Mass Measurements of heavy actinides with SHIPTRAP*

E. Minaya Ramirez[1,2]*, D. Ackermann*[2]*, K. Blaum*[3,4]*, M. Block*[2]*, C. Droese*[5]*, Ch. E. Düllmann*[1,2,6]*, M. Dworschak*[2]*, M. Eibach*[6]*, S. Eliseev*[3]*, E. Haettner*[2,7]*, F. Herfurth*[2]*, F.P. Heßberger*[1,2]*, S. Hofmann*[2]*, J. Ketelaer*[3]*, J. Ketter*[3]*, G. Marx*[5]*, D. Nesterenko*[8]*, Yu. Novikov*[8]*, W.R. Plass*[2,7]*, D. Rodríguez*[10]*, C. Scheidenberger*[2,7]*, L. Schweikhard*[5]*, P.G. Thirolf*[11,*]*, G.K. Vorobjev*[2,8]*, and C. Weber*[11,*]

[1]Helmholtz-Institut Mainz; [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt; [3]Max-Planck-Institut für Kernphysik, Heidelberg; [4]Ruprecht-Karls-Universität Heidelberg; [5]Ernst-Moritz-Arndt-Universität, Greifswald; [6]Johannes Gutenberg-Universität Mainz; [7]Justus-Liebig-Universität Gießen; [8]PNPI RAS Gatchina, St. Petersburg; [10]Universidad de Granada; [11]Ludwig-Maximilians-Universität München

Masses in the region of the heaviest elements could previously only be derived indirectly by linking mass differences between nuclides and their decay products using measured α-decay energies. However this approach depends on the knowledge of nuclear level schemes. In contrast, direct mass measurements yield absolute mass values, binding energies and provide anchor points to pin down α-decay chains. This is especially important for odd-odd and odd-A nuclides, where the α decay typically populates excited states. In the absence of complete and quantitative information of the nuclear structure, no unambiguous mass determination is possible. Mass measurements of nuclides, e.g., around ^{254}No allow determining the masses of nuclides located in the superheavy element region.

Nuclides above fermium can only be produced at very low rates. Nonetheless, recently the first direct measurements on transuranium nuclides have been performed with SHIPTRAP [1]. The obtained accurate mass values provided anchor points to fix α-decay chains passing through the nobelium isotopes $^{252-254}$No [2]. The measurements have now been extended to further even more exotic nuclides, namely ^{255}No and $^{255-256}$Lr. The radionuclides were produced and separated from the primary beam by the velocity filter SHIP. Fusion-evaporation reactions of a ^{48}Ca beam with lead and bismuth targets were used to produce different nobelium and lawrencium isotopes with cross sections as low as about 50 nb. Evaporation residues were guided to SHIPTRAP. In a first step their energy was decreased from tens of MeV to a few eV using a buffer-gas filled stopping cell. Afterwards they were injected into a 7-Tesla double-Penning-trap system. The mass was determined by measuring the cyclotron frequency ν_c = qB/(2πm) of the ions using a time-of flight ion-cyclotron-resonance detection technique. An important development to substantially reduce long-term fluctuations of the magnetic field [3] allowed the recording of a single resonance over a period of 4 days in the case of ^{256}Lr. This measurement represents a significant breakthrough towards direct mass measurements of superheavy nuclides.

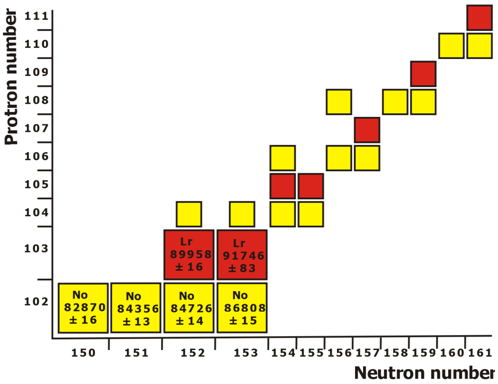

Figure 1: Decay chains linked to the direct mass measurements from this work. The mass excess is indicated in keV.

In the Atomic-Mass Evaluation 2003, the masses of the lawrencium isotopes ^{255,256}Lr were only estimated from systematic trends. The combination of our direct mass measurements with spectroscopic data allows determining the masses of superheavy nuclides (see Fig 1). The masses of α-decay chains starting with even-even nuclides, as for example ^{270}Ds (Z = 110), are now established with low uncertainties. For the first time we also provide anchor points for nuclides with an odd number of protons. Moreover, the new mass value from ^{255}No complement our previous results on the neutron-rich side of the N = 152 deformed shell. Thus our experimental binding energies provide precise values for the two-neutron separation energies S_{2n}. This allows mapping the deformed shell gap at N = 152, which is connected to the predicted spherical shell gap at N = 184 as it originates from the the same single-particle orbitals. Therefore the results obtained with SHIPTRAP enhance our knowledge of shell effects nearby the predicted island of stability.

References

[1] M. Block et al., Nature 463 (2010) 785.

[2] M. Dworschak et al., Phys. Rev. C 81 (2010) 064312.

[3] C. Droese et al., Nucl. Instrum. Meth. A 632 (2011) 157.

---

[*] Work supported by the BMBF (06ML236I, 06ML9148, 06GF9103I, RUS-07/015), Rosminnauki (2.2.1), GSI (Grant GFMARX1012), the Max-Planck Society, and the Research Center Elementary Forces, Mathematical Foundations and the Helmholtz Institute Mainz