J. Nucl. Phys. Mat. Sci. Rad. A. Vol. 9, No. 2 (2022), pp.177–185

CHITKARA

Journal of Nuclear Physics, Material Sciences, Radiation and Applications

Journal homepage: https://jnp.chitkara.edu.in/

Systematics of Reduced $B(E3)$ Transition Probabilities and Configurations of Octupole (ΔI=3) Isomers in Mass A∼200 Region

P S Rawat[1*], S Kumar[1], H Chutani[2], and M Goyal[3]

[1] *Department of Physics & Astrophysics, University of Delhi, Delhi-110007*

[2] *Department of Physics, Hansraj College, University of Delhi, Delhi-110007*

[3] *Department of Physics, Shyam Lal College, University of Delhi, Delhi-110007*

*prernasinghrawat4@gmail.com (Corresponding Author)

ARTICLE INFORMATION

Received: February 04, 2022
Accepted: May 30, 2022
Published Online: June 20, 2022

Keywords:
Isomeric states, $E3$ decay, reduced $B(E3)$ transition probability, configurations

DOI: 10.15415/jnp.2022.92026

ABSTRACT

Background: Strong octupole correlations are observed in mass A∼200 region giving rise to a number of isomeric states decaying via $E3$ type of transition involving $\Delta j = \Delta l = 3$ interacting orbitals. Particularly, the $g_{9/2}$ and $j_{15/2}$ neutron orbitals or the $f_{7/2}$ and $i_{13/2}$ proton orbitals are predicted to be involved in these enhanced $E3$ decays.

Purpose: To report the systematics of reduced $B(E3)$ transition probabilities and configurations of isomers that decay via $E3$ transition and also to compare these isomers based on their structures such as **even-even, even-odd, odd-even and odd-odd.**

Methods: The data for a total of 235 isomers is collected from the ENSDF/XUNDL Database of NNDC. The reduced $B(E3)$ transition probabilities are evaluated and compiled using the available data on half-life and branching ratios of the isomeric states having $E3$ decay. In about 25 cases, the new adopted values of half-lives are obtained to get the $B(E3)$ transition probabilities by RULER program.

Results: A systematic variation in the reduced $B(E3)$ transition probability is discussed as a function of neutron and proton number to see the contribution/effect from the core particles. An enhancement is seen for the isomeric states involving the $g_{9/2}$ and $j_{15/2}$ neutron orbitals or the $f_{7/2}$ and $i_{13/2}$ proton orbitals.

Conclusions: The enhanced $E3$ transition rates are observed in nuclei having configurations with octupole effects such as $i_{13/2} \rightarrow f_{7/2}$ and $j_{15/2} \rightarrow g_{9/2}$. The $E3$ transitions with $i_{13/2} \rightarrow f_{5/2}$ are having lowest $B(E3)$ (10^{-4} to 10^{-5} W. u.) values.

1. Introduction

Nuclear isomers have been used as a great tool to understand the nucleon configuration in nuclear structure [1]. Nuclear isomers are already identified throughout the nuclear chart [2] and are the metastable states having life-time equal to or longer than 1 *ns* confronting some hindrance in their gamma-decay as proposed by Weizsäcker in 1936 [3]. The hindrance can be caused by many factors such as (i) a large change in angular momentum giving rise to spin isomers [4-6] and are the most usual isomers found across the nuclear chart decaying via transitions of higher multipolarity; (ii) a large change in K quantum number (ΔK) probably greater than the multipole order of gamma-ray (λ) and result in a high degree of forbiddenness producing K-isomers [5, 6]. Also, shape isomers [5, 7] are reported in many nuclei due to hindrance resulting from the difference in their shape. Further, if a heavy nucleus is trapped in the secondary minimum [8] which can decay via spontaneous fission [9], it is called fission isomer [5]. The seniority isomers [5] are resulted due to gamma-decay between the states of same seniority. The detailed works about different isomers have already been published [2, 10] which provide an access to the experimental data on their properties such as excitation energies, spin, etc.

In mass A∼200 region, a large number of isomers are observed to decay via enhanced $E3$ gamma-ray transition. These isomers are mostly seen as high-spin isomers that have their origin in strong octupole effects [11-14] and are also termed as octupole isomers. The octupole-octupole interaction couples the single particle orbitals of opposite parity having Δj=Δl=3 and the interaction strength increases as the energy difference between these levels decreases when these orbitals are very close to the Fermi surface. The particle numbers *34, 56, 88,* and *134* lie just above the closed shell where octupole correlations result due to coupling between $1g_{19/2}$ and $2p_{3/2}$, $1h_{11/2}$ and $2d_{5/2}$, $1i_{13/2}$ and $2f_{7/2}$ & $1j_{15/2}$ and $1g_{9/2}$ orbitals, respectively. As the energy spacing between orbitals giving rise to octupole effects decreases with increasing

©Author(s) 2022. This article is published with open access at https://jnp.chitkara.edu.in.
ISSN No.: 2321-8649(Print) ISSN No.: 2321-9289(Online); Registration No. : CHAENG/2013/51628

mass number [11], the strongest octupole correlations are predicted theoretically and observed experimentally in isotopes of Z=84−90 in terms of simplex bands [11], octupole vibrational states [15] and octupole isomers [12].

2. Methodology and Policies

2.1 Methodology for Data Compilation/ Evaluation

In the present work, systematic variations of the octupole isomers are presented for (i) variation of the reduced $B(E3)$ transition probabilities [16] as a function of proton/neutron numbers and (ii) their corresponding configurations resulting from the compilation/evaluation [17]. For the extraction of experimental data, the ENSDF (Evaluated Nuclear Structure Data Files) Database [18] and the XUNDL (Experimental Unevaluated Nuclear Data List) Database [19] available at NNDC (National Nuclear Data Centre) [20] are used which contains the information about the measured data. The spin-parity, half-lives, and reduced $B(E3)$ transition probabilities considered for the present compilation are the adopted values given by the evaluators if no information after the cutoff date of ENSDF is available. To consider all data, the unevaluated measurements are also checked till 31st January 2022 for any new half-life, branching ratio, or reduced transition probability measurement. If new measurement(s) is/are reported in the XUNDL database which is/are not considered in ENSDF data, the new value of half-life is evaluated for such cases by considering both new and old measurements. For the evaluation purpose, various data evaluation programs such as FMTCHK [21], GTOL [22], BrIcc [23, 24], RULER [25] are used to get the final evaluated value of reduced $B(E3)$ transition probabilities.

