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Brief Reports

Brief Reports are short papers which report on completed research or are addenda to papers previously published in the **Physical Review**. *A Brief Report may be no longer than 3½ printed pages and must be accompanied by an abstract and a keyword abstract.*

Alpha-decay properties of ^{205,206,207,208}Fr: Identification of ^{206}Fr^m

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Alpha-particle and γ-ray spectral measurements were made for $^{205-208}$Fr. A new α emitter ($T_{1/2} = 0.7 \pm 0.1$ sec and $E_\alpha = 6.930 \pm 0.005$ MeV) was observed and identified with the decay of a previously unknown isomer in ^{206}Fr. From the α particle and γ ray intensities, α decay branching ratios were deduced for $^{205-208}$Fr utilizing available information concerning the nuclides' (electron capture + positron) decay properties. Reduced widths were calculated and compared with those of neighboring nuclei.

[RADIOACTIVITY ^{205,206,207,208}Fr, measured E_γ, I_γ, E_α, I_α; deduced α-branching ratios; identified ^{206}Fr^m. Mass separation.]

The α decays of francium nuclei with $N \leq 126$ have been studied by several groups and their findings have been summarized by Gauvin *et al.*[1] For various reasons, none of these groups incorporate observations of the electron capture + positron decay (EC + β^+) properties of these nuclei. We have reexamined the decays of $^{205-208}$Fr and, by observing both the intensities of the α and (EC + β^+) decay modes, have deduced their α branching ratios in a manner which is more straightforward than the methods used by previous investigators.

In the present investigation, evidence was also obtained which indicates the existence of a previously unobserved α-emitting isomer in ^{206}Fr. Gamma-ray data taken simultaneously with the α data provide clues to levels within ^{206}Fr and its daughter ^{202}At.

The francium nuclei of interest were produced by bombarding natural iridium with 120-MeV ^{20}Ne ions accelerated in the Oak Ridge isochronous cyclotron. The reaction products were mass separated on line at the University Isotope Separator at Oak Ridge (UNISOR) facility. The separator ion sources were operated in a surface-ionization mode to release exclusively the francium product nuclei. A high temperature ion source[2] was used for most of the experiments.

The mass-separated francium nuclei were assayed with surface barrier Si(Au) α particle detectors and large volume Ge(Li) γ-ray detectors positioned in absolutely calibrated geometries. Energy and absolute efficiency calibrations were made with standard sources of known strength. The α and γ data were taken simultaneously in a spectrum multiscale mode using the UNISOR data acquisition system described previously.[3] A precision pulser was used to provide time normalization for the multiscale data.

The francium α-branching ratios were based on α intensities and the intensities of the first-excited to ground state γ transitions in the (EC + β^+) daughters. In parallel investigations,[4,5] no transitions to the ground states were observed to bypass the first-excited states. Additionally, direct (EC + β^+) feeding to the radon ground states is unlikely since the spin difference between the parent and daughter is in all cases $\geq 2\hbar$. Thus the first-excited to ground state transition intensities represent the (EC + β^+) decay strengths.

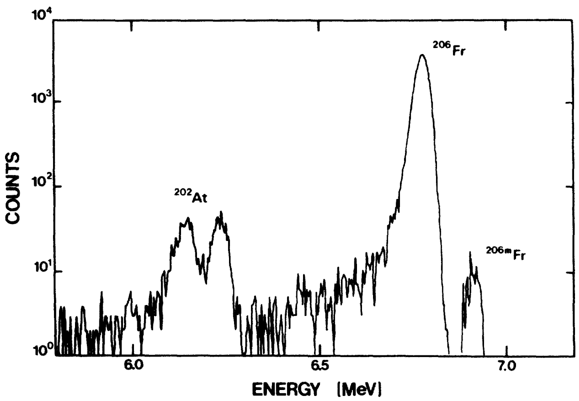

FIG. 1. Alpha spectrum measured for $A = 206$ nuclides. The spectrum shows a previously unreported α group at 6.930 ± 0.005 MeV. The remaining peaks are due to the α decay of ^{206}Fr and its daughter ^{202}At.

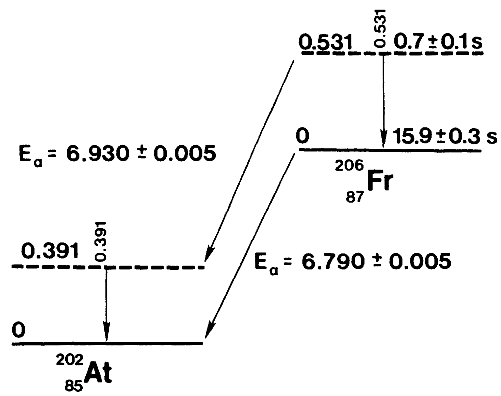

FIG. 2. Proposed α-decay schemes for ^{206}Fr and ^{206}Fr^m. Level and transition energies are given in MeV.

