Direct mass measurements of neutron-deficient xenon isotopes with the ISOLTRAP mass spectrometer

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The masses of Xe isotopes with $124 \geq A \geq 114$ have been measured using the ISOLTRAP spectrometer at the on-line mass separator ISOLDE/CERN. A mass resolving power of 500000 was chosen resulting in an accuracy of $\delta m \approx 12\,keV$ for all isotopes investigated. Conflicts with existing mass data of several standard deviations were found.

Key words: Radioactive ions, atomic masses, mass spectrometry, Penning trap, xenon isotopes

1 Introduction

Accurate mass measurements can uncover interesting manifestations of nuclear structure. The case of Xe (Z=54) is interesting since mid-shell effects (in this case $50 \leq N \leq 82$) can sometimes reveal surprises such as nuclear shape coexistence [1]. Most of the masses in this region are determined by Q-beta measurements which are often erroneous if not performed carefully. For these reasons, the direct technique of ISOLTRAP, since years well established as reliable and accurate, was applied.

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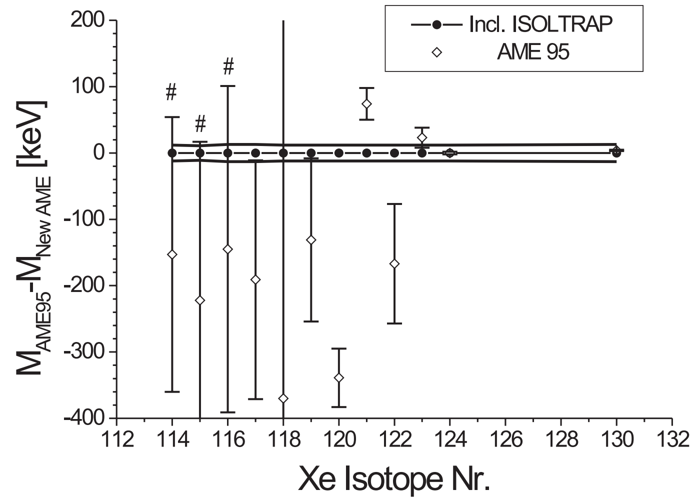

Fig. 1. Difference between mass values from the Atomic Mass Evaluation 1995 (AME 95) [2] (data points with error bars) and an evaluation including the ISOLTRAP data (zero line with error band). For isotopes marked with # masses are estimated from the extrapolation of systematic trends [2].

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 (RFQ) trap [3,4] and two Penning traps [5,6]. 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 magnetic field B is calibrated via a cyclotron frequency measurement of stable ^{133}Cs, delivered from a test ion source.

3 Measurements

The mass measurements of stable and neutron-deficient Xe isotopes reported in this paper were taken in one run that last only 29 hours. Very few ions were accumulated in the precision trap for the mass determination procedure in order to minimize systematic errors caused by frequency shifts due to possible contaminations [7]. A radiofrequency excitation time of the ions of $T_{RF} = 0.9$s

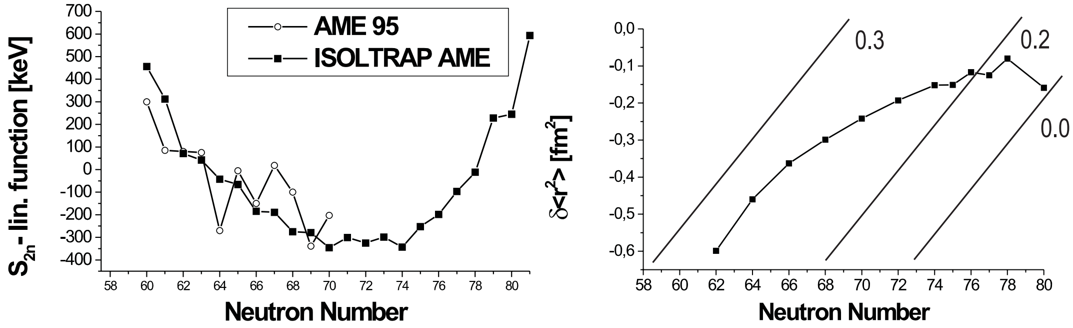

Fig. 2. Left: Two-neutron separation energy for some Xe isotopes as a function of neutron number. A linear function, that describes the linear trend, has been subtracted. The values with and without ISOLTRAP data are