For every octupole isomer considered for the present work, the configurations in terms of neutron and proton single particle orbitals [26] of initial and final states involved in the $E3$ decay branch are also tabulated from various references in NSR Database [27]. In present work, the systematics of reduced $B(E3)$ transition probabilities are reported for 235 isomeric states which are compiled in Ref. [17], out of which about *25* are evaluated by considering the new measurement(s) from the XUNDL data. The data is presented in four groups namely even-even (*80*), even-odd (55), odd-even (55), and odd-odd (45) nuclei having the proton number 80 < Z < 92 and having neutron 98 < N < 130. The main component of particle transitions or core excitation are also listed for these isomers.

2.2 Policies

The policies used in the compilation work are:

- Different nuclei are compiled in the reference [17] in the increasing order of their atomic number (Z). For a given element, the isotopes are arranged in increasing order of their neutron number (N).
- All $E3$ decays are considered in this work, irrespective of whether they are pure or mixed. The mixed transitions are specified in [17] by superscript *. Most of them have half-life greater than *1 ns* except few cases having half-life in *ps* or *fs* range decaying via $E3$ transitions.

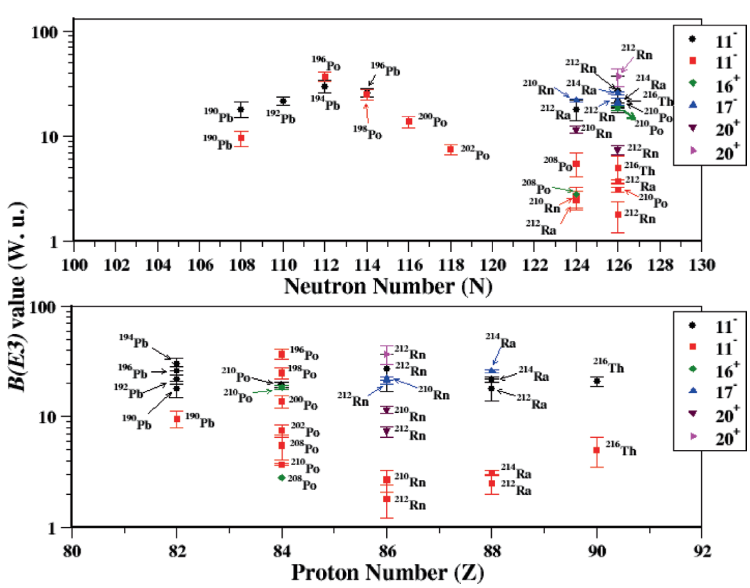

Figure 1: The variation of reduced $B(E3)$ transition probabilities for isomeric states in even-even nuclei as a function of proton and neutron number (In ^{208}Po, the shown value for 16^+ isomer is the lower limit for $B(E3)$ value).

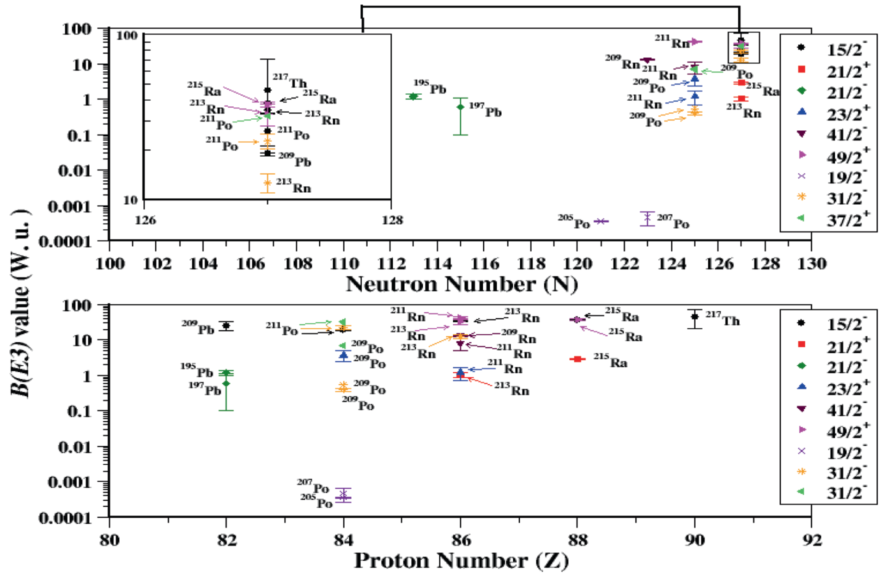

Figure 2: The variation of reduced $B(E3)$ transition probabilities for isomeric states in even-odd nuclei as a function of proton and neutron number (the given values for $37/2^{+}$ isomer in $^{209,211}Po$ are the lower limit on $B(E3)$ value).

