Mass Measurements of Stored Exotic Nuclei

Yu.A. Litvinov[1,2], J. Stadlman[3], F. Attallah[1], K. Beckert[1], F. Bosch[1], M. Falch[4], B. Franczak[1], B. Franzke[1], H. Geissel[1,3], M. Hausmann[1], Th. Kerscher[4], O. Klepper[1], H.-J. Kluge[1], C. Kozhuharov[1], K.E.G. Löbner[4], G. Münzenberg[1], N. Nankov[1,3], F. Nolden[1], Yu.N. Novikov[2,5], Z. Patyk[1], T. Radon[1], H. Schatz[1], C. Scheidenberger[1], M. Steck[1], Z. Sun[1], H. Weick[1], H. Wollnik[3]

[1] GSI, Darmstadt, Germany, [2] State University, St. Petersburg, Russia,
[3] JLU, Giessen, Germany, [4] LMU, München, Germany, [5] PNPI, St. Petersburg, Russia

Exotic nuclei are produced via projectile fragmentation of different primary beams in beryllium targets placed at the entrance of the Fragment Separator (FRS). The fragments are spatially separated by the FRS, injected and stored in the Experimental Storage Ring (ESR) for direct mass measurements. Two complementary methods have been applied:

1 Schottky Mass Spectrometry (SMS)

Masses of more than 100 neutron-deficient heavy nuclides in the lead region were directly measured for the first time with a precision of roughly 100 keV in our first run with ^{209}Bi projectiles [1]. The combination of these measurements with experimental Q_α values allowed the determination of more than 60 new masses in addition [2]. The measured masses in this experiment cover a large area of proton-rich heavy nuclei up to the proton dripline.

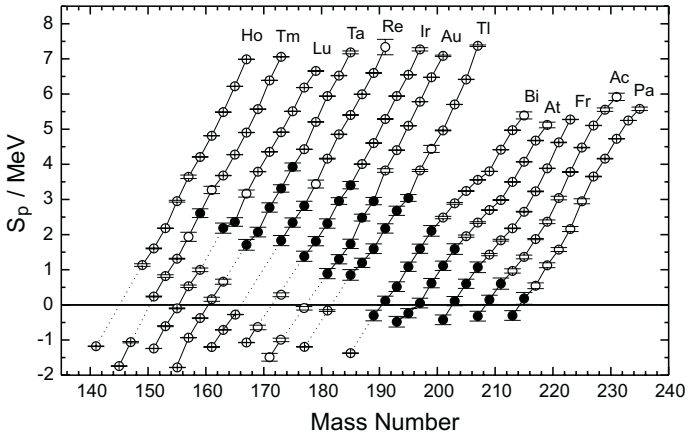

Figure 1: One-proton separation energies for odd-Z and odd-A nuclides. The full circles represent masses determined in this experiment [2].

Fig. 1 shows the one-proton separation energies for odd-Z and odd-A isotopes in the measured region. These data allowed to determine the experimental one-proton dripline for elements from bismuth to protactinium. For even-Z elements from tungsten to radium our data allow to predict reliably the two-proton dripline.

The single particle gap G_p is defined as $2G_p \equiv S_{2p}(Z,N) - S_{2p}(Z+2,N)$, where S_{2p} is the correspondig two-proton separation energy. The G_p values for the Z=82 shell region are shown in Fig. 2. Moving away from the doubly magic ^{208}Pb nucleus towards the proton dripline the shell gap is drastically reduced, which has not been observed for other

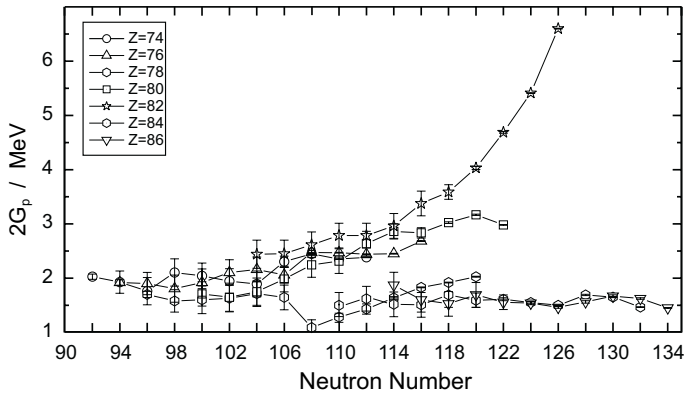

Figure 2: Experimental shell gaps G_p for different elements (see insert) in the vicinity of the Z=82 shell [2].

magic numbers. This can be explained, for example, by nuclear shape changes along the isotopic chains.

