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**GLOBAL SET OF QUADRUPOLE DEFORMATION PARAMETERS
FOR EVEN-EVEN NUCLEI***

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S. Raman and C. W. Nestor, Jr.

Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831

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Global Set of Quadrupole Deformation Parameters for Even-Even Nuclei

S. Raman and C. W. Nestor, Jr.

Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

Abstract

We have completed a compilation of experimental results for the reduced electric quadrupole transition probability $[B(E2)\uparrow]$ between the 0^+ ground state and the first 2^+ state in even-even nuclei. This compilation together with certain simple relationships noted by other authors can be used to make reasonable predictions of unmeasured $B(E2)\uparrow$ values. The quadrupole deformation parameter β_2 immediately follows, because β_2 is proportional to $[B(E2)\uparrow]^{1/2}$.

We have collected experimental results for the reduced electric-quadrupole transition probability, $B(E2)\uparrow$, between the 0^+ ground state and the first 2^+ state in even-even nuclides [1]. These $B(E2)\uparrow$ values represent rather basic nuclear information complementary to our knowledge of the energies of low-lying levels in these nuclides. Generally larger than expected from the single-particle model, they have emphasized the widespread occurrence of quadrupole distortions in nuclides.

Fig. 1. Energy of the first-excited 2^+ state.

Our starting point was a previous $B(E2)\uparrow$ compilation [2], which contained 476 measured $B(E2)\uparrow$ values from 133 references leading to adopted $B(E2)\uparrow$ values for 155 nuclides. The current compilation contains 1765 entries from 793 references, leading to adopted $B(E2)\uparrow$ values for 281 nuclides. The energies of the first 2^+ states are now known for 457 nuclides. An overall view of the data in this compilation is shown graphically in Figs. 1 and 2.

Assuming a uniform charge distribution out to the distance $R(\theta, \phi)$ and zero charge beyond, the quadrupole deformation parameter β_2 is related to $B(E2)$ by the formula

$$\beta_2 = (4\pi/3ZR_0^2) [B(E2)\uparrow/e^2]^{1/2}. \quad (1)$$

We have taken R_0 to be $1.2 A^{1/3}$ fermis and the single-particle $\beta_{2(sp)}$ to be $1.59/Z$.

For nuclides without an experimentally determined $B(E2)\uparrow$ value, a reasonable prediction based on systematics can be obtained by adopting the approaches suggested by GRODZINS [3]; HAMAMOTO [4]; ROSS and BHADURI [5]; PATNAIK, PATRA, and SATPATHY [6]; and CASTEN [7]. We have first tested these approaches with the data in our compilation. In general, predictions of $B(E2)\uparrow$ values for nuclei off the stability line can then be made to an accuracy of $\pm 25\%$. Such predictions can be used to deduce systematic trends in deformation as was done recently [8] in the case of the Ce, Nd, Sm, and Gd isotopes.

Fig. 2. Reduced transition probability, $B(E2)\uparrow$.

GRODZINS [3] noted first that the γ -ray mean life τ_γ was approximately proportional to E^{-4} , where E is the energy of the $2^+ \rightarrow 0^+$ transition. He then suggested the following empirical relationship (τ_γ in psec and E in keV):

$$\tau_\gamma \approx 3.33 \times 10^{13} E^{-4} Z^{-2} A . \quad (2)$$

Our equivalent plot is shown in Fig. 3. A least-squares fit to the current data yields

$$\tau_\gamma \approx 5.96 \times 10^{10} E^{-3.6} Z^{-8.4} A^{7.1} . \quad (2)$$

Fig. 3. Gamma-ray mean life as a function of E . This plot is similar to Fig. 2 of Ref. [2].

HAMAMOTO [4] plotted the quantity $[\beta_2/\beta_{2(sp)}]/N_p N_n$ as a function of Z , where the valence number of protons (neutrons) N_p/N_n is defined as the number of particles below midshell and the number of holes past midshell. She noted that the above quantity was roughly constant over the entire mass region (both spherical and deformed) except for the regions near closed shells. Our equivalent plot is shown in Fig. 4.