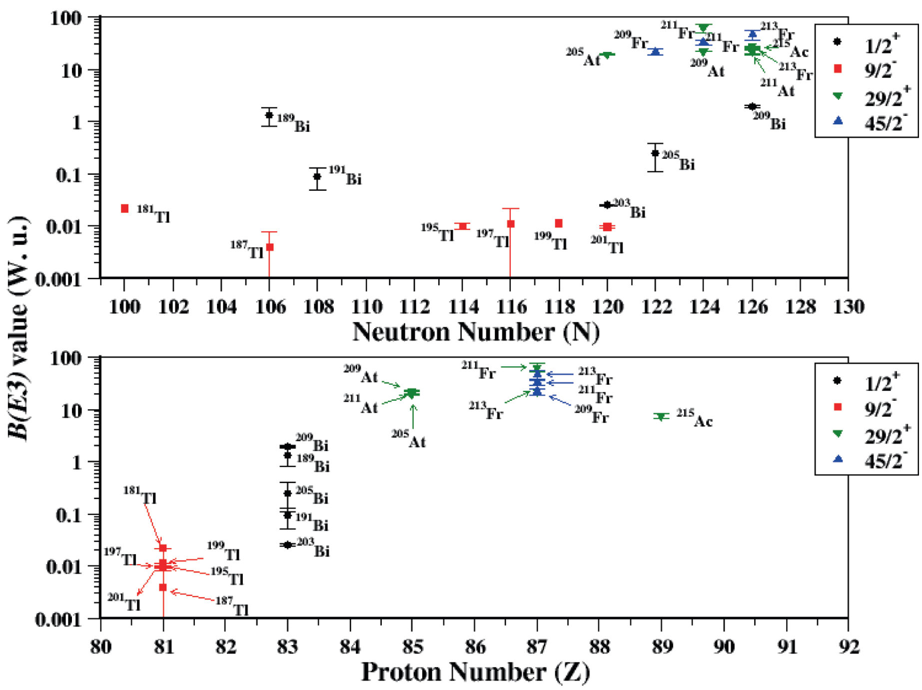

Figure 3: The variation of reduced $B(E3)$ transition probabilities for isomeric states in odd-even nuclei as a function of proton and neutron number.

For the present study, the systematics of the reduced $B(E3)$ transition probabilities and configurations are presented where the isomeric state occurs more than *2* times and has same type of spin and configurations. Further, the well-known vibrational states namely 3^{-} are not considered. The data on reduced $B(E3)$ transition probabilities in Weisskopf units (W. u.) are plotted as a function of neutron and proton number in Fig. 1-4 for even-even, even-odd, odd-even, and odd-odd nuclei respectively. The summary of the range of reduced $B(E3)$ transition probabilities and particle transitions involved are listed in Table 1.

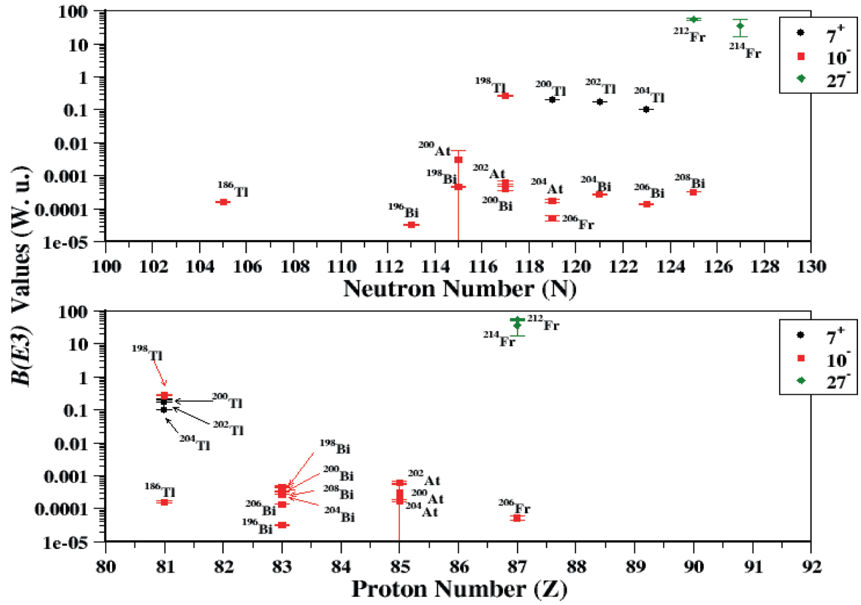

Figure 4: The variation of reduced *B*(*E3*) transition probabilities for isomeric states in odd-odd nuclei as a function of proton and neutron number.

Table 1: Experimentally observed range of reduced *B*(*E3*) transition probabilities and particle transitions (as given in the references) involved in *E3* decay of isomeric states in mass *A*~*200* region.

Group	Isomer	*B(E3)* value range (W. u.)	Particle Transition	Nuclei
Even-even	11-	15-35	$\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$	^{190}Pb [28], ^{192}Pb [29], ^{194}Pb [30], ^{196}Pb$^{\#}$ [31], ^{210}Po [32], ^{212}Rn [33], ^{212}Ra [34], ^{214}Ra [35], ^{216}Th [36]
		1-37	$\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$	^{190}Pb [28], ^{196}Po [37], ^{198}Po [38], ^{200}Po [39], ^{202}Po [40], ^{208}Po [41], ^{210}Po [32], ^{210}Rn [42], ^{212}Rn [33], ^{212}Ra [34], ^{214}Ra [35], ^{216}Th [36]
	17^{-}	21-26	$\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$	^{210}Rn [42], ^{212}Rn [33], ^{214}Ra [35]
	20^{+}	7-12	$\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$	^{210}Rn [43], ^{212}Rn [44]
		37	$\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$	^{212}Rn [44]
	16^{+}	>2.8	$\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$	^{208}Po$^{\#}$ [41], ^{210}Po [32]
Even-odd	15/2^{-}	18-50	$\nu(j_{15/2}) \rightarrow \nu(g_{9/2})$	^{209}Pb [45], ^{211}Po [46], ^{213}Rn [47], ^{215}Ra [48], ^{217}Th [49]
	49/2^{+}	30-35	$\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$	^{211}Rn [50], ^{213}Rn [47], ^{215}Ra [48]
	21/2^{+}	1-3	$\nu(g_{9/2}) \rightarrow \nu(j_{15/2})$	^{213}Rn [47], ^{215}Ra [48]
	21/2^{-}	0.1-1.4	$\nu(i_{13/2}) \otimes 5^{-}(^{196}Pb) \rightarrow \nu(i_{13/2}) \otimes 2^{+}(^{196}Pb)$	^{195}Pb* [53], ^{197}Pb* [54]
	41/2^{-}	5-14	$\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$	^{209}Rn [51], ^{211}Rn [50]
	23/2^{+}	0.7-5	$\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$	^{209}Po [52], ^{211}Rn [50]
	37/2^{+}	>6.9	$\nu(j_{15/2}) \rightarrow \nu(g_{9/2})$	^{209}Po [52], ^{211}Po [46]