Our second experiment with ^{209}Bi projectiles contained several improvements. The better cooler performance, stabilization of power supplies and a new data aquisition system [3] increased the resolving power by a factor of two to $m/\Delta m \approx 700000$. This allows to resolve peaks with close mass-to-charge ratios as demonstrated in Fig. 3 for

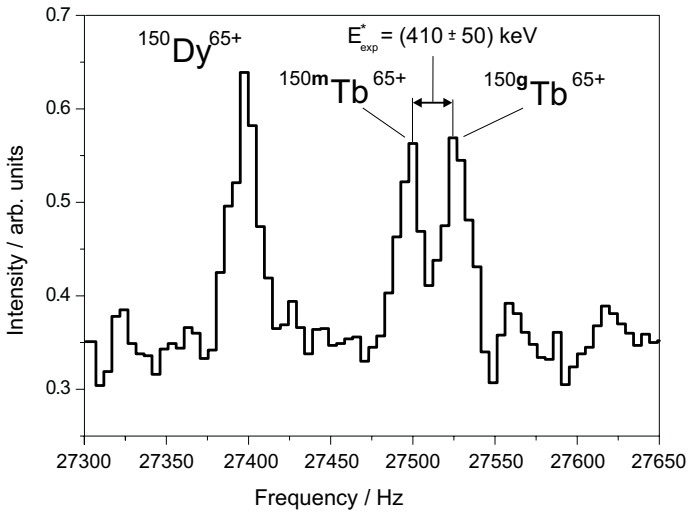

Figure 3: Schottky spectrum representing the ground state of ^{150}Dy^{65+} ions and bare ^{150}Tb^{65+} ions in the ground and isomeric state respectively. Note that the peaks of the ground and the isomeric state of ^{150}Tb correspond to only one particle each.

the frequency peaks of the ground and isomeric states of ^{150}Tb. The excitation energy deduced from our mass measurements is in good agreement with the literature [4]. The measured mass surface of the recent experiment covers our previous measurement and adds roughly 50 new proton-rich unknown masses. Although the data analysis is still in progress we can expect a precision of the mass values of about 50 keV. Schottky Mass Spectrometry was successfully applied to nuclides with half-lives longer than 10 sec, which is needed for cooling and spectrum recording.

2 Isochronous Time of Flight Mass Spectrometry (IMS)

To extend the study to shorter half-lives the ESR was operated in an isochronous mode where the inherent velocity spread of the hot fragments is compensated by different orbit lengths [5], i.e., the revolution time is independent on the velocity spread. Therefore, precise mass measurements can be performed without beam cooling. A time-of-flight detector was used to measure the revolution times of the stored fragments within a few hundred turns in the ESR (approx. 500 ns/turn). The stored ions penetrate a thin carbon foil (17 μg/cm^2) covered with CsJ [6] (approx. 10 μg/cm^2) on each side and release secondary electrons at each turn. These electrons are detected by micro channel plates (MCPs) and the signals are recorded by a digital sampling oscilloscope. The time differences between different occurences of a particle were used to deduce its revolution time. Spectra of the revolution times were generated using the data from several injections with an identical setting. The example of such a spectrum in Fig. 4 shows only a part of the m/q - acceptance of about $\pm$ 7.5%. The mass values of ^{70,71}Se therein were unknown according to ref. [4] and the uncertainities given for ^{68}As and ^{73}Br were large. Therefore, we measured masses for these nuclides.

