Mass Measurements of No and Lr isotopes with SHIPTRAP*

M. Block[1], D. Ackermann[1], K. Blaum[2,3], C. Droese[4], Ch. E. Düllmann[5,6,1], M. Dworschak[1], M. Eibach[3,5], S. Eliseev[2], A. Gonschior[5], E. Haettner[1,7], F. Herfurth[1], F.P. Heßberger[1,6], S. Hofmann[1], J. Ketelaer[2], G. Marx[4], M. Mazzocco[8], E. Minaya Ramirez[6], D. Nesterenko[9], Yu. Novikov[9], W. R. Plaß[1,7], D. Rodríguez[10], C. Scheidenberger[1,7], L. Schweikhard[4], P. Thirolf[11], and C. Weber[11]

[1]GSI, Darmstadt, Germany; [2]MPI-K Heidelberg, Germany; [3]Universität Heidelberg, Germany; [4]Universität Greifswald, Germany; [5]Universität Mainz, Germany; [6]Helmholtz Institut Mainz, Germany; [7]Universität Gießen, Germany; [8]Universita di Padova, Italy; [9]Petersburg Nuclear Physics Institute, Gatchina, Russia; [10]Universidad de Granada, Spain; [11]LMU München, Germany

High-precision mass measurements of radionuclides provide information about their binding energy and are thus a powerful method to study their nuclear structure and to benchmark nuclear models. The region of superheavy elements that owe their existence to nuclear shell effects is of particular interest. However, these nuclides can only be produced in fusion-evaporation reactions at rather low rates of a few particles per second or less. Therefore, information about their masses was so far exclusively available from the observation of their decay. Recently, the first direct measurements on transuranium nuclides, three nobelium (Z = 102) isotopes, have been performed with SHIPTRAP [1]. The obtained accurate mass values provide anchor points to fix α-decay chains as demonstrated for the nobelium isotopes $^{252-254}$No [2]. This is especially important for odd-odd and odd-A nuclides where the α decay typically populates excited states complicating an unambiguous mass determination.

SHIPTRAP receives radionuclides after separation from the primary beam in the velocity filter SHIP. It is presently the only Penning trap for high-precision mass measurements of elements above fermium. Recently, the masses of the nuclides ^{255}No and ^{255,256}Lr ($Z = 103$) produced in the reactions ^{208}Pb(^{48}Ca,n)^{255}No and ^{209}Bi(^{48}Ca,xn)$^{257-x}$Lr have been measured. A primary beam energy of 4.55 AMeV was chosen resulting in production cross sections of about 50–200 nb. The corresponding production rate was as low as about one particle per minute entering the SHIPTRAP gas cell in the case of the nuclide ^{256}Lr, the lowest yield for which a Penning trap mass measurement was performed to date. The reaction products were decelerated in degrader foils and stopped in a gas cell in 50 mbar helium. The nuclides were extracted from the gas cell mainly as doubly charged ions. After cooling and accumulation in a radiofrequency quadrupole ion-beam cooler short bunches were injected into a double-Penning trap system inside a $B = 7$ T magnet. The mass was determined by measuring the cyclotron frequency $\nu_c = qB/(2\pi m)$ of the ions using a time-of-flight ion-cyclotron-resonance detection technique.

An example of a resonance for ^{255}No is shown in Fig. 1. An important development enabling these measurements

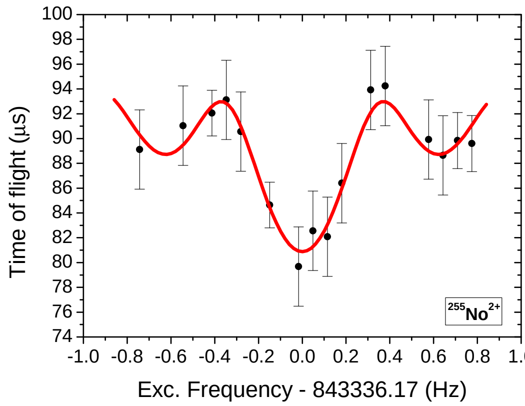

Figure 1: Cyclotron resonance of ^{255}No^{2+}. The solid line is a fit of the theoretical line shape to the data points.

was the implementation of active regulation systems controlling the pressure in the helium cryostat and the temperature in the bore of the superconducting solenoid [3]. In this way fluctuations of the magnetic field are reduced substantially and the time interval between successive calibration measurements can be increased. This is crucial for measurements of rare isotopes with low yield such as ^{256}Lr where a single resonance was recorded over a period of about 48 hours. Prior to our measurements the masses of both Lr isotopes listed in the Atomic-Mass Evaluation 2003 were only estimated from systematic trends. Now these isotopes have been established as new anchor points above uranium. In addition, the chain of neighboring nobelium isotopes whose masses have been measured directly has been extended across neutron number $N = 152$. This allows, for example, studying the neutron shell gap via the three-point difference of binding energies $\Delta^{(3)}(N) = (-1)^N/2[B(N+1) + B(N-1) - 2B(N)]$.

The SHIPTRAP measurements on nobelium and lawrencium are important steps towards direct mass measurements of superheavy nuclides in the near future.

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 (2011) in Press.

* Work supported by the BMBF (06ML236I, 06ML9148, 06GF9103I, RUS-07/015), Rosminnauki(2.2.1), the Max-Planck Society, and the Research Center Elementary Forces and Mathematical Foundations