Prediction of Exotic Deformations in the Generalized Differential Equation Model for B(E2)↑ and E2

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Introduction

The two physical quantities namely, the reduced electric quadrupole transition probability B(E2)↑ for the transitions from the ground state to the first 2^+ state and the corresponding excitation energy E2 of even-even nuclei play very decisive role[1] in identifying occurrences of increased collectivity. The resulting quadrupole deformation parameters β_2 and the ratio of β_2 to the Weisskopf single-particle $\beta_{2(sp)}$ derived from them significantly help in this regard. Hence the study of these two physical quantities B(E2)↑ and E2 has been under constant investigation both by experimentalists and theorists. In this regard our recently developed differential equation model[2–4] for B(E2)↑ and E2 can be exploited for possible existence of exotic deformations in the exotic regions of the nuclear chart.

The Generalized Differential Equation Model

According to this model, the value for both these quantities for a given even-even nucleus are expressed in terms of their derivatives with respect to the corresponding neutron and proton numbers N,Z as

$$C[N,Z]/A = \frac{1}{2}[(1+\beta)\Big(\partial C/\partial N\Big)_Z + (1-\beta)\Big(\partial C/\partial Z\Big)_N], \quad (1)$$

This relation (1) connects both B(E2)↑ and E2 of a given nucleus with their partial derivatives with respect to the neutron and proton numbers N and Z. Then using the usual either forward or backward definitions for both the derivatives appearing in the equation (1), directly yields the following two recursion relations in C, each connecting three neighboring even-even nuclei. These are

$$C[N,Z] = \frac{N}{A-2}\,C[N-2,Z] + \frac{Z}{A-2}\,C[N,Z-2], \quad (2)$$

$$C[N,Z] = \frac{N}{A+2}\,C[N+2,Z] + \frac{Z}{A+2}\,C[N,Z+2]. \quad (3)$$

These two relations are exploited to obtain the unknown values of the neighboring isotopes from the known data base. Again each of them can be rearranged in three different ways to generate six alternate values for a given nucleus, the mean of which is taken as the predicted value.

For computing explicitly the value of deformation, we calculate the quadrupole deformation parameter β_2 from B(E2)↑ using the standard model-dependent relation

$$\beta_2 = (4\pi/[3Zr_0^2A^{2/3}])[B(E2)\uparrow/e^2]^{1/2}, \quad (4)$$

and also the intrinsic electric quadrupole moment Q_0 in units of b given by

$$Q_0 = \left[\frac{16\pi}{5}\frac{B(E2)\uparrow}{e^2}\right]^{1/2}. \quad (5)$$

Here r_0 is the usual nuclear radius parameter taken for compilation of such data as 1.2 fm.

Calculations and Results

Our calculation procedure uses the available experimental data[5, 6] in predicting values

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of the two physical quantities B(E2)↑ and E2 both for the known as well as for the hitherto unknown even-even nuclides. The predictions made in the first generation thus obtained for the unknown, are again used along with the known data in the second step to generate the next generation predictions and so on.This procedure is continued to reach out more and more neighbouring regions of nuclear chart. Our present calculations have yielded hitherto unknown B(E2)↑ data of 278 adjacent even-even isotopes and E2 values of 175 isotopes apart from for those of the known data set in the β-stable region spanning from Z= 8 to 100. These predicted data are again used to calculate the deformation parameters β_2 using Eqs.(4). One may note that its value beyond 0.3 for a given nucleus is considered to reflect large deformation.

Critical analysis of the values of the B(E2)↑ and E2 data obtained in our model along with those of the deformation parameters β_2 and Q_0 convincingly support possible existence of large collectivity for the nuclides $^{30,32}Ne$, ^{34}Mg, ^{60}Ti, $^{42,62,64}Cr$, $^{50,68}Fe$, $^{52,72}Ni$, $^{72,70,96}Kr$, $^{74,76}Sr$,$^{78,80,106,108}Zr$, $^{82,84,110,112}Mo$, ^{140}Te,^{144}Xe, ^{148}Ba, ^{122}Ce, $^{128,156}Nd$, $^{130,132,158,160}Sm$ and $^{138,162,164,166}Gd$ whose values of β_2 are found to exceed 0.3 and even 0.4 in some cases. The quadrupole deformation parameter β_2 for all these nuclei mostly exceeds 0.3 and even lies in the range 0.45-0.55 for some of them like $^{30,32}Ne$, ^{34}Mg, ^{60}Ti, ^{62}Cr, $^{72,70,96}Kr$, $^{74,76}Sr$,$^{106,108}Zr$ and ^{82}Mo. Such large collectivity is well supported by the corresponding relatively smaller values of the supplementary physical quantity, namely, the excitation energy E2. The E2 values mostly lie in the range 0.35-1.4 MeV for these nuclei in the low- and medium-mass region, while the same in the heavy-mass region lie in the range 0.07-0.5 MeV. Even some of the available experimental data in this regard do lie in the range 0.7-1.1 MeV.

Our prediction of strong deformation in case of $^{30,32}Ne$, ^{34}Mg, ^{60}Ti, $^{62,64}Cr$ and ^{68}Fe also agree with the experimental observations[7–10] supporting the existence of the "Islands of Inversion" caused by breaking of the N=20 shell-closure by the intruder states from the pf-shell and N=40 sub-shell closure by the intruder states from the gd-shell respectively. Thus such agreement with the experimental findings in the medium-low and medium mass nuclei in the exotic n-rich regions have made us to conjecture the existence of another "Island of Inversion" in the heavy-mass region possibly caused by breaking of the N=70 sub-shell closure by the intruder states from the hfp-shell as we find strong deformation for the nuclides ^{108}Zr and ^{112}Mo. Thus it appears that the existence of such "Islands of Inversion" in the exotic n-rich regions of the nuclear chart may be a general feature of nuclear dynamics waiting to be explored by future experiments. In fact, analysis[11] of the two-neutron separation energy systematics derived from mass predictions[11] in the INM model of atomic nuclei supports the existence of such islands in the heavy-mass region.

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