Evidence of high-spin isomers in ^{216}Fr

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Introduction

Study of excited states in nuclei is of great interest in order to develop understanding of the nuclear structure. Various sequences of such states reveal different physical phenomena. For example, nuclei in the vicinity of doubly magic ^{208}Pb ($Z = 82$, $N = 126$) display characteristics of spherical shape, which is very well understood in terms of single particle excitations, while those in the Ra − Th region with $A \approx 220$ are observed to have reflection-asymmetric shapes. These nuclei display sequences of the $\Delta J = 2$ transitions originating from alternating parity states. The two sequences are interconnected by enhanced $E1$ transitions. A competition between the different modes of excitation is expected in the nuclei lying between the two regions.

Several high-spin isomers have been reported in the nuclei with $Z \geq 82$ and $N \geq 126$. For example, eight isomers including the $65/2^-$, 4.5 μs isomer at $\approx$ 8.0 MeV were observed in ^{213}Fr [1]. Also, five isomers have been reported in each of ^{212}At, ^{214}Rn and ^{215}Fr nuclei with $T_{1/2}$ ranging from 5 − 250 ns [2–4], while two isomeric states in ^{216}Ra were observed to have $T_{1/2} \sim 10$ ns [3]. Some of these isomers have been explained in terms of interaction between the single-particle degrees of freedom and the octupole vibrational mode. It was recently proposed by Pragati *et al.* [5], that ^{216}Fr ($Z = 87$, $N = 129$) lies at the lower edge of the region, beyond the doubly magic ^{208}Pb, which displays octupole collectivity. In view of this, it is interesting to search for isomers in ^{216}Fr where the competition between single particle and collection motion is expected.

Experimental Details

The reaction ^{208}Pb(^{11}B, $3n$) was used to populate the high-spin states in ^{216}Fr at beam energies 57 − 62 MeV. The beam was provided by the 15-UD Pelletron accelerator at IUAC, New Delhi. The isotopically enriched ($\sim$ 99%) self-supporting ^{208}Pb target of thickness $\sim$ 6 mg/cm^2 was bombarded by the beam with $\approx$4 pnA current. The gamma rays emitted in the process of de-excitation of residual nuclei were detected using Indian National Gamma Array (INGA). The array consisted of 14 Compton suppressed clover detectors, which were positioned at 90°, 123°, 148° with respect to the beam direction. Two or higher fold coincidence data were collected using CANDLE [7] and sorted into various histograms. These histograms were further analyzed using RADWARE [8].

Results and Discussion

Figure 1 shows coincidence spectra in the gate of 528 keV transition in three different coincidence time windows. Fig.1(a) illustrates

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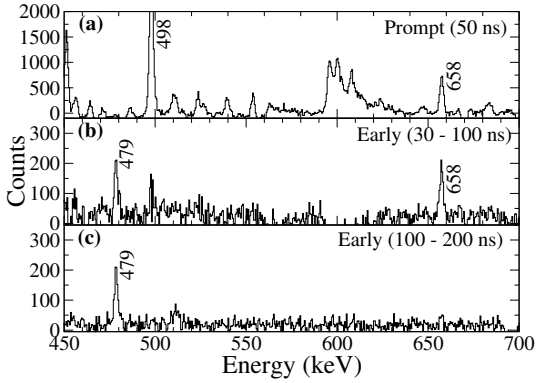

FIG. 1: Spectra in the gate of the 528 keV transition within (a) prompt 50 ns (b) 30 − 100 ns "early" and (c) 100 - 200 ns "early", coincidence time window.

a part of the prompt spectrum within the 50 ns window, while Figs. 1(b) and 1(c) depict "early" spectra within 30 − 100 ns and 100 − 200 ns time windows obtained from early-delayed matrices, respectively. The two observations can be noted by comparing the three spectra. First, the 479 keV gamma ray is present only in the early spectra. Second, the 658 keV gamma ray is visible only in the spectrum with 30 − 100 ns coincidence window and the prompt gamma-ray spectrum [Fig. 1(a)]. Also, the 479 keV transition is observed in prompt coincidence with the 658 keV transition only. These observations suggest the presence of two high-spin isomeric states in ^{216}Fr. The comparison also suggests that the state which is populated by the 658 keV transition is at lower excitation energy than the one which is populated by the 479 keV transition.

As discussed earlier, the nuclei with a few nucleons outside the ^{208}Pb core such as ^{214}Rn, ^{215}Fr and ^{216}Ra are known to have isomers with spins in 20 − 24 $\hbar$ range[3, 6]. These isomers are understood in terms of coupling of proton orbitals $1h_{9/2}$, $2f_{7/2}$ and $1i_{13/2}$ with the neutron orbitals $2g_{9/2}$, $2i_{11/2}$ and $1j_{15/2}$. For example, 20^+ and 22^+ high-spin isomeric states in ^{214}Rn were assigned $(\pi h_{9/2}{}^4)_{12^+} \otimes (\nu g_{9/2}{}^2)_{8^+}$ and $(\pi h_{9/2}{}^4)_{12^+} \otimes (\nu g_{9/2} i_{11/2})_{10^+}$ configurations, respectively [3]. The present study suggests that the spins of the isomeric states populated by the 479- and 658 keV transitions in ^{216}Fr will be in 20 − 24 $\hbar$ range. Thus, the above discussion can be extended for explanation of isomers in ^{216}Fr. The detailed experimental and theoretical results will be presented during the symposium.

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