After defining $F(N,Z) = [E \times B(E2)]^{-1}$, ROSS and BHADURI [5] found that the value of $F(N,Z)$ for the anchor N,Z nucleus is related to the values for the three neighboring nuclides by the difference equation

$$F(N,Z) + F(N+2,Z+2) - F(N+2,Z) - F(N,Z+2) \sim 0 . \quad (4)$$

PATNAIK, PATRA, and SATPATHY [6] further noted that a similar difference equation is also satisfied by E , the energy of the first 2^+ state, and by the reduced transition probability $B(E2)^\dagger$.

$$E(N,Z) + E(N+2,Z+2) - E(N+2,Z) - E(N,Z+2) \sim 0 . \quad (5)$$

$$B(E2)[N,Z] + B(E2)[N+2,Z+2] - B(E2)[N+2,Z] - B(E2)[N,Z+2] \sim 0 . \quad (6)$$

Fig. 4. Quadrupole deformation parameter, β_2 divided by $\beta_{2(sp)}$ ($= 1.59/Z$) as a function of Z . This plot is similar to Fig. 2 of Ref. [4].

We have tested the difference equations (4) and (6) with the data in our compilation. The results are shown in Fig. 5. Except near closed shells, both approaches yield deviations of the difference equations from zero that are typically $\pm 25\%$. Even though they were proposed more than a decade ago, these difference equations have not received the attention that they probably deserve.

Fig. 5. Test of the difference equations of (a) ROSS and BHADURI [5]—see Eq. (3), and (b) PATNAIK, PATRA, and SATPATHY [6]—see Eq. (5). The deviation from zero of either Eq. (3) or Eq. (5) is divided by the average of the four values, expressed as a percentage, and plotted along the ordinate.

Finally, CASTEN [7] has recently attempted a systemization of a considerable amount of spectroscopic data, especially in the five nuclear transition regions [$A \approx 100$, $A \approx 130$, $A \approx 150$ ($Z < 64$), $A \approx 150$ ($Z \geq 64$), and $A \approx 190$] in terms of the valence nucleon product $N_p N_n$. He has shown that the $B(E2)$ values in the $A \approx 150$ ($Z \leq 64$), $A \approx 150$ ($Z \geq 66$), and $A \approx 100$ regions fall on relatively smooth curves. Some of CASTEN's conclusions are based on *a posteriori* counting of valence nucleons. Separating the $A \approx 150$ region into $Z \leq 64$ and $Z \geq 66$ parts is just one example, for which he has provided ample justification in terms of a subshell closure. Our equivalent plot for the $A \approx 100$ region is shown in Fig. 6. We use his prescription that if $N < 60$, the proton shell is 38 to 50, and if $N \geq 60$, the proton shell is 28 to 50.

Fig. 6. $B(E2)$ systematics for the $A \approx 100$ region. This plot is similar to Fig. 25 of Ref. [7]. The curve is drawn to guide the eye.

Returning to HAMAMOTO's [4] original idea, we have plotted in Fig. 7 the quantity $\beta_2/\beta_{2(sp)}$ vs $N_p N_n$ for the isotopes of eight even- Z elements with $64 < Z < 82$. The curve drawn there accounts rather well for 61 data points.

We have shown that there are several ways of systematizing the $B(E2)$ values and the related quantities τ_γ and $\beta_2/\beta_{2(sp)}$. It is relatively straightforward then to arrive at a global set of recommended $B(E2)$ and β_2 values by combining measured values with predictions. We are currently in the process of arriving at such a set.

Fig. 7. Quadrupole deformation parameter, β_2 , divided by $\beta_{2(sp)}$ ($= 1.59/Z$) as a function of the quantity $N_p N_n$ for even- Z isotopes in the $64 < Z < 82$ region. The curve is drawn to guide the eye.

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