Mass measurements of $^{114-124,130}$Xe with the ISOLTRAP Penning trap spectrometer

J. Dilling [a,*] G. Audi [b] D. Beck [c,**] G. Bollen [d,***] F. Herfurth [a] A. Kellerbauer [e] H.-J. Kluge [a] D. Lunney [b] R.B. Moore [g] C. Scheidenberger [a] S. Schwarz [e,***] G. Sikler [a] J. Szerypo [f] and the ISOLDE Collaboration [e]

[a] *GSI Darmstadt, Postfach 110552, D-64220 Darmstadt, Germany*
[b] *CSNSM-IN2P3-CNRS, F-91405 Orsay-Campus*
[c] *K.U.Leuven, Celestijnenlaan 200 D, B-3001 Leuven, Belgium*
[d] *Sekt. Physik, Ludwig-Maximilians-Universität München, D-85748 Garching*
[e] *CERN, CH-1211 Geneva 23, Switzerland*
[f] *JYFL, University of Jyväskylä, Fin-40351 Jyväskylä, Finland*
[g] *Foster Radiation Laboratory, McGill University, Montreal, H3A 2B1, Canada*

The masses of the xenon isotopes with $114 \leq A \leq 123$ were directly measured for the first time. The experiments were carried out at the ISOLTRAP triple trap spectrometer at the on-line mass separator ISOLDE/CERN. A mass resolving power of the Penning trap spectrometer of $m/\Delta m \approx 500000$ was chosen and an accuracy of $\delta m \approx 12$ keV for all investigated isotopes was achieved. An atomic mass evaluation was performed and the results of this adjustment are compared with theoretical predictions. The new results for the xenon isotopes and their effects on neighboring isotopes are discussed within the two-neutron separation energy picture.

Keywords: Penningtrap mass spectroscopy, xenon, nuclear binding energy, radioactive isotopes, atomic masses.

1. Introduction

Penning traps are devices especially suited for high-precision experiments such as g-factor determination [1,2], test of CPT-invariance [3] or atomic mass measurements. Recently the mass of stable ^{133}Cs was determined on a sub-ppb level [4]. At ISOLTRAP such a device is employed for the measurements of masses of unstable nuclei. So far, high-precision measurements on nearly 200 radioactive nuclides have been performed with an accuracy of typically 10^{-7}.

* *Corresponding author:* J. Dilling, E-mail: J.Dilling@gsi.de, Tel (Fax): +49 6159 71 2742 (2901)
** *present address:* GSI, Darmstadt
*** *present address:* NSCL/MSU, East Lansing

2. Set-Up

The ISOLTRAP mass spectrometer is installed at the on-line facility ISOLDE/CERN in Geneva. It consists of a linear radio frequency quadrupole (RFQ) trap [5] and two Penning traps [6,7]. The quasi-continuous ion beam delivered by ISOLDE with typically 30 or 60 keV is injected into the linear RFQ trap filled with He buffer gas. Here, the beam is electrostatically retarded, cooled by buffer gas collisions, bunched and extracted at low energy. The ions at typical 2.5 keV transport energy are transferred to the first Penning trap where mass selective buffer gas cooling is applied to further cool and isobarically clean the ion sample. Subsequently these ions with a charge-to-mass ratio q/m are delivered to the precision Penning trap where their cyclotron frequency $\nu_c = q/m \cdot B/2\pi$ is determined. The cyclotron frequency is determined by exiting the ion motion with a radiofrequency field for a period T_{RF} and by employing a time-of-flight technique. The magnetic field B is calibrated via a cyclotron frequency measurement of stable ^{133}Cs, delivered from a test ion source.

3. Measurements

In the case of the here presented Xe mass measurements a radiofrequency excitation time of the ions of $T_{RF} = 0.9$ s was chosen resulting in a resolving power of $R = 5 \cdot 10^5$. With typically 6000 detected ions per isotope a statistical accuracy in the mass determination of $\delta m/m = 3 \cdot 10^{-8}$ was achieved. As a conservative estimate of possible systematic errors an additional error of $1 \cdot 10^{-7}$ is added quadratically yielding a total uncertainty for ISOLTRAP mass values of all xenon isotopes of $\delta m \approx 12$ keV.

4. Results

Mass measurements were performed for the Xe isotopes with mass number $114 \leq A \leq 124$ and A = 130. Figure 1 on the left shows the difference between mass values from the Atomic Mass Evaluation 1995 (AME 95) and an evaluation including the new ISOLTRAP data. The masses of ^{114}Xe, ^{115}Xe, and ^{116}Xe were previously unknown. In the case of ^{118}Xe, the experimental mass uncertainty could be reduced by a factor of 100 whereas the uncertainties of the masses of ^{117}Xe and ^{119}Xe are reduced by one order of magnitude. The masses of ^{124}Xe and ^{130}Xe are known from literature with high accuracy. The deviation of those values from the ISOLTRAP data is δm(^{124}Xe) = 1 $\pm$ 12.5 keV and δm (^{130}Xe) = 3 $\pm$ 13 keV demonstrating the reliability of the ISOLTRAP data.

