a finite system, by means of an effective β-deformation determined by minimizing the energy surface after projection onto the appropriate $O(5)$ symmetry [8]. For a $X(5)$-like first-order phase transition the intrinsic energy surface has two degenerate minima separated by a low barrier. The effective deformation is determined by minimizing an $L = 0$ projected energy surface combined with two-level mixing [10]. In both cases wave functions of a particular analytic form are used to derive finite-N estimates for energies and quadrupole rates at the critical point.

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