Decay of $^{200,201}$Fr$^+$

Z. Kalaninová$^{1,}$ S. Antalic$^1$, A.N. Andreyev$^{2,3}$, F.P. Heßberger$^{4,5}$, D. Ackermann$^4$, B. Andel$^1$, L. Bianco$^6$, S. Hofmann$^4$, M. Huys$^7$, B. Kindler$^4$, B. Lommet$^4$, R. Mann$^4$, R.D. Page$^6$, P. Sapple$^6$, J. Thomson$^6$, P. Van Duppen$^1$, and M. Venhart$^{8,1}$

$^1$Comenius University, Bratislava, Slovakia; $^2$University of York, York, UK; $^3$ASRC, JAEA, Ibaraki, Japan; $^4$GSI, Darmstadt, Germany; $^5$Helmholtz Institut Mainz, Mainz, Germany; $^6$University of Liverpool, Liverpool, UK; $^7$KU Leuven, Leuven, Belgium; $^8$Institute of Physics, SAS, Bratislava, Slovakia

In the region of neutron-deficient nuclei above lead several interesting nuclear-structure phenomena can be observed, e.g., coexistence of states with different shapes within one nucleus, or $\beta$-delayed fission. This motivated us to investigate the neutron-deficient isotopes $^{200,201}$Fr.

The studied nuclei were produced at the velocity filter SHIP (GSI, Darmstadt) in fusion-evaporation reactions $^{56}$Fe$+^{147}$Sm at several beam energies from 236 to 275 MeV. Evaporation residues (ERs) were separated from other particles and transported into a focal-plane detector system. ERs were implanted into a 16-strip position-sensitive silicon detector (PSSD) recording also their $\alpha$ decays. Escaping $\alpha$ particles were recorded by a system of six silicon detectors placed upstream the beam covering 80% of $2\pi$. A germanium clover detector placed closely behind the PSSD registered $\gamma$ and X-rays.

We measured $E_{\alpha} = 7470(5)$ keV and $T_{1/2} = 46(4)$ ms for $^{200}$Fr confirming known $\alpha$-decay data for this isotope. For its daughter isotope, $^{196}$At, we observed a new weak $\alpha$ line at 6732(8) keV with a relative intensity of 4(2) % besides the main 7045(5)-keV $\alpha$ line. The determined energy of the level in $^{192}$Bi populated by the 6732(8)-keV decay is 320(10) keV. Within a 5- $\mu$s coincidence time with implanted ERs followed by $^{200}$Fr we observed weak $\gamma$ lines at 75.5 and 77.1 keV and K$_{\alpha}$(Fr) X-rays. They indicate a short-lived $\gamma$-decaying state in $^{200}$Fr with $T_{1/2} = 0.6^{+0.5}_{-0.2}$ $\mu$s. One $\beta$-delayed fission ($\beta$DF) event attributed to $^{200}$Fr was observed. Deduced probability of $\beta$DF for the daughter isotope $^{200}$Rn is more than 1.4 %.

We identified a short-lived $\gamma$-decaying activity with $T_{1/2} = 0.7^{+0.5}_{-0.2}$ $\mu$s also in $^{211}$Fr based on the registration of $\gamma$ and K$_{\alpha}$ X-rays. From the analysis of K-shell internal conversion coefficients ($\alpha_K$) [1] and estimated single-particle half-lives ($T_{1/2,SP}$) according to Weisskopf [2] we suppose that observed $\gamma$ and X-rays arise from an internal transition of $M_2$ multipolarity. We tentatively assigned the spin and parity of $13/2^+$ to the observed isomeric state in $^{201}$Fr. The lower energy limit for this level was determined to be higher than the $K$-shell atomic-electron binding energy of francium (101.13 keV) because of the detection of K X-rays. The upper energy limit was roughly estimated to be 300 keV from the comparison of experimental and expected $\alpha_K$ and $T_{1/2,SP}$ for $M_2$ transitions.

For most of the neutron-deficient francium ($Z = 87$) and astatine ($Z = 85$) isotopes a 9/2$^−$ state related to a spherical shape was identified to be a ground state. In astatine isotopes, the 7/2$^−$, 1/2$^+$, and 13/2$^+$ levels, related to oblate shapes, were observed with energies decreasing at decreasing N (see Fig 1). Starting with $^{195}$At ($N = 110$), the 1/2$^−$ level becomes the ground state in astatine isotopes [3]. The energy interval of the tentative 13/2$^+$ level in $^{201}$Fr estimated from our data follows the trend of decreasing energies at decreasing N of this level in francium isotopes. A similar trend was also observed for the 1/2$^+$ level. In the lightest francium isotopes we can expect a change of spin of the ground state, but it was not definitely identified so far. All of the 13/2$^+$, 7/2$^−$, 1/2$^+$ levels were reported to be detected in $^{199}$Fr within 300 keV [4]. However, in recent measurements at SHIP we only observed the 7/2$^−$ level, and tentatively also the 1/2$^+$ level [5]. Higher statistics are needed to disentangle the level structure in this isotope.

References