	$19/2^-$	$(3–5) \times 10^{-4}$	$\nu(f_{5/2}^{(-1)}) \rightarrow \nu(i_{13/2}^{(-1)})$	^{205}Po [55], ^{207}Po [55]
	$31/2^-$	11-25 (>0.54 for ^{209}Po)	$\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$	^{209}Po [52], ^{211}Po [46], ^{213}Rn [47]
Odd-even	$9/2^-$	$10^{-3} – 10^{-2}$	$\pi(h_{9/2}) \rightarrow \pi(d_{3/2})$	^{181}Tl$^{\#}$ [56], ^{185}Tl$^{\#}$ [57], ^{187}Tl [58], ^{193}Tl [59], ^{195}Tl [60], ^{197}Tl [59], ^{199}Tl [61], ^{201}Tl [62]
	$29/2^+$	18-28	$\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$	^{205}At [63], ^{209}At [64], ^{211}At [65], ^{211}Fr [66], ^{213}Fr [66], ^{215}Ac [67]
	$1/2^+$	0.01-0.3	$\pi(s_{1/2}) \rightarrow \pi(f_{7/2})$	^{189}Bi [68], ^{191}Bi [69], ^{203}Bi [70], ^{205}Bi [71], ^{209}Bi [72]
	$45/2^-$	20-65	$\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$	^{209}Fr [73], ^{211}Fr$^{\#}$ [66], ^{213}Fr [66]
	$3/2^+$	1-20	$3^- \otimes$ proton configurations	^{207}Bi [74], ^{209}Bi [72]
Odd-odd	10^-	10^{-5}- 10^{-4}	$\nu(i_{13/2}) \rightarrow \nu(f_{5/2})$	^{186}Tl [79], ^{198}Tl [80] ^{196}Bi [81], ^{198}Bi [82], ^{200}Bi [83], ^{204}Bi [84], ^{206}Bi [84], ^{208}Bi* [85], ^{200}At$^{\#}$ [86] ^{202}At [86], ^{204}At [87], ^{206}Fr [86]
	7^+	0.1-0.3	$\pi(s_{1/2}) \otimes \nu(i_{13/2}) \rightarrow \pi(d_{3/2}) \otimes \nu(f_{5/2})$	^{200}Tl [88], ^{202}Tl [89], ^{204}Tl [90]
	27^-	35-55	$\nu(i_{13/2}) \rightarrow \nu(f_{7/2})$	^{212}Fr [66], ^{214}Fr [91]

$^{\#}$ The transitions for which the reduced $B(E3)$ transition probabilities are evaluated using RULER

* Mixed transitions

Results & Discussion

For comparison, the results on the $B(E3)$ values and configurations of $E3$ transitions are given in the Table *1* along with the references.

In even-even nuclei as shown in Fig. *1*, the 11^- isomer is observed in most of the nuclei. It is found to decay by two $E3$ branches, (i) $\pi(i_{13/2}) \rightarrow (f_{7/2})$ branch in $^{190,192,194,196}Pb$ [28-31], ^{210}Po [32], ^{212}Rn [33], $^{212,\,214}Ra$ [34, 35] and ^{216}Th [36] and (ii) a $\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$ branch in ^{190}Pb [28], $^{196,\,198,\,200,\,202,\,208,\,210}Po$ [37-41, 32], $^{210,212}Rn$ [42, 33], $^{212,214}Ra$ [34, 35] and ^{216}Th [36]. For ^{190}Pb, ^{210}Po, ^{212}Rn, $^{212,\,214}Ra$ and ^{216}Th nuclei both the branches are observed. The $\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$ branch showed an enhancement in the reduced $B(E3)$ transition probabilities (as shown in Fig. 1 in black color filled circle) with increasing neutron number whereas the reduced $B(E3)$ transition probabilities for $\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$ branch (as shown in Fig. 1 in red color filled square) are found to decrease with increasing neutron number. The enhancement in octupole collectivity for the $\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$ branch is attributed to the presence of the octupole $\Delta j = \Delta l = 3$ orbitals near the Fermi level. For $E3$ decay of 17^- isomer in $^{210,\,212}Rn$ [42, 43] and ^{214}Ra [35], the reduced $B(E3)$ transition probabilities are quite high and are arising from the $\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$ particle transitions.

In ^{210}Rn [43] and ^{212}Rn [44], the 20^+ isomer arising from the $\pi(h_{9/2}^2 i_{13/2}^2)$ configuration is seen and it decays to a state with $\pi(h_{9/2}^3 i_{13/2}^1)$ configuration, hence have $\pi(i_{13/2}) \rightarrow (h_{9/2})$ particle transition with reduced transition probability of order of *7-12 W. u.* (shown in Fig. 1 in magenta color filled down triangle). Another decay branch to $\pi(h_{9/2}^2 f_{7/2}^1 i_{13/2}^1)$ state from 20^+ isomer in ^{212}Rn[44] is also observed (shown in Fig. 1 in pink color filled right triangle) for which reduced $B(E3)$ transition probability is *37(4) W. u.* and hence again shows the effect of octupole interactions in terms of enhanced transition rates due to $\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$ transition. The $^{208,210}Po$ have 16^+ isomer, and found to decay via $B(E3) > 2.3$ *W. u.* for ^{208}Po [41] and 18.4^{+9}_{-9} *W. u* for ^{210}Po [32] respectively.