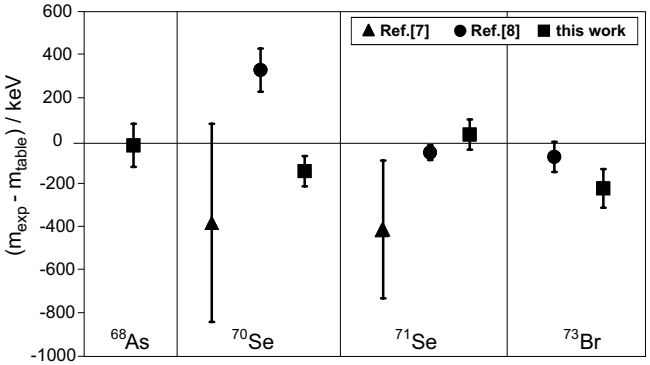

Figure 5: Comparison of mass values obtained from the isochronous TOF-measurements and other experiments [7, 8] with the table values of ref. [4]. Uncertainties of the table values are not included.

Fig. 5 shows the comparison of our results and recent measurements of ref. [7, 8] with the table values of ref. [4].

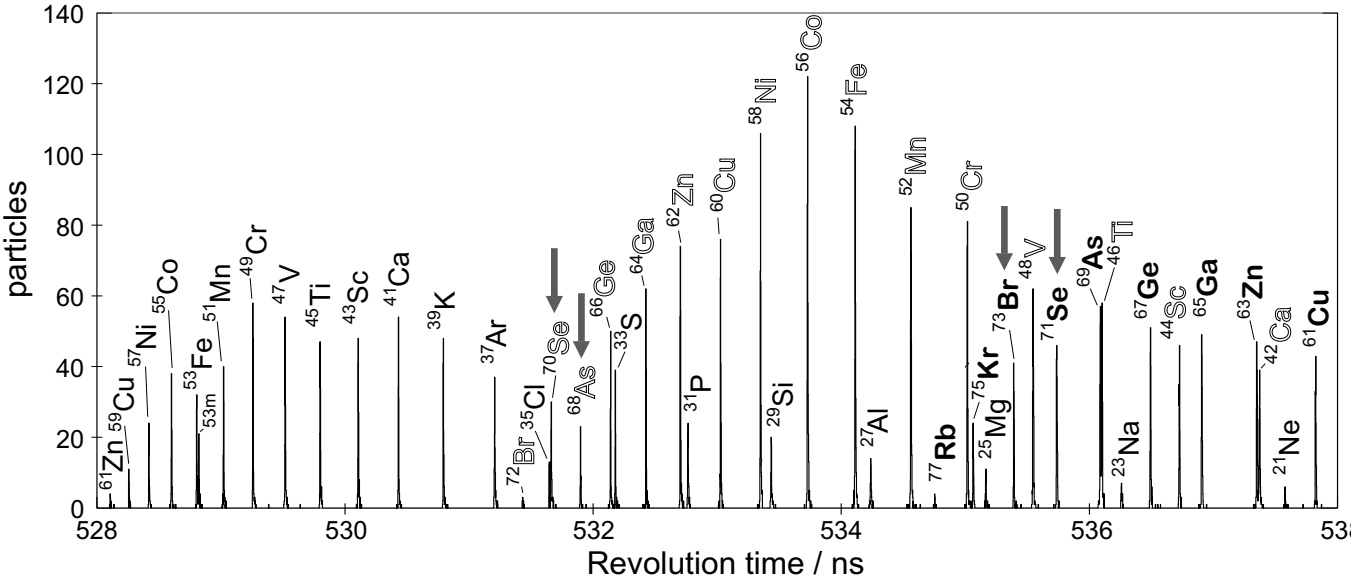

Figure 4: Revolution time spectrum of uncooled projectile fragments from a ^{84}Kr beam with an incident energy of 445.3 $A\cdot$ MeV. Groups of ions with the same isospin are marked with the same font. The arrows indicate those species which are shown in Fig. 5.

A mass resolving power of $m/\Delta m = 110000$ and a precision of δm $\approx$ 100 keV have been obtained. IMS is especially suited for direct mass measurements of nuclides with short half-lifes down to a few 10 μs.

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