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LETTER TO THE EDITOR

Measurement of the static quadrupole moments of the first 2^+ states of ^{102,104}Ru

M F Nolan, I Hall, D J Thomas and M J Throop†

Oliver Lodge Laboratory, University of Liverpool, Oxford Street, Liverpool L69 3BX, UK

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Abstract. The static quadrupole moments of the first excited states of ^{102}Ru and ^{104}Ru have been measured by Coulomb excitation. Both are negative, the ^{104}Ru moment being the larger and of approximately the magnitude given by the rotational model.

The even nuclei in the $Z \simeq 50$ region of the periodic table are fairly well described by the vibrational model. The most serious discrepancy between experiment and this model in its simplest (harmonic) form lies in the large static electric quadrupole moments of the first excited 2^+ states of many of these nuclei. We report here values of these moments in ^{102}Ru and ^{104}Ru, these measurements being part of a continuing systematic study in this mass region.

The experimental method exploits the fact that the quadrupole moment of a state has a second order effect on the Coulomb excitation probability of the state. Because the effect is approximately proportional to the mass of the bombarding ion, the quadrupole moment may be deduced from an accurate comparison of excitation probabilities measured with two different bombarding ions.

Targets of natural ruthenium were bombarded with 35·17 MeV ^{16}O and 8·85 MeV ^{4}He ions from the Liverpool tandem Van de Graaff generator. The Coulomb excitation of the 475 keV 2^+ state of ^{102}Ru and the 358 keV 2^+ state of ^{104}Ru was measured by counting the decay γ rays in coincidence with ions scattered through a mean angle of 162° into an annular silicon detector. The γ ray detector was a 40 cm^3 Ge(Li) crystal placed at an angle of 66° to the beam direction and 3·7 cm from the target. The electronics comprised a conventional fast–slow coincidence system and coincidence events were sorted in time and γ ray energy using an on-line computer. Thus we measured the ratio of the γ ray yield per scattered particle for ^{16}O to the corresponding quantity for ^{4}He. This ratio was found to be $9{\cdot}00 \pm 0{\cdot}25$ for ^{102}Ru and $8{\cdot}68 \pm 0{\cdot}19$ for ^{104}Ru.

This ratio may be computed given the experimental parameters (bombarding energy, geometry of detectors, etc) and the E2 matrix elements of the states which play any significant part in the Coulomb excitation process. For both ^{102}Ru and ^{104}Ru the lowest five levels were included in the analysis and table 1 gives the values of the reduced E2 matrix elements M_{rs} used in the computation made with the de Boer–Winther Coulomb excitation program. These are based on the B(E2) values reported by McGowan *et al* (1968). The matrix elements were arbitrarily all set negative. Their

† Present address: Physics Department, University of Oregon, Eugene, Oregon 97403, USA.

Table 1. Reduced E2 matrix elements (in eb) used in the analysis

			^{102}Ru		
Level	1	2	3	4	5
1	0	−0·87	0	∓0·13	0
2	−0·87	M_{22}	−0·25	−0·64	−1·35
3	0	−0·25	0	0	0
4	∓0·13	−0·64	0	0	0
5	0	−1·35	0	0	0
			^{104}Ru		
Level	1	2	3	4	5
1	0	−0·96	0	∓0·17	0
2	−0·96	M_{22}	−1·40	−0·78	−0·28
3	0	−1·40	0	0	0
4	∓0·17	−0·78	0	0	0
5	0	−0·28	0	0	0

The matrix elements are defined by:
$M_{rs} = \langle s \| i^{\lambda} \mathcal{M}(E\lambda) \| r \rangle$ where $\mathcal{M}(E\lambda)$ is the multipole operator and $\lambda = 2$.
$M_{rs}^2 = (2I_r+1)\, B(E2, r \rightarrow s)$ and the quadrupole moment of the 2^+ state is given by $Q_2 = -0{\cdot}758\, M_{22}$.

relative phases are unimportant except in the case of level 4 (the second 2^+ state) through which there is an interference term in the excitation of the first 2^+ state whose sign is not known. Accordingly each computation of yield ratio was made with alternate signs of the matrix element M_{14}. Computations were made using trial values of the diagonal element M_{22} and values of M_{22} were deduced by comparison with the measured ratios. The quadrupole moments so deduced are given in table 2; the quoted errors are due mainly to counting statistics.

Table 2. Deduced quadrupole moments Q_2 of the first 2^+ states

Sign of M_{14}	Q_2(eb)	
	^{102}Ru	^{104}Ru
+	−0·19±0·24	−0·53±0·21
−	−0·37±0·24	−0·84±0·21

In common with many other nuclei in this region the quadrupole moments of the first 2^+ states of ^{102}Ru and ^{104}Ru are negative. Our data, supported by an earlier result of Stelson *et al* (1968, private communication to de Boer J and Eichler J 1968 *Adv. nucl. Phys.* **1** 1–65) giving $Q_2 = -0{\cdot}63 \pm 0{\cdot}20$ eb, indicate a large quadrupole moment in the case of ^{104}Ru. This is approximately the magnitude given by the rotational model for this nucleus: $|Q_2| \simeq 0{\cdot}87$ eb. The result $|Q_2(^{104}\text{Ru})| > |Q_2(^{102}\text{Ru})|$ is consistent with the apparent correlation observed in the isotopes of Pd and Te (Harper *et al* 1971), that is, that $|Q_2|$ increases with increasing $B(\text{E2}, 0^+ \rightarrow 2^+)$ and decreasing level energy across a set of isotopes.

The nuclei ^{102}Ru and ^{104}Ru form sets of isotones ($N = 58$ and 60) with ^{104,106}Pd and ^{106,108}Cd. For both sets the excitation energy of the first 2^+ state increases from Ru through Pd to Cd, and the $B(\text{E2}, 0^+ \rightarrow 2^+)$ correspondingly decreases. Thus, in the simple view above, one might expect $|Q_2|$ to decrease from Ru to Cd across these isotones. The $|Q_2|$ reported here for ^{102}Ru and ^{104}Ru are somewhat larger than those reported by Christy *et al* (1970) for ^{104}Pd and ^{106}Pd respectively, but the latter are significantly smaller than the large $|Q_2|$ reported by Steadman *et al* (1970) for ^{106}Cd and ^{108}Cd. Recent measurements by us, however, indicate quite small $|Q_2|$ for ^{106,108}Cd which are consistent with a trend $|Q_2(\text{Ru})| > |Q_2(\text{Pd})| > |Q_2(\text{Cd})|$ for these sets of isotones. This point will be discussed more fully in a later paper on the Cd isotopes.

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