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Spectroscopy of ^{98}Ru

Adriana Nannini[1,a], Andrea Perego[1,2], and Pietro Sona[1,2]

[1] *Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, Italy*
[2] *Dipartimento di Fisica e Astronomia, Università di Firenze, Italy*

Abstract. The nucleus ^{98}Ru has been investigated by means of γ-γ coincidence, γ-γ angular correlation and K-internal conversion coefficient measurements. The results have led to spin-parity assignment to several levels and to the determination of $E2/M1$ mixing ratios for the most intense transitions.

1 Introduction

Even ruthenium isotopes are situated in a region of transition from vibrational to γ-unstable nuclei. They have been the object of a variety of theoretical analyses along the years, ranging from microscopic calculations [1] to the search for critical-point nuclei [2]. However, for some isotopes, an extended comparison of experimental and calculated values was prevented by the lack of many important spectroscopic data, such as a definite spin-parity assignment to several levels. To provide new spectroscopic data useful to the interpretation of the properties of low-lying states in the ruthenium chain, we have performed γ-γ angular correlation and K-internal conversion coefficient measurements in ^{98}Ru. Our study has led to an improved knowledge of the decay scheme, to the spin-parity assignment to several levels, and to the determination of E2/M1 mixing ratios for the most intense transitions.

2 Experimental results

The ^{98}Ru nucleus was produced at the CN accelerator of Laboratori Nazionali di Legnaro via the ^{97}Mo(^{3}He,2n) reaction, at a beam energy of about 13 MeV. In–beam γ–γ angular correlation measurements were performed in three separate runs, for a total measuring time of about 80 hours. In the case of K–conversion coefficient measurements the total measuring time was about 55 hours.

2.1 Internal Conversion Measurements

Internal conversion electrons were detected by means of a magnetic transport system which focuses electrons onto a 5 cm^2 $\times$ 6 mm Si(Li) detector cooled to liquid nitrogen temperature. The momentum acceptance of the system was $\Delta p/p$ = 18% (Full Width Half Maximum) and the energy resolution of the detector was 2.2 keV for 1 MeV electrons. The overall full energy peak efficiency was approximately constant at a value of about 1% over the 150 − 1200 keV energy range and dropped to about

[a] e-mail: nannini@fi.infn.it

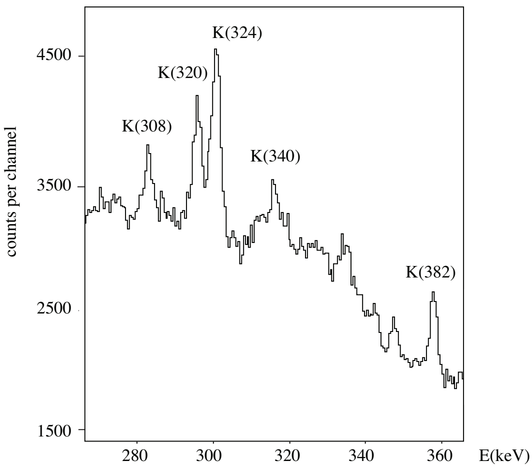

Figure 1. Relevant section of a spectrum showing the internal conversion electrons for an energy region around 350 keV.

0.3% at 1.8 MeV. Internal conversion coefficients were determined by means of the Normalized Peak-to-Gamma (NPG) method [3]. The strong 652 keV, $2_1^+ \rightarrow 0_1^+$ transition was used for normalisation. The values of the measured K-internal conversion coefficients are shown in the fifth column of Table 1. The experimental α_K for the 824 keV, $6_1^+ \rightarrow 4_1^+$ transition is reported to give an idea of the internal consistency of our data. From comparison of the experimental values of α_K with the theoretical ones [5] we deduced the information on the levels reported in the last column of Table 1.

Table 1. Experimental values of the K-internal conversion coefficients (in units of 10^{-3}) for the specified ^{98}Ru transitions are compared with the theoretical values for E1, E2, M1, transitions. Spin-parity assignments to the initial state, deduced from the K-internal conversion coefficients, are given in the last column.

