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Coulomb-Nuclear Interference (CNI) Results of the Collective Quadrupolar Excitations in Odd and Even Ru Isotopes

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The study of the odd $^{99,101}Ru$ nuclei complements the investigation of the collectivity of the first quadrupolar excitations in $^{100,102,104}Ru$. Angular distributions for the $^{99,101}Ru(d,d')$ reactions at 13 MeV were obtained in the Pelletron Laboratory using nuclear emulsion plates on the focal plane of the Enge spectrograph. A Coulomb-Nuclear Interference analysis employing DWBA-DOMP predictions with global optical potential parameters was applied to the excitation of states which could belong to the multiplet built on the first quadrupolar excitation of the core. In the analysis, three states were identified for each of the isotopes and associated, respectively, with adopted levels in the Nuclear Data Sheets Compilation of $J^\pi = 5/2^+$, $7/2^+$ and $9/2^+$. Through the comparison of experimental and predicted cross section angular distributions, the values of $(\delta_L^N)^2$ and of the ratio $C = \delta_L^C/\delta_L^N$ were obtained.

1 Introduction

The São Paulo Nuclear Spectroscopy with Light Ions Group, employing the Pelletron-Magnetic-Spectrograph system, has contributed to the experimental study of the complicated region of $A \sim 100$ with the investigation of the Coulomb-Nuclear interference (CNI) on even nuclei [1, 2], in the inelastic scattering of isoscalar projectiles (deuterons,alphas and lithium).

The present study of the odd $^{99,101}Ru$ nuclei complements the survey of the collectivity of the first quadrupolar excitations in $^{100,102,104}Ru$ [1], allowing for the simultaneous extraction of the square of mass deformation length ($(\delta_L^N)^2$), obtained through the scale factor from the fit of predictions of the distorted wave Born approximation (DWBA), within the deformed optical model potential (DOMP), to the experimental data, and of the ratio $C = \delta_L^C/\delta_L^N$, extracted through of the analysis of the angular distribution shape.

Since the cross sections of inelastic scattering on odd nuclei are much smaller than the corresponding ones on even nuclei, due to the fragmentation of the multipolar excitations, there are relatively less studies on odd targets. In particular, no previous study of the odd ruthenium isotopes is available, although one theoretical interpretation [3] of ^{99}Ru, linking it to its even neighbour, had aroused an interesting question about the magnitude of the quadrupolar deformation length, therein predicted to be much smaller for the odd isotope.

2 Experimental Procedure

Data for the $^{99}Ru(d,d')$ and $^{101}Ru(d,d')$ reactions at 13 MeV were obtained in the Pelletron Laboratory, with the beam trimmed to produce a conveniently small object on the ^{99}Ru and ^{101}Ru targets (97% enriched).

The products of each reaction were momentum analysed by the Enge split-pole spectrograph and detected in nuclear emulsion plates, positioned on the focal plane of the spectrograph. Thirteen and sixteen inelastic scattering spectra, respectivily for ^{99}Ru and ^{101}Ru, with an energy resolution between 6 keV and 12 keV, were measured in the angular range of $16.5^\circ \leq \theta_{lab} \leq 64^\circ$. The use of nuclear emulsion and the good energy resolution of the experimental facilities were essential to achieve the aims of this study. Fig. 1 displays part of one spectrum for each reaction.

Through the comparison of the elastic scattering experimental angular distribution (taken at five angles between 30° and 70° for each target) with optical model predictions, the normalization of the data was obtained.

3 Analysis

In the analysis, three states were identified and associated, respectively, with adopted levels in the Nuclear Data Sheets Compilation [4, 5] of $J^\pi = 5/2^+$, $7/2^+$ and $9/2^+$. The parameters C and δ_L^N have been extracted in the characterization of the coulomb-nuclear interference. These states, excited by inelastic scattering from the $5/2^+$ G.S. of ^{99}Ru