In Fig. 2, the isomeric states observed in even-odd nuclei in mass $A{\sim}200$ region and variation of their reduced $B(E3)$ transition probability as a function of N *&* Z are shown. For $15/2^-$ isomer in ^{209}Pb [45], ^{211}Po [46], ^{213}Rn [47], ^{215}Ra [48] and ^{217}Th [49], the $\nu(j_{15/2}) \rightarrow \nu(g_{9/2})$ interacting orbitals are responsible for the high octupole transition probability of order of *18-50 W. u.* which is found to increase with increasing contribution from proton core. This is expected as the *Ra-Th* region is known to have strong octupole admixtures. The $49/2^+$ isomer in $^{211,213}Rn$ [50, 47] and ^{215}Ra [48] is observed with $\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$ kind of particle transition with $B(E3)$ values varying between *30-35 W. u.* The $41/2^-$ isomer in ^{209}Rn [51] and ^{211}Rn [50]; $23/2^+$ isomers in ^{209}Po [52] and ^{211}Rn [50] & $31/2^-$ isomer in ^{209}Po [52], ^{211}Po [46] and ^{213}Rn [47] for which the $\pi(i_{13/2}) \rightarrow \pi(h_{9/2})$ kind of interaction is involved, the transition probabilities vary over a wide range from *1-23 W. u.* and are found to decrease with increasing proton number for all the cases. In ^{209}Po [52], two $31/2^-$ isomers are observed having different configurations. For isomer at 4265.4 *keV*, the $[\pi(i_{13/2}) \otimes \nu(g_{9/2}^{+1} p_{1/2}^{-2})] \rightarrow [\pi(h_{9/2}) \otimes \nu(i_{13/2}^{-1})]$ transition result in $B(E3)$ value of *0.40(4) W. u.* and the other at *4354.1 keV* with $\pi(i_{13/2}) \rightarrow (h_{9/2})$ transition has a lower limit of *0.54 W. u.* on $B(E3)$ value. In case of 21/2⁻ isomer in $^{195,197}Pb$ [53, 54], the *E3* transition results from the single particle configurations having a $i_{13/2}$ neutron hole coupled to the 5⁻ and 2⁺ states of the respective core. The 37/2⁺ isomer in $^{209,211}Po$ [52, 46] is having $\nu(j_{15/2}) \rightarrow \nu(g_{9/2})$ octupole kind of particle transition with lower limits of *6.9* and *32 W. u.*, respectively. For 19/2⁻ isomer in ^{205,207}Po [55] and 21/2⁺ isomer in ^{213}Rn [47] and ^{215}Ra [48], the configurations are $\nu(f_{5/2}^{(-1)}) \rightarrow \nu(i_{13/2}^{(-1)})$ and $\nu(g_{9/2}) \rightarrow \nu(j_{15/2})$ and have low $B(E3)$ values of order of 10^{-4} *W. u.* for 19/2⁻ isomer and *1-3 W. u.* for 21/2⁺ isomer.

For odd-even nuclei, the reduced $B(E3)$ transition probabilities are plotted as a function of neutron and proton number in Fig. 3. The 9/2⁻ isomer is observed in $^{181,185,187,193,195,197,199,201}Tl$ [56-62] having $\pi(h_{9/2}) \rightarrow \pi(d_{3/2})$ single particle configurations showing *low* $B(E3)$ values. For ^{193}Tl, the gamma-ray energy is not specifically known and hence the reduced $B(E3)$ transition probability varies from *0.005 W. u.* for E_γ = 13 *keV to 0.14 W. u.* for E_γ=*2.2 keV* (not shown in Fig. 3). The 29/2⁺ isomer observed in $^{205,209,211}At$ [63-65], $^{211,213}Fr$ [66], ^{215}Ac [67], the reduced $B(E3)$ transition probabilities are found to vary between 18-28 *W. u.* showing signature of strong octupole effects. In case of 1/2⁺ isomer identified in $^{189,191,203,205,209}Bi$ [68-72], reduced $B(E3)$ transition probability is found to increase while approaching *N=126* neutron number from mid shell. The 45/2⁻ isomer in $^{209,211,213}Fr$ [73, 66] are showing an enhancement in $B(E3)$ values with increasing neutron core contribution. The octupole vibrational state 3/2⁺ is also observed in $^{207,209}Bi$ isotopes [74, 72], due to coupling of 3⁻ state with $h_{9/2}$ proton. There are also 13/2⁺ isomeric states in $^{187,199,201,209}Bi$ [68, 69, 75-78] and ^{193}At [69], but their systematic variation cannot be discussed as no half-life measurements are done in case *of* $^{201,209}Bi$ and thus no $B(E3)$ values can be calculated. Also, no configurations are assigned for ^{193}At [69].

In the case of odd-odd nuclei, the reduced transition probabilities are plotted in Fig. 4. The 10⁻ isomers observed in $^{186,198}Tl$ [79, 80], $^{196,198,200,204,206,208}Bi$ [81-85], $^{200,202,204}At$ [86, 87] and ^{206}Fr [86] nuclei are having very low $B(E3)$ values for the *E3* decay branch. In ^{186}Tl, the decay is due to $\pi(h_{9/2}) \rightarrow \pi(s_{1/2})$ particle transition while in all other cases the $\nu(i_{13/2}) \rightarrow \nu(i_{5/2})$ particle transition is involved in the decay. The 7⁺ isomer is observed in $^{200,202,204}Tl$ [88-90] isotopes having neutron number *N*=119, 121, and 123. The configuration involved in its decay is $[\pi(s_{1/2})\otimes\nu(i_{13/2})] \rightarrow [\pi(d_{3/2})\otimes\nu(f_{5/2})]$ which is purely single particle and hence again the reduced $B(E3)$ transition probabilities are quite low. The 27⁻ state in ^{212}Fr [66] and ^{214}Fr [91] are having quite high $B(E3)$ values due to the involvement of $\pi(i_{13/2}) \rightarrow \pi(f_{7/2})$ octupole configuration in their *E3* decay branch. There are also 14⁻ isomer in ^{214}Fr [91, 92], ^{210}Bi [93, 94] and 22⁻ isomer in $^{210,212}At$ [95, 96] having $\nu(j_{15/2}) \rightarrow \nu(g_{9/2})$ configurations. As there is no half-life measurement for 14⁻ state in ^{210}Bi and 22⁻ state in ^{210}At, so no reduced transition probability values are calculated, but the expected values may be as high as 25^{+5}_{-5} *W. u.* for ^{214}Fr [91, 92] and 29^{+10}_{-6} *W. u.* for ^{212}At [96].

Conclusion

The systematics of the reduced $B(E3)$ transition probabilities are presented in mass *A*∼200 region as a function of proton and neutron number by considering the nuclear structure groups- even-even, even-odd, odd-even, and odd-odd. The particle transitions (as given in Table 1) involved in the *E3* isomeric decay are discussed to see the structural role on the reduced $B(E3)$ transition probabilities. The experimental data on reduced $B(E3)$ transition probabilities show an enhancement for the transitions involving the $g_{9/2}$ and $j_{15/2}$ neutron orbitals and the $f_{7/2}$ and $i_{13/2}$ proton orbitals and attributed to the octupole correlations in this mass region. The systematics provided the up to date information on *E3* decays in this mass region and the possibilities for existence of new isomeric states in mass *A*∼200 region which are not observed yet. In even-*Z* nuclei, the isotopes of *Po*, *Rn*, and *Ra* show the maximum enhancement in reduced $B(E3)$ transition probabilities. For odd-odd nuclei, the 10⁻ isomer arising from single particle configurations has large suppression in the reduced $B(E3)$ transition probabilities. It is seen that the intensity of the strongest decay branch in ENSDF for some of the transitions is listed without uncertainty which may result in the lower value of final uncertainties of reduced $B(E3)$ transition probabilities. Also, the life-time measurements are required for some of the observed isomers to complete the systematics of reduced $B(E3)$ transition probabilities. In future, the complete compilation will be published and will be extended to other mass regions. We will try to assign Nilsson configurations wherever not assigned and try to analyze the effect of deformation.