E_{level}(keV)	J_i^π[4]	E_γ(keV)	J_f^π	α_K^{exp}	α_K(E1)	α_K(E2)	α_K(M1)	J^π
1797.0	3^+	382.7	2^+	9.0(8)		10.5	7.8	
		1144.5	2^+	0.65(15)		0.575	0.627	
1817.2	$(2)^+$	1164.8	2^+	1.0(3)		0.554	0.604	
2222.5	6^+	824.7	4^+	1.29(9)		1.22		
2266.6	4^+	253.8	3^+	20(2)		40.5	22.0	
2276.8	(2^+)	879.0	2^+	0.80(29)	0.428	1.05	1.13	$(2)^+$
2547.0	$(5,6)^+$	324.5	6^+	11.0(8)		17.8	11.8	$(5,6)^+$
2867.7	(6^+)	320.7	$(5,6)^+$	12.2(12)	4.55	18.5	12.2	$(6)^+$
		645.2	6^+	2.44(52)	0.821	2.28	2.24	
3068.7		846.2	6^+	1.36(30)	0.462	1.15	1.21	$(4\text{-}8)^+$
3190.2	(8^+)	967.7	6^+	0.84(20)	0.355	0.835	0.901	$(8)^+$
3245.4	(6^+)	978.9	4^+	0.81(27)	0.347	0.814	0.878	$(6)^+$
3250.9		984.4	4^+	1.22(38)	0.343	0.803	0.868	$(2\text{-}6)^+$
3538.4	$(6^+,7,8^+)$	991.4	$(5,6)^+$	0.97(48)	0.339	0.790	0.854	

2.2 Angular Correlation Measurements

To perform γ-γ angular correlation measurements we employed five HPGe detectors mounted on a circular track positioned at fixed angles (60°, 110°, 215°, 270°, 315°) with respect to the beam

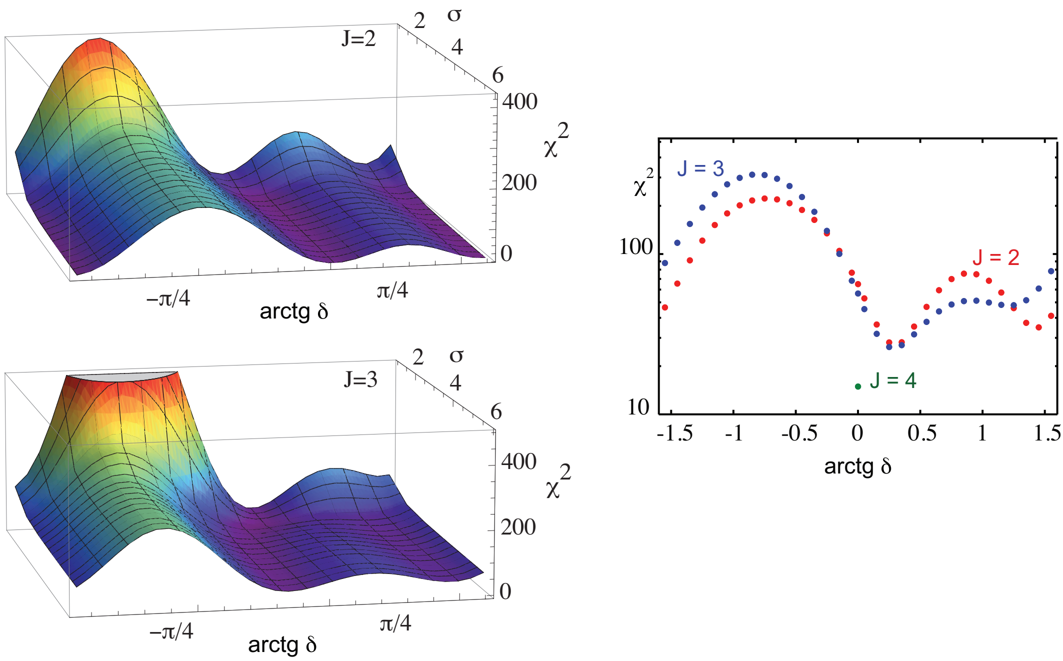

Figure 2. As an example of the information on the spin of a given level obtained from angular correlations the case of the 1774 keV transition from the 2427 keV level [4] is shown. Left side: three- dimensional $\chi^2(\sigma, \text{arctg}\delta)$ contour plots. Right side: corresponding projections (for σ=2) on the plane χ^2 versus arctgδ; the χ^2 for J=4 is reported arbitrarily at a zero value of the abscissa.