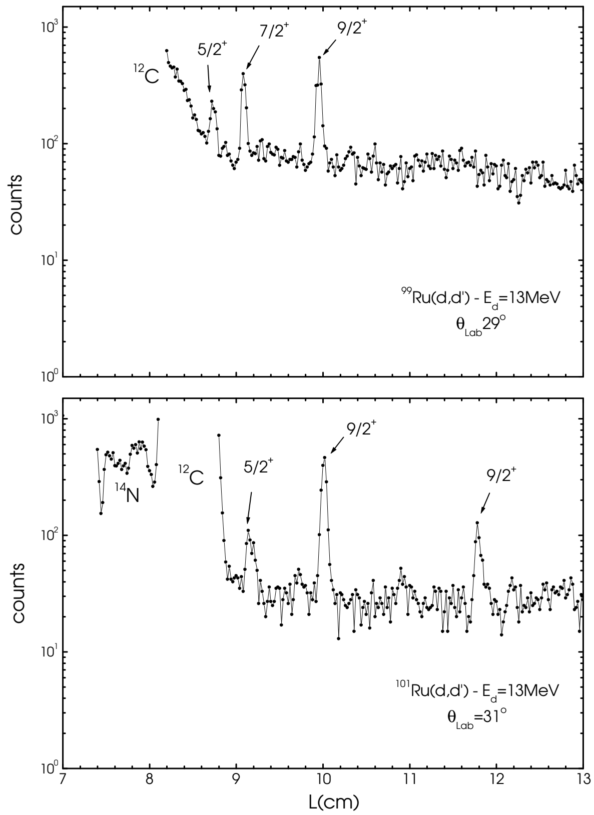

Figure 1. Parts of deuteron spectra from the $^{99}Ru(d,d')$ and $^{101}Ru(d,d')$ reactions at 29° and 31°, respectively. Peaks corresponding to states of ^{99}Ru and ^{101}Ru are identified. The $7/2^+$ of ^{101}Ru is hindered by the peak associated with the elastic scattering by ^{12}C.

and ^{101}Ru, could be members of the multiplet built on the first quadrupolar excitation of the core coupled to the $d_{5/2}$ particle.

The analyses of the multiplet states associated with the first quadrupolar excitation in ^{99,101}Ru were done through the comparison of the experimental angular distributions with DWBA-DOMP predictions employing the DWUCK4 [6] code and the global deuteron optical potential parameters of Perey & Perey [7], with the usual correction for nonlocality effects. The relation between the experimental results and the DWBA-DOMP description of the cross section is written as:

$$\sigma^{exp}(\theta) = \alpha^2 \sigma_L^{DW}(\theta, C),$$

with $C = \delta_L'^C/\delta_L'^N = \delta_L^C/\delta_L^N$ and $\delta_L'^N$ proportional to α, where (δ_L^C) and (δ_L^N) are the charge and mass deformation lengths, respectively. The usual deformation length parameter δ_L^N is related to $\delta_L'^N$ through:

$$\delta_L'^N = \sqrt{\frac{(2J_f+1)}{(2J_i+1)(2L+1)}}\, \delta_L^N,$$

where J_i and J_f are the spins of the initial and final states.

The fits of the experimental angular distributions are performed by a χ^2 minimization procedure, using the iterative method of Gauss [8], since C and $\delta_L'^N$ are correlated.

4 Results and Comments

Figure 2 shows the predicted angular distributions, fitted to the experimental data, as well as two other curves, with a variation around the fitted C value. The sensibility of the method is, thus, illustrated.

The results obtained for the more strongly excited $7/2^+$ and $9/2^+$ states are compared with information given in the literature for some of the even nuclei in the chain of Ru, as shown in Table I. The less intense $5/2^+$ excitations are still under analysis and upper limits for the other states which could belong to the multiplet [3] are also being investigated.

Table I shows that in the odd nuclei the contribution of the protons to the excitations of interest is considerably higher than that of the neutrons, in comparison with the homogeneous collective model, which predicts $C = 1$ for the contributions in the ratio Z/N. The analysis also points to a mass deformation length associated with the quadrupolar excitation in the odd isotopes at the same level as those experimentally determined for either ^{100}Ru or ^{102}Ru [1], but much higher than that employed in the theoretical description of ^{99}Ru [3].

