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Flerovium spectroscopy – benchmarking nuclear theory at proton number $Z = 114$

In the wake of the discovery of superheavy elements, nuclear spectroscopy experiments aim at providing anchor points at the uppermost end of the nuclear chart for nuclear structure theory, which otherwise had to solely rely on extrapolations. In two runs in 2019 and 2020, such a nuclear spectroscopy experiment was conducted to study α -decay chains stemming from isotopes of flerovium (element $Z = 114$). One incentive to study flerovium isotopes is that many, but not all, nuclear structure models or model parametrizations favour $Z = 114$ as the next magic proton number beyond lead, $Z = 82$.

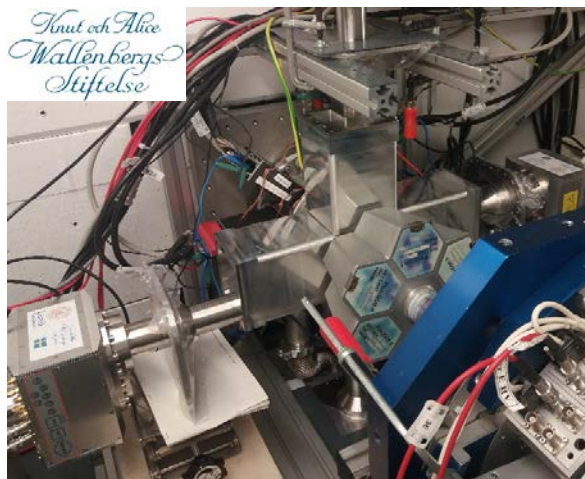


Fig. 1: Upgraded TASISpec decay station in the focal plane of the TASCA gas-filled separator, comprising four new COMPEX Germanium detectors, as well as a former EUROBALL Cluster detector. The idea is to detect X rays and γ rays stemming from α -decay chains of the heaviest elements (photo: © A. S  mark-Roth, Lund University).

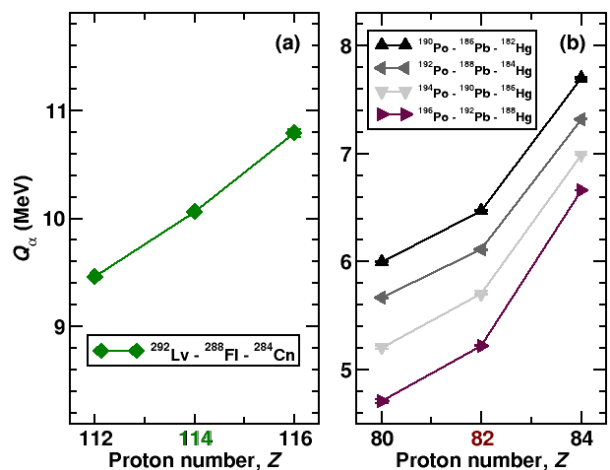


Fig. 2: (a) Q_α sequence across $Z = 114$, flerovium, at $N = 174$. (b) Several Q_α sequences across the magic number $Z = 82$, lead, about twenty neutrons away from doubly magic ^{208}Pb .

The U310 experiment employed an upgraded TASISpec decay station, which is shown in Fig.1. It was placed behind the gas-filled separator TASCA. The fusion-evaporation reactions $^{48}\text{Ca}+^{242}\text{Pu}$ and $^{48}\text{Ca}+^{244}\text{Pu}$ provided a total of 32 flerovium-candidate decay chains in effectively 18 days of beam time. Two and eleven decay chains were firmly assigned to even-even ^{286}Fl and ^{288}Fl isotopes, respectively. The – admittedly unexpected – observations include (i) an excited 0^+ state at 0.62(4) MeV excitation energy in ^{282}Cn , and (ii) a $Q_\alpha = 9.46(1)$ MeV decay branch (1 out of in total 51 known) from ^{284}Cn into ^{280}Ds [1]. Both observations indicate that there is hardly any shell gap at proton number $Z = 114$ - at least not at neutron numbers $N \approx 172$ -174. This statement is supported by demanding beyond-mean-field model calculations, which include the necessary triaxial shapes [2,3]. The existence of the excited 0^+ state in ^{282}Cn requires “an understanding of both shape coexistence and shape transitions for the heaviest elements” [1]. Second, using the known $Q_\alpha = 10.79(4)$ MeV for the $^{292}\text{Lv} \rightarrow ^{288}\text{Fl}$ α decay as well as the now precisely measured $Q_\alpha = 10.06(1)$ MeV for $^{288}\text{Fl} \rightarrow ^{284}\text{Ds}$, a smooth Q_α sequence across $Z = 114$ could be established. This is illustrated in Fig. 2(a) and compared with Po-Pb-Hg sequences in Fig. 2(b). Obviously, there is hardly any kink seen for $Z = 114$, while it is characteristic for any pronounced shell gap, i.e., magic numbers, such as the one at $Z = 82$.

The present results thus reinforce the benchmarking capability of nuclear spectroscopy experiments in the superheavy element regime itself. Future technical developments on beam intensity, target integrity, and detection efficiency should allow to “wring out tantalizing physics from compound nucleus production data where cross-sections are in the picobarn range” (quote referee report of [1]) – the sailing tour to the long-sought Island of Stability continues.

References:

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