The decay of $N = 126$, ^{213}Fr nucleus

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Introduction

A direct information on the single-particle states is essential to test the accuracy and applicability of the nuclear shell model. Such information can be obtained by experimental investigation of nuclei in the proximity of the shell closures. The heaviest doubly-magic shell closure is known to occur at ^{208}Pb. It is predicted [1] that there exists even heavier region of shell-closure than the one at ^{208}Pb where specific combinations of proton and neutron numbers yield extra stability. Search for such super heavy elements occupies considerable part of experimental efforts at various facilities world wide.

Although a large amount of information is available on high spin states in many nuclei in the vicinity of ^{208}Pb, not much is known about the single particle states. Such states can be established via beta decay studies. Here we present the first $\alpha-$ and $\beta-$ decay study of $N = 126$, ^{213}Fr nucleus.

Experimental Details

The experiment was performed at the CERN isotope separator on-line (ISOLDE) facility, where a 1.4 GeV proton beam from the CERN PS-Booster was used for the spallation of a 46 g/cm^2 UC_2 target. The spallation products with $A = 213$ were separated by a General Purpose Separator at the ISOLDE. Following the separation, the products were collected on a tape and transported to a measurement station at regular interval of 33.6 s. The gamma rays and conversion electrons emitted in the decay process were detected by two high-purity germanium (HPGe) detectors and an electron spectrometer, respectively. The data were collected using a commercially digital data acquisition system Pixie4 [2].

Result and Discussion

A relatively pure beam of ^{213}Fr, among the other isobars, could be obtained due to the lower surface ionization potential of francium. Earlier studies [3] show that ^{213}Fr decays via α as well as β emission with relative probability of 99.44% and 0.56%, respectively. Both the decays were known to proceed directly to the ground state of their respective daughter nuclei with half-life of 34.82 (14) s.

The $\gamma - \gamma$ and $\gamma-$x-ray coincidence analysis revealed that both, $\alpha-$ and $\beta-$, decays populate several states in the daughter nuclei, ^{209}At and ^{213}Rn respectively. Figure 1 shows various spectra with different gates which establish the assignment of transitions to ^{213}Rn. Apart from this, a fit to the decay curve of 605.9 keV conversion electrons (corresponding to 704.3 keV γ ray) yields half-life which is in agreement with the ground-state half-life of ^{213}Fr, thus confirming the origin of the level at

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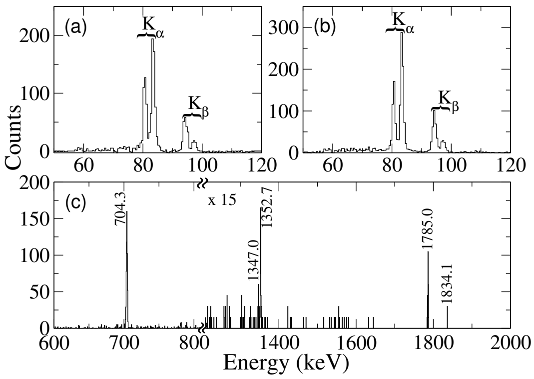

FIG. 1: Spectra showing radon K_α and K_β x rays obtained with gates on (a) 704.3 keV events from the $\gamma-\gamma$ matrix and (b) 605.9 keV conversion electrons (corresponding to 704.3 keV γ rays) from γ-ray−conversion-electron matrix. Fig. (c) shows γ-ray spectra obtained from adding K_{α_1}, K_{α_2}, and K_{β_1} radon x-ray gates using the $\gamma-\gamma$ matrix.

704.3 keV. This level was established in earlier [4] high-spin studies. Most of the new states were observed to decay directly to the ground state of ^{213}Rn. All these states can have any spin from 7/2 to 11/2 with a possibility of either parity. However, the conversion coefficient of 704.3 keV transition firmly establishes its M1 nature, which is in agreement with earlier studies [4].

The ^{213}Fr ground state branching to the ground state of ^{213}Rn cannot be ignored in calculating the log*ft* values, since both the states have same spin of 9/2 but with opposite parity. Therefore, lower limit of 5% and upper limit of 30% was assumed for this first-forbidden transition. The assumed branching limits correspond to log*ft* values of 7.5 and 6.6, which are around the highest expected value of 7 for the first-forbidden transitions. This assumption, in turn, gives two log*ft* values for each newly observed state. It is found that the two values are within the errors on the average of them.

As mentioned earlier, the $\alpha-$decay of the ^{213}Fr ground state was known to have only a single branch populating the ground state of ^{209}At. However, the present study revealed that the decay has more than one branching, populating already established levels in high-spin studies. The half-life obtained from the fit to the decay curve of the 577 keV γ transitions (which is already known to belong to ^{209}At) is in agreement with the ground state half-life of ^{213}Fr, hence confirming the origin of the level at 577 keV in the $\alpha-$decay of ^{213}Fr ground state.

In the case of ^{213}Rn, which has $N = 127$, all the shell model orbitals available for the last neutron have positive parity except the $1j_{15/2}$ orbital. Therefore, the level scheme at low excitation energy is expected to be dominated by positive parity states. The shell model calculations using the OXBASH [5] code employing the KHP interaction also support this interpretation. This, in the absence of multipolarity measurements, helps to constrain the parities of experimental levels to be positive.

In summary, the decay study of ^{213}Fr has established new $\alpha-$ and $\beta-$ decay branches leading to the excited states in ^{209}At and ^{213}Rn, respectively. This has established several new states in ^{213}Rn which can be explained using the shell model.

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References

[1] A.Lukasiak *et al.*, *Acta Physica Polonica* **B**6 (1975).
[2] http://www.xia.com/DGF_Pixie-4.html.
[3] M.S.Basunia, Nucl. Data Sheets **108**, 633 (2007).
[4] A.E.Stuchbery *et al.*, Nucl. Phys. A **482**, 692 (1988).
[5] B.A.Brown *et al.*, MSU-NSCL Report No. 524, 1985.