The $A = 206$ α multiscale spectra revealed the presence of a new α group at 6.930 ± 0.005 MeV (see Fig. 1) which decayed with a half-life of 0.7 ± 0.1 s. Based on the following arguments, we identify it as the α decay of an isomer in ^{206}Fr:

(a) no element with Z greater than 87 (francium) can be produced in the heavy-ion reaction used;

(b) the decay curve of the group was that characteristic of a first order (parent) decay equation rather than that of a higher order (daughter) curve; and

(c) radon, astatine, and polonium atoms do not surface ionize to an appreciable extent, requiring any of their isotopes deposited as sources in these experiments to be daughters of francium decay.

Analysis of the γ-ray data revealed two transitions of energy 391 and 531 keV with half-lives (1.1 ± 0.4 and 0.7 ± 0.1 s, respectively) nearly equal to that of the 6.930 MeV α group. The correspondence of the half-lives and energy differences between these γ rays and the two α groups of ^{206}Fr indicate that they are transitions within ^{206}Fr and ^{202}At. Their suggested placements in the two nuclei are indicated by the level schemes shown in Fig. 2. Gamma-ray coincidence data taken in these experiments possessed insufficient statistical significance either to support or detract from such a proposal. Therefore, since no excited levels within ^{202}At or ^{206}Fr are known at this time, further experiments are needed to confirm the proposed level structures.

Table I summarizes our determinations of the ^{205,206,207,208}Fr branching ratios, half-lives, and α-decay energies. The interested reader is referred to the compilation of Gauvin *et al.*[1] for a detailed comparison with currently available data[6,7,8] for the same four nuclides. We will only mention that within error limits our α-decay energies agree with the published values. The same is true for half-lives with the exception of those given in Ref. 6 for ^{208}Fr and ^{207}Fr, i.e., 37.5 ± 2.0 and 18.7 ± 0.8 s, respectively. Only Hornshöj *et al.*[8] have measured α branches. Their values, $74 \pm 3\%$, $93 \pm 3\%$, $85 \pm 2\%$, and $\gtrsim 97\%$ for ^{208}Fr, ^{207}Fr, ^{206}Fr, and ^{205}Fr, respectively, are generally lower than our ratios (see Table I). Perhaps these discrepancies are due to differences in the experimental techniques. Their method[8] is based on the observed intensities of the francium and daughter (astatine) α groups. A correction must be made for recoil losses following α decay and the daughter α branches have to be known. Neither the correction nor the daughter branching ratios are required when using our method.

TABLE I. Summary of results obtained for $^{205-208}$Fr.

Nuclide	E_α (MeV)	α-decay branching ratio (%)	Half-life (s)
^{208}Fr	6.636 ± 0.005	90 ± 4	59.1 ± 0.3
^{207}Fr	6.766 ± 0.005	97^{+2}_{-3}	14.9 ± 0.1
^{206}Fr^m	6.930 ± 0.005	0.3 ± 0.1	0.7 ± 0.1
^{206}Fr	6.790 ± 0.005	93 ± 4	15.9 ± 0.3
^{205}Fr	6.917 ± 0.005	~100[a]	3.96 ± 0.04

[a]No evidence of (EC+β^+) decay for ^{205}Fr was observed—upper limit ~1%.

The information obtained for $^{206}Fr^m$ is also included in Table I. Its α-branching ratio of $(0.3 \pm 0.1)\%$ was deduced by comparing the intensities of the ^{206}Fr and $^{206}Fr^m$ α groups and by using the experimentally determined ^{206}Fr α branch.

Alpha-decay rates are customarily considered within a theoretical framework in which relative probabilities can be obtained after removing the dependence on Q value as well as on the atomic and mass numbers. One convenient formalism has been developed by Rasmussen[9] wherein a reduced width δ^2 is defined as $\delta^2 = \lambda h/P$. In the equation, λ is the decay constant, h is Planck's constant, and P is the penetrability factor. The barrier for the α particle to tunnel through includes an optical-model potential; a centrifugal barrier is also added so that l dependence in α decay can be considered. In α decay, transitions between ground states of doubly-even nuclei are taken to represent unhindered decays. The reduced widths of these s-wave transitions are taken to be standard. Hindrance factors for other α decays are then deduced by comparing their widths with those of neighboring s-wave transitions.

The δ^2 values for neutron-deficient francium isotopes with $N \leq 130$ were calculated by using half-lives, branching ratios, and decay energies from Table I for $^{205-208}Fr$, and Ref. 1 for the remaining nuclides. Angular momentum transfers were deduced either from experimental spins[10] or from inferences based on systematics. The calculations showed that the δ^2 values, when considered as a function of neutron number, have a sharp minimum at $N = 126$. This effect has long been observed not only for francium nuclei (Ref. 8), but for other heavy elements as well.[8,11] The pronounced dip has been explained[12] as being due to the influence of the major $N = 126$ closed shell. In addition, the widths for both odd-N and even-N franciums were found to be similar in magnitude to those of neighboring s-wave transitions for polonium, radon, and radium nuclei (Ref. 11). The francium nuclides therefore have unhindered α-decay rates. This lack of hindrance reflects[12] a large overlap between the wave functions of the initial and final states connected by the α decay. It would appear that the levels in the francium parents and astatine daughters connected by each of the α transitions considered have the same spin and parity.

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