Acknowledgement

One of the authors (P. S. Rawat) acknowledges the financial assistance from UGG-DAE-KC. The financial support from research grant (IOE/FRP/PCMS/2020/27) under Faculty Research Programme (FRP) of Institute of Eminence(IOE), University of Delhi is also acknowledged.

Authorship Contribution

The contribution for the idea, execution, and compilation goes to Dr. Suresh Kumar and P. S. Rawat. The other two authors, H. Chutani and M. Goyal contributed in editing the content and finalizing the manuscript.

Funding

Funding from UGG-DAE-KC with project CRS/19/NP07/0918/0960 and research grant (lOE/FRP/PCMS/2020/27) under Faculty Research Programme (FRP) of Institute of Eminence (IOE), University of Delhi.

Declaration

It is an original data and has neither been sent elsewhere nor published anywhere.

References

[1] G. D. Dracoulis, Phys. Scr. T 1**52**, 014015 (2013). https://doi.org/10.1088/0031-8949/2013/T152/014015

[2] A. K. Jain, B. Maheshwari, S. Garg, M. Patial and B. Singh, Nucl. Data Sheet **128**, 1 (2015). https://doi.org/10.1016/j.nds.2015.08.001

[3] C. F. V. Weizsäcker, Naturewissenschaften **24**, 813 (1936). https://doi.org/10.1007/BF01497732

[4] P. Walker and G. Dracoulis, Nature, **399**, 35 (1999). https://doi.org/10.1038/19911

[5] A. K. Jain, B. Maheshwari and Alpana Goel, Nuclear Isomers: A Primer (Springer, chem, 2021), Edition 1. https://doi.org/10.1007/978-3-030-78675-5

[6] P. Walker and Z. Podolyák, Phys. Scr., **95**, 044004 (2020). https://doi.org/10.1088/1402-4896/ab635d

[7] Chin Fu Tsang and S. G. Nillson, Nucl. Phys. A **140**, 275 (1970). https://doi.org/10.1016/0375-9474(70)90326-X

[8] V. Metag, R. Repnow, P. Von Brentano, F. Dickmann and K. Dietrich, Phys. Lett. B **34**, 257 (1971). https://doi.org/10.1016/0370-2693(71)90597-1

[9] N. Schunck and L. M. Robledo, Rep. Prog. Phys. **79**, 116301 (2016). https://doi.org/10.1088/0034-4885/79/11/116301

[10] F. G. Kondev, G. D. Dracoulis and T. Kibédi, Atomic Data and Nuclear Data Tables **103**, 50 (2015). https://doi.org/10.1016/j.adt.2015.01.001

[11] S. C. Pancholi, The Pear Shaped Nuclei (World Scientific, New York, 2020), Edition 1. https://doi.org/10.1142/11754

[12] P. A. Butler and W. Nazarewicz, Rev. Mod. Phys. **68**, 349 (1996). https://doi.org/10.1103/RevModPhys.68.349

[13] W. Nazarewicz and P. Olanders, Nucl. Phys. A **441**, 420 (1985). https://doi.org/10.1103/physrevc.32.602

[14] P. A. Butler, J. Phys. G: Nucl. Part. Phys.**,** **43**, 073002 (2016). https://doi.org/10.1088/0954-3899/43/7/073002

[15] L. K. Peker, J. H. Hamilton and J. O. Rasmussen, Phys. Rev. C **24**, 1336 (1981). https://doi.org/10.1103/PhysRevC.24.1336

[16] J. M. Blatt and V. F. Weisskopf, Theoretical Nuclear Physics (Springer, New York, 2012), Edition 1. https://doi.org/10.1007/978-1-4612-9959-2

[17] P. S. Rawat, S. Kumar, H. Chutani and M. Goyal, (to be communicated)

[18] Evaluated Nuclear Structure Data Files (ENSDF) Database. https://www.nndc.bnl.gov/ensdf/

[19] Experimental Unevaluated Nuclear Data List (XUNDL) Database. https://www.nndc.bnl.gov/ensdf/ensdf/xundl.jsp

[20] National Nuclear Data Centre (NNDC). https://www.nndc.bnl.gov/

[21] T. W. Burrows, FMTCHK Version 10.3a (private communication, 2007). https://www-nds.iaea.org/pub-lic/ensdf_pgm/utility/fmtchk/readme-fmtchk.pdf

[22] T. W. Burrows, GTOL Version 7.2f (private communication, 2010). https://www-nds.iaea.org/pub-lic/ensdf_pgm/analysis/gtol/readme-gtol-2.pdf

[23] T. Kibédi, BrIcc – program to evaluate conversion coefficients User's manual for version 2.3b (private communication, 2007). https://www-nds.iaea.org/public/ensdf_pgm/analysis/BrIcc/BrIcc.pdf

[24] T. Kibédi, T. W. Burrows, M. B. Trzhaskovskaya and P. M. Davidson, Nucl. Inst. And Meth. in Phys. Res. A **589**, 202 (2008). https://doi.org/10.1016/j.nima.2008.02.051

[25] T. W. Burrows, Program RULER (private communication, 1984). https://www-nds.iaea.org/pub-lic/ensdf_pgm/analysis/ruler/ruler.pdf

[26] S. G. Nillson, Dan Mat Fys Medd **29**, 16 (1955). https://cds.cern.ch/record/212345

[27] Nuclear Science References (NSR) Database. https://www.nndc.bnl.gov/nsr/

[28] G. D. Dracoulis, A. P. Byrne and A. M. Baxter, Phys. Lett. B **432**, 37 (1998). https://doi.org/10.1016/S0370-2693(98)00620-0