The one particle-rotor model calculations [3], had to resort to a deformation length reduced by about a factor of two with respect to the even neighbour. The $7/2^+$ and $9/2^+$ states in ^{99}Ru and $7/2^+$ in ^{101}Ru seem to follow the usual statistical $(2J_f+1)$ factor in the excitation of the multiplets, but the $9/2^+$ excitation in ^{101}Ru is appreciably weaker than would be predicted by a simple weak coupling model. In fact, as shown in Fig.1, the intensity of this state is fragmented to another $9/2^+$ state of ^{101}Ru, at 928.77(5) keV.

Also shown in Table I are preliminary results associated with this second $9/2^+$ state detected in ^{101}Ru. The sum of the deformation lengths for both $9/2^+$ states reaches the same value, considering the uncertainties, of the deformation length extracted for the $7/2^+$. In the last column of the table the correspondent parameters using the reduced mass radius of 1.16 fm are indicated for a easier comparison with information of the literature for other nuclei.

Acknowledgments

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TABLE I: Parameters C, δ^N and β^N extracted in the present work for $^{99,101}Ru$ and compared with their even neighbours. Only statistical uncertainties are shown and preliminary analysis are indicated by †.

Nuclei	State	C	δ^N (fm)	β^N
^{99}Ru	$5/2^+$†	1.05 (20)	0.73 (9)	0.135 (16)
	$7/2^+$	1.20 (7)	0.92 (4)	0.171 (8)
	$9/2^+$	1.22 (6)	1.03 (4)	0.192 (7)
^{100}Ru[1]	2_1^+	1.04 (3)	1.11 (3)	0.206 (6)
^{101}Ru	$7/2^+$	1.35 (5)	1.05 (3)	0.194 (5)
	$9/2_1^+$	1.43 (6)	0.73 (2)	0.136 (4)
	$9/2_2^+$†	1.87 (23)	0.33 (3)	0.061 (6)
^{102}Ru[1]	2_1^+	1.14 (3)	1.12 (3)	0.207 (6)

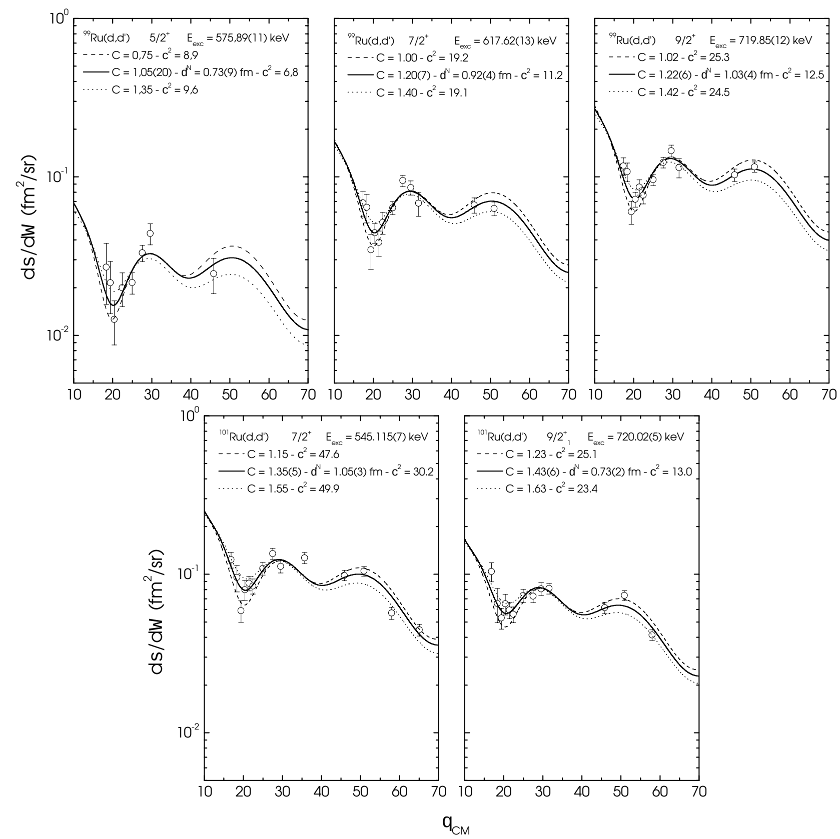

Figure 2. Experimental angular distributions for states associated with the first quadrupolar excitation in ^{99}Ru and ^{101}Ru. The solid line corresponds to the DWBA-DOMP best fit.

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