direction and at a distance of 11.5 cm from the target. The detectors had a typical energy resolution of 2.3 keV (FWHM) at 1.33 MeV energy and 25% relative efficiency. Cone-shaped lead shields (internally copper-lined) were utilized to define the acceptance of the detectors. To extract information on E2/M1 mixing ratios δ and on spin values for each $J_1 \rightarrow J_2 \rightarrow J_3$ γ-cascade, the coincidence data from each pair of germanium detectors were divided by the corresponding ones from the $0^+_2 \rightarrow 2^+_1 \rightarrow 0^+_1$ γ-cascade, taken as a reference. Corrections for the relative efficiencies and attenuation factors were taken into account. The analysis of the angular correlation data was performed by means of a dedicated computer code based on the expressions of Ref. [6]. The code assumes a gaussian distribution of the population of the magnetic substates of the upper level, so that only one additional parameter, the standard deviation σ of the gaussian, is introduced. In the cascade the lower gamma transition connects states of known spin values with $|J_2 - J_3| = 2$, and has a pure E2 multipolarity. The code computes, for each assumed value of the spin J_1, a table of χ^2 values evaluated over a rectangular grid of equidistant values for σ and arctan(δ), δ being the mixing ratio of the $J_1 \rightarrow J_2$ transition to be determined. An example of the information on the spin of a given level obtained from angular correlation measurements is displayed in Fig. 2, for the $(2^+) \rightarrow 2^+_1 \rightarrow 0^+_1$ cascade, starting from the 2427 keV level. Spin J=4 has clearly to be assigned to this level.

The preliminary results obtained according to the procedure described above are summarized in Table 2. The deduced value for the mixing ratio of the gamma transition connecting the first two state of the cascade is also reported.

Table 2. Spins deduced for the levels reported in column (1) from angular correlation measurements of $J_1 \to J_2 \to J_3$ cascades are given in column (5). In the sixth column are reported the values deduced for the $\delta(E2/M1)$ mixing ratio of the gamma transition of column (3).

E_{lev}(keV)	J_1^π	E_γ(keV)	J_2^π	J	δ
1414.3	2_2^+	761.8	2_1^+		$+12^{+20}_{-5}$
1797.0	3_1^+	1144.5	2_1^+		$+8^{+6}_{-2}$
1817.2	$(2)^+$	1164.7	2_1^+	2	$-1.1(2)$
2012.7	3_2^+	598.4	2_2^+		$+0.37^{+0.09}_{-0.17}$
	3_2^+	614.9	4_1^+		$-0.48(9)$
2245.9	$(2^+, 3^+)$	1593.4	2_1^+	2	$-1.5(3)$
2266.5	4^+	868.7	4_1^+		$+4^{+7}_{-2}$
2276.8	(2^+)	879.0	4_1^+	3	$-0.28^{+0.11}_{-0.07}$
		1624.3	2_1^+	3	$+0.59(12)$
2427.1	$(2)^+$	1774.5	2_1^+	4	E2
2656.5	(5^-)	1258.7	4_1^+	5	$+0.16^{+0.05}_{-0.09}$
2720.3	(3)	1322.5	4_1^+	(4)	$-0.10^{+0.18}_{-0.12}$
2867.7	(6^+)	645.2	6_1^+	6	$-0.22(7)$
3068.7		846.2	6_1^+	(6)	$-0.29(11)^{+0.12}_{-0.09}$

3 Conclusions

The new spectroscopy information on levels and transitions of ^{98}Ru allows us to make important changes to the previous existing level scheme. The γ-γ coincidence relations were crucial to place the γ-transition in the level scheme, while spin-parity assignments were primarily deduced from angular correlation and internal conversion coefficient measurements. Many new γ–transitions have been placed in the decay scheme and several spin and/or parity have been definitely assigned.

The even-even ruthenium and palladium isotopes with N$\geq$ 54 have been analyzed in the framework of IBM-2 in [7, 8]. From those analyses it became evident that, to correctly reproduce the properties of the levels, it is necessary to take into account the presence of mixed-symmetry (MS) states, i.e. of states not completely symmetric in the proton-neutron degrees of freedom. However, for some isotopes, an extended comparison of experimental and calculated values was prevented by the lack of many important spectroscopic data, such as definite spin-parity assignment to low-lying levels. Work to extend the comparison of the predictions of the IBA-2 model to the new data in ^{98}Ru is in progress.

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