[29] A. N. Wilson *et al.*, Eur. Phys. J A **43**, 145 (2010). https://doi.org/10.1140/epja/i2010-10905-3

[30] J. J. Van Ruyven et al., Nucl. Phys. A **449**, 579 (1986). https://doi.org/10.1016/0375-9474(86)90235-6

[31] G. D. Dracoulis *et al.*, Phys. Rev. C **72**, 064319 (2005). https://doi.org/10.1103/PhysRevC.72.064319

[32] G. D. Dracoulis *et al.*, Phys. Rev. C **77**, 034308 (2008). https://doi.org/10.1103/PhysRevC.77.034308

[33] F. L. Liu and L. B. Zhao, At. Data Nucl. Data Tables **131**, 101285 (2020). https://doi.org/10.1016/j.adt.2019.06.004

[34] T. Kohno *et al.*, Phys. Rev. C **33**, 392 (1986). https://doi.org/10.1103/PhysRevC.33.392

[35] A. E. Stuchbery *et al.*, Nucl. Phys. A **548**, 159 (1992). https://doi.org/10.1016/0375-9474(92)90081-T

[36] P. Kuusiniemi *et al.*, Eur Phys. J. A **25**, 397 (2005). https://doi.org/10.1140/epja/i2005-10117-0

[37] X. Huang, Nucl. Data Sheets **108**, 1093 (2007). https://doi.org/10.1016/j.nds.2007.05.001

[38] D. Alber *et al.*, Z. Phys. A **339**, 225 (1991). https://doi.org/10.1007/BF01284056

[39] A. Maj *et al.*, Z. Phys. A **324**, 123 (1986). https://doi.org/10.1007/BF01325123

[40] H. Beuscher, D. R. Zolnowski, D. R. Haenni and T. T. Sugihara, Phys. Rev. Lett. **36**, 1128 (1976). https://doi.org/10.1103/PhysRevLett.36.1128

[41] A. R. Poletti et al., Nucl. Phys. A **615**, 95 (1997). https://doi.org/10.1016/S0375-9474(96)00428-9

[42] K. H. Maier, D. J. Decman, H. Grawe, H. Haas and W. D. Zeitz, Hyperfine Interactions **9**, 87 (1981). https://doi.org/10.1007/BF01020903

[43] A. R. Poletti, G. D. Dracoulis, C. Fahlander and I. Morrison, Nucl. Phys. A **380**, 335 (1982). https://doi.org/10.1016/0375-9474(82)90109-9

[44] G. D. Dracoulis *et al.*, Phys. Rev. C **80**, 054320 (2009). https://doi.org/10.1103/PhysRevC.80.054320

[45] M. Rejmund *et al.*, Eur. Phys. J. A **1**, 261 (1998). https://doi.org/10.1007/s100500050060

[46] J. P. McDermott, E. Rost, J. R. Shepard and C. Y. Cheung, Phys. Rev. Lett. **61**, 814 (1988). https://doi.org/10.1103/PhysRevLett.61.814

[47] A. E. Stuchbery, G. D. Dracoulis, A. P. Byrne, S. J. Poletti and A. R. Poletti, Nucl. Phys. A **482**, 692 (1988). https://doi.org/10.1016/0375-9474(88)90176-5

[48] A. E. Stuchbery *et al.*, Nucl. Phys. A **641**, 401 (1998). https://doi.org/10.1016/S0375-9474(98)00484-9

[49] G. D. Dracoulis *et al.*, Nucl. Phys. A **493**, 145 (1989). https://doi.org/10.1016/0375-9474(89)90537-X

[50] P. M. Davidson *et al.*, Nucl. Phys. A **560**, 822 (1993). https://doi.org/10.1016/0375-9474(93)90173-U

[51] A. R. Poletti, G. D. Dracoulis, C. Fahlander and A. P. Byrne, Nucl. Phys. A **440**, 118 (1985). https://doi.org/10.1016/0375-9474(85)90045-4

[52] A. R. Poletti *et al.*, Nucl. Phys. A **665**, 318 (2000). https://doi.org/10.1016/S0375-9474(99)00421-2

[53] M. Pautrat *et al.*, Phys. Scr. **34**, 378 (1986). https://doi.org/10.1088/0031-8949/34/5/005

[54] C. Stenzel, H. Grawe, H. Haas, H.-E. Mahnke and K. H. Maier, Z. Phys. A **322**, 83 (1985). https://doi.org/10.1007/BF01412020

[55] V. Rahkonen *et al.*, Nucl. Phys. A **441**, 11 (1985). https://doi.org/10.1016/0375-9474(85)90165-4

[56] A. N. Andreyev *et al.*, Phys. Rev. C **80**, 024302 (2009). https://doi.org/10.1103/PhysRevC.80.024302

[57] A. G. Schmidt *et al.*, Phys. Lett. B **66**, 133 (1977). https://doi.org/10.1016/0370-2693(77)90158-7

[58] J. Missimer and L. M. Simons, Nucl. Phys. A**356**, 317 (1981). https://doi.org/10.1016/0375-9474(81)90192-5

[59] R. M. Diamond and F. S. Stephens, Nucl. Phys. **45**, 632 (1963). https://doi.org/10.1016/0029-5582(63)90838-1

[60] K. H. Hicks, T. E. Ward, J. Wiggins, C. A. Fields and F. W. N. de Boer, Phys. Rev. C **25**, 2710 (1982). https://doi.org/10.1103/PhysRevC.25.2710

[61] J. O. Newton, S. D. Cirilov, F. S. Stephens and R. M. Diamond, Nucl. Phys. A **148**, 593 (1970). https://doi.org/10.1016/0375-9474(70)90650-0

[62] J. Uyttenhove, K. Heyde, H. Vincx and M. Waroquier, Nucl. Phys. A **241**, 135 (1975). https://doi.org/10.1016/0375-9474(75)90368-1

[63] R. F. Davie, A. R. Poletti, G. D. Dracoulis, A. P. Byrne and C. Fahlander, Nucl. Phys. A**430**, 454 (1984). https://doi.org/10.1016/0375-9474(84)90049-6

[64] T. P. Sjoreen *et al.*, Phys. Rev. C **14**, 1023 (1976). https://doi.org/10.1103/PhysRevC.14.1023

