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Electric Quadrupole Moment of Even-Even Nuclei

1 Introduction

A nucleus with unpaired nucleons will have a charge distribution which results in an electric quadrupole moment. Properties of these nuclei with several nucleons outside a closed shell are described in a first approximation by their interactions with an inert core plus other nucleons which can interact with the core and mutually with each other via a residual interaction [1], [2]. The allowed nuclear energy levels are shifted unequally due to the interaction of the nuclear charge with an electric field supplied by the non-uniform charge distribution [3]. One of the main cause of nuclear deformation is made apparent by connection with electric quadrupole moments [4], together with the low energy spectrum contains sequences of rotational states varying with quantized angular momentum [5].

2 Nuclear Electric Quadrupole Moment

An even-even nucleus with mass M in the region $150 < A < 190$ can rotate about an axis at right angles to the axis of symmetry, forming an axiallysymmetric rigid rotator with uniform mass distribution [6], these rotations can only be observed in nuclei with non-spherical equilibrium [7], [8]. The energy spectrum of such rotator with moment of inertia $\mathcal{I}$ and quantized angular momentum I is given by $E_I = (\sim^2/2\mathcal{I})I(I+1)$ [9], with the moment of inertia is taken to be a classical spheriod of rotation, $\mathcal{I} = \frac{1}{5}M(a^2 + c^2)$, where a denotes the distance along the axis of symmetry and c is the distance along the axis perpendicular to the axis of symmetry. The quantum analogue of the moment of inertia can be obtained from the relation, $(\sim^2/2)[dE/dI(I+1)]^{-1}$ [10]. By definition the intrinsic quarupole

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moment, $\int d\tau\rho r^2(3\cos^2\theta - 1)$ [11], which is evaluated for the case of an axiallysymmetric rigid rotator of total number of charges Z uniformly distributed,
$Q_0 = \frac{2}{5}Z(a^2 - c^2)$. For well deformed axially symmetric nuclei, the measured quadrupole moment Q can be related to the intrinsic quadrupole moment, $Q = Q_0[3K^2 - I(I + 1)]/[[(2I + 1)(I + 1)]$ [12], where K is the projection of total nuclear spin I onto the axis of symmetry, $K = 0$ for even-even axially symmetric nuclei [13]. Under the assumption that the deformation is volume preserving, $a^2 \propto 1/c$, the quadrupole moment for a number of deformed eveneven nuclei can be computed by using the measured energy of first excited state E_{2^+}, corresponding to ground state rotational band $K = 0$. Values so obtained are shown in Table 1.

Table 1: The units of the ground state energy E_{2^+} is given in (keV), sphroid volume a^2c in (fm^3), and quadrupole moment $Q(E_{2^+})$ in (b). The observed values listed in last column with no sign if it was not determined by experiment [14].

Nucleus	E_{2^+}	$a2c$	Q_{cal}	Q_{exp}	Nucleus	E_{2^+}	$a2c$	Q_{cal}	Q_{exp}
$^{154}_{64}$Gd	123	193	−1.80	−1.82(4)	$^{170}_{70}$Yb	84	218	−2.20	2.1(4)
$^{156}_{64}$Gd	89	254	−1.96	−1.93(4)	$^{174}_{70}$Yb	77	267	−2.18	2.1(3)
$^{158}_{64}$Gd	80	271	−2.00	−2.01(4)	$^{176}_{70}$Yb	82	221	−2.22	2.2(4)
$^{160}_{64}$Gd	75	240	−2.08	−2.08(4)	$^{176}_{72}$Hf	88	242	−2.04	−2.01(2)
$^{160}_{66}$Dy	87	243	−1.89	1.8(4)	$^{178}_{72}$Hf	93	266	−2.02	−2.02(2)
$^{164}_{66}$Dy	73	574	−2.08	−2.02(15)	$^{182}_{74}$W	100	217	−2.11	−2.1(4)
$^{166}_{68}$Er	81	132	−2.70	−2.7(9)	$^{184}_{74}$W	111	202	−1.92	−1.9(2)
$^{170}_{68}$Er	79	274	−1.91	−1.9(2)	$^{186}_{74}$W	123	189	−1.61	−1.6(3)

3 Conclusion

We conclude that in the framework of the nuclear collective model, the quadrupole moments of a number of permanent deformed nuclei are calculated successfully. The obtained values of electric quadrupole moment show good agreement compared with earlier suggested references. Spheroid radii of deformed nuclei in question are also obtained. We noticed small changes in volume of listed nuclei either are inflated or deflated when compared with the size of their constituent nucleons. More accuracy in calculations can be achieved via nuclear volume, on the other hand, further nuclear parameters can be determined straight forward.