Observation of excited states and isomeric decays in doubly-odd ^{208}Fr

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Introduction

The nuclei near the doubly magic ^{208}Pb are predicted to exhibit various interesting structural phenomena, one of which is a wealth of isomerism. However, little experimental data are available in $Z > 82$, $N \leq 126$ mass region till date. As Z increases from 82 and/or N decreases from 126, survival probability for compound nucleus decreases steeply and fission dominates over the formation of evaporation residue. Though the high spin states and isomeric decay of a few odd-A nuclei in this region have been studied in recent times [1, 2], there was almost no information available on the structure of odd Z-odd N isotopes like ^{208}Fr ($Z=$ 87, $N=$ 121), ^{210}Fr ($Z=$ 87, $N=$ 123) except only two low lying transitions of ^{208}Fr produced via projectile fragmentation reaction [3]. However, a detailed study of high spin states of ^{211,212,213}Fr has already been done [4]. Structure of such trans-Lead nuclei can be interpreted in terms of the shell model states, and the high spin states of these nuclei are interpreted as single particle configurations arising from the $(1h_{\frac{9}{2}}, 2f_{\frac{7}{2}}, 1i_{\frac{13}{2}})$ protons and $(3p_{\frac{1}{2}}, 2f_{\frac{5}{2}}, 3p_{\frac{3}{2}}, 1i_{\frac{13}{2}})$ neutrons. One of the major interests in the spectroscopic investigation of these nuclei is the role played by the $i_{\frac{13}{2}}$ state in creating isomeric levels which decay through transitions of higher multipolarity, or are hindered by the close proximity of the levels below. A systematic study of these nuclei will possibly reveal many other interesting structural features.

Data analysis and results

The experiment to produce ^{208}Fr was carried out at the Inter-University Accelerator Centre (IUAC), New Delhi using INGA facility [5]. The Fr isotopes were populated through ^{197}Au (^{16}O,xnγ) reaction at 88, 94 and 100 MeV. The relevant details of the experiment have been reported in Ref [6].

The relative yields of different Fr isotopes were obtained by measuring excitation function at three different bombarding energies and also by offline decay data analysis [6]. The trends are comparable to that predicted from PACE. For online data taken at 100 MeV beam energy, $\gamma\gamma$ matrices, Francium X-ray gated $\gamma\gamma$ matrices, the prompt and various delayed $\gamma\gamma$ matrices and the γ-gated $\gamma\Delta T$ matrices were constructed to establish the ^{208}Fr level scheme and resolve the isomeric transitions from known sequence of ground state transitions. Based on the intensity correlations obtained from our gated spectra, and also from the DCO ratio measurements, the level scheme has been developed for ^{208}Fr (see Fig. 1). In all the major sequences in this level scheme, ordering of the transitions are cross-checked by intensity correlations and also by reverse gating. Because of the existence of low lying isomer with half lives $\sim 200 - 400$ ns, and also due to the large internal conversion of some of the levels, the intensity balance across the isomeric levels could only approximately be done.

A systematic search for isomeric transitions

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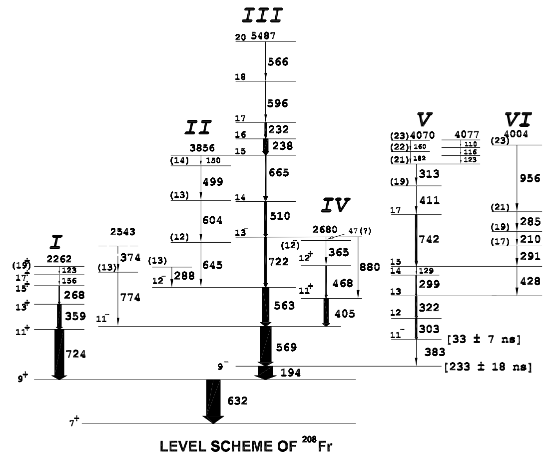

FIG. 1: Level scheme of ^{208}Fr obtained from our work.

has been done from our data and the half lives were extracted. Gamma-gated $\gamma\Delta T$ matrices were generated for the analysis. The ΔT spectral measurements covered a $\pm$400 ns TDC range, but an useful range of $\sim$ 500 ns could be utilized due to delay matching of the detector array. From the 194 keV and 632 keV Gamma-gated $\gamma\Delta T$ coincidence matrices, we have projected the gated ΔT spectra for the 569 keV, 563 keV, 299 keV, 303 keV, 322 keV and 742 keV gated transitions. The ΔT spectra for the first two gated transitions are found to be similar in nature. Likewise ΔT spectra for 299, 303, 322 and 742 keV gated levels are similar in nature among themselves. But these two groups differ significantly that the exponential decay is much faster in 2nd case, indicating the existence of another faster isomeric transition above the 826 keV level. By comparing the prompt and delayed gated spectra, a new but weak 383 keV isomeric transition was found and it was placed just above the 826 keV level along the sequence V. The half life of the 826 keV isomeric level was extracted by fitting exponential decay function to the 563+569 combined ΔT spectra and a half life of 233 $\pm$ 18 ns was obtained, which is consistent with the result $\sim$ 200 ns quoted in Ref [3]. Half life of the 1209 keV isomeric level was extracted from the 299+303+322+742 combined ΔT spectra in a similar way. The result obtained is: 33$\pm$7 ns. To find out the correctness of the present technique, half lives have been extracted for a number of isomeric transitions already known in several nuclei produced in our in-beam experiment. These are listed in the Table I. The isomer half lives spanned from $\sim$ 150 ns to $\sim$ 600 ns. The results are found to be in good agreement with the earlier measurements, within the quoted uncertainties. Further refinement of analysis, search for other isomers are in progress. Interpretation of the level scheme based on shell model and other calculations are being attempted.

TABLE I: Half lives of isomeric levels of different nuclei produced in the experiment.

Nucl.	Level (keV)	E_γ (keV)	$T_{1/2}$(ns) (This expt)	$T_{1/2}$(ns) (Earlier)
^{208}Fr	826	194.1	233(18)	432(11) [7]
				$\sim$ 200 [3]
^{208}Fr	1209	382.9	33(7)	
^{208}Rn	1828	88.7	590(144)	509(14) [8]
^{206}At	807	121.6	377(44)	410(80) [9]
				813(21) [7]
^{204}Po	1639	12.1	161(4)	158(2) [10]

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