[65] I. Bergstrom, B. Fant, C. J. Herrlander, K. Wikstrom and J. Blomqvist, Phys. Scr. **1**, 243 (1970). https://doi.org/10.1088/0031-8949/1/5-6/008

[66] A. P. Byrne *et al.*, Nucl. Phys. A**448**, 137 (1986). https://doi.org/10.1016/0375-9474(86)90185-5

[67] D. J. Decman, H. Grawe, H. Kluge and K. H. Maier, Z. Phys. A **310**, 55 (1983). https://doi.org/10.1007/BF01433610

[68] A. Hurstel *et al.*, Eur. Phys. J. A **15**, 329 (2002). https://doi.org/10.1140/epja/i2002-10032-x

[69] H. Kettunen *et al.*, Eur. Phys. J. A **16**, 457 (2003). https://doi.org/10.1140/epja/i2002-10130-9

[70] G. LoBianco *et al.*, Z. Phys. A **318**, 195 (1984). https://doi.org/10.1007/BF01413468

[71] F. G. Kondev, Nucl. Data Sheets **166**, 1 (2020). https://doi.org/10.1016/j.nds.2020.05.001

[72] K. H. Maier *et al.*, Phys. Re. C **27**, 1431 (1983). https://doi.org/10.1103/PhysRevC.27.1431

[73] G. D. Dracoulis *et al.*, Phys. Rev. C **79**, 054313 (2009). https://doi.org/10.1103/PhysRevC.79.054313

[74] G. Astner and M. Alpsten, Nucl. Phys. A **140**, 643 (1970). https://doi.org/10.1016/0375-9474(70)90585-3

[75] W. F. Piel *et al.*, Phys. Rev. C **31**, 2087 (1985). https://doi.org/10.1103/PhysRevC.31.2087

[76] R. A. Braga, P. B. Semmes, W. R. Western and R. W. Fink, Nucl. Phys. A **459**, 359 (1986). https://doi.org/10.1016/0375-9474(86)90139-9

[77] J. R. Beene, O. Hausser, T. K. Alexander and A. B. McDonald, Phys. Rev. C **17**, 1359 (1978). https://doi.org/10.1103/PhysRevC.17.1359

[78] O. J. Roberts *et al.*, Phys. Rev. C **93**, 014309 (2016). https://doi.org/10.1103/PhysRevC.93.014309

[79] A. J. Kreiner, C. Baktash, G, Garcia Bermudez and M. A. J. Mariscotti, Phys. Rev. Lett. **47**, 1709 (1981). https://doi.org/10.1103/PhysRevLett.47.1709

[80] P. Sen, N. Cue, H. Bakhru, Phys. Rev. C **12**, 716 (1975). https://doi.org/10.1103/PhysRevC.12.716

[81] P. Van Duppen, E. Coenen, K. Deneffe, M. Huyse and J. L. Wood, Phys. Rev. C **35**, 1861 (1987). https://doi.org/10.1103/PhysRevC.35.1861

[82] H. Pai *et al.*, Phys. Rev. C **90**, 064314 (2014). https://doi.org/10.1103/PhysRevC.90.064314

[83] U. Hagemann, K.-H. Kaun, W. Neubert, W. Schulze and F. Stary, Nucl. Phys. A **197**, 111 (1972). https://doi.org/10.1016/0375-9474(72)90750-6

[84] Y. N. Rakivnenko *et al.,* Yad. Fiz. 20, 617 (1974).; Sov. J. Nucl. Phys. **20**, 331 (1975).

[85] H. Hilscher, E. Korthaus and W. D. Krebs, Nucl. Phys. A **97**, 52 (1967). https://doi.org/10.1016/0375-9474(67)90769-5

[86] M. Huyse *et al.*, Phys. Rev. C **46**, 1209 (1992). https://doi.org/10.1103/PhysRevC.46.1209

[87] P. Gippner, K.-H. Kaun, W. Neubert, W. Schulze and F. Stary, Nucl. Phys. A **237**, 142 (1975). https://doi.org/10.1016/0375-9474(75)90468-6

[88] F. G. Kondev and S. Lalkovaski, Nucl. Data Sheets **108**, 1471 (2007). https://doi.org/10.1016/j.nds.2007.06.002

[89] N. Fotiades, R. O. Nelson, M. Devlin and J. A. Becker, Phys. Rev. C **76**, 014302 (2007). https://doi.org/10.1103/PhysRevC.76.014302

[90] N. Fotiades, R. O. Nelson, M. Devlin and J. A. Becker, Phys. Rev. C **77**, 024306 (2008). https://doi.org/10.1103/PhysRevC.77.024306

[91] A. P. Byrne *et al.*, Nucl. Phys. A **567**, 445 (1994). https://doi.org/10.1016/0375-9474(94)90158-9

[92] M. E. Debray *et al.*, Phys. Rev. C **48**, 2246 (1993). https://doi.org/10.1103/PhysRevC.48.2246

[93] N. Cieplicka *et al.*, Acta Phys. Pol. B**45**, 205 (2014). https://doi.org/10.5506/APhysPolB.45.205

[94] H. Langevin-Joliot *et al.*, Phys. Rev. C **38**, 1168 (1988). https://doi.org/10.1103/PhysRevC.38.1168

[95] S. Bayer *et al.*, Nucl. Phys. A **694**, 3 (2001). https://doi.org/10.1016/S0375-9474(01)00922-8

[96] S. Bayer *et al.*, Nucl. Phys. A **650**, 3 (1999). https://doi.org/10.1016/S0375-9474(99)00103-7

CHITKARA

Journal of Nuclear Physics, Material Sciences, Radiation and Applications

Chitkara University, Saraswati Kendra, SCO 160-161, Sector 9-C, Chandigarh, 160009, India

Volume 9, Issue 2 **February 2022** **ISSN 2321-8649**

Copyright: [© 2022 P S Rawat et al.] This is an Open Access article published in Journal of Nuclear Physics, Material Sciences, Radiation and Applications (J. Nucl. Phy. Mat. Sci. Rad. A.) by Chitkara University Publications. It is published with a Creative Commons Attribution- CC-BY 4.0 International License. This license permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.