In the case of ^{120}Xe, a drastic discrepancy by 8 standard deviations between the literature value and the ISOLTRAP result was observed whereas smaller deviations were measured for ^{121}Xe (3σ), ^{122}Xe (2σ), and ^{118}Xe and ^{119}Xe (1σ).

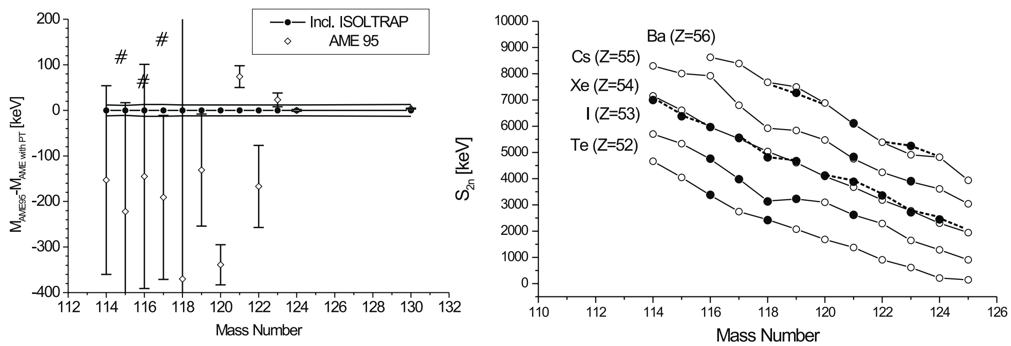

Figure 1. Left: Difference between mass values from the Atomic Mass Evaluation 1995 (AME 95) [8] (data points with error bars) and an evaluation including the ISOLTRAP data (zero line with error band). For isotopes marked with # masses are estimated from the extrapolation of systematic trends [8]. Right: Two-neutron separation energy S_{2n} as a function of mass number A. Filled circles show the new values, open circles old data from AME 95. No error-bars are shown.

The discrepancies were mainly due to incorrect β-endpoint measurements or underestimation of errors for those. The high-accuracy ISOLTRAP data influence via the manifold correlations quite a number of mass values of other isotopes. This impact can be seen most directly by a plot of the two-neutron separation energies in the xenon region as a function of mass number A (Fig. 1, right). Open circles indicate literature values taken from the previously published atomic mass evaluation AME 95 [8]. The 23 S_{2n}-values determined or significantly changed by the present work are shown as full dots.

Generally, a very smooth behaviour of the two-neutron separation energies (especially for the nuclides with even proton number) is found in this region of the chart of nuclides, indicating the absence of any drastic nuclear structure effects in these neutron mid-shell nuclides. The only stronger irregularities observed at A = 116 for cesium and at A = 118 for iodine might be due to the rather large uncertainties for the masses of ^{114}Cs and ^{116}Cs, respectively, or a nuclear structure effect for the case of ^{118}I.

5. Comparing the results with mass formulas

A comparison with three selected nuclear mass models is carried out within this work. More details about this comparison can be found in [9], and an overview on those formulas is given in [10]. The graphs in figure 2 show the difference between experimental and theoretical values. The model of Pearson et al. [11], based upon an extended Thomas-Fermi-Strutinski ansatz includes a Skyrme term to describe the interaction between the nucleons. The deforma-

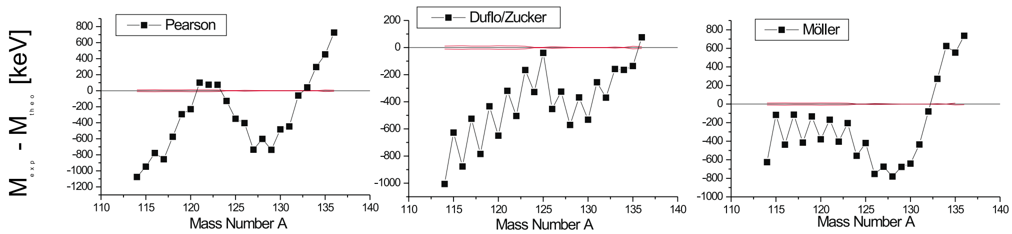

Figure 2. Comparison of the experimental mass values with the prediction of selected mass models for xenon isotopes with 114≤A≤136. The experimental masses are given as a zero line with an error band. Note the different scale on the energy axes for the three graphs.

tion energies used for correcting the primary model, seem to overestimate the behavior at around A = 121, here, no change in the experimental values is recognizable. The root-mean-squares (RMS) deviation for the xenon isotopes in the mass region 114≤A≤136 is $\Delta m(RMS) = 301\,\text{keV}$. The mass values by Duflo and Zuker [12] are derived by a so called microscopic mass formula. The odd-even staggering is clearly over-estimated in this mass formula. But the trend towards the closed neutron shell N = 82 (A = 136) is well covered. The deviation found is $\Delta m(RMS) = 413\,\text{keV}$. For the macroscopic-microscopic model of Möller and Nix [13] also the odd-even staggering seems to be too pronounced, since the differences between neighboring experimental values are on the order of $100 - 200$ keV. But the trend is best described by this model, the same smooth deformation-change towards the N = 82 shell is found. The RMS-difference for this model is $\Delta m(RMS) = 253\,\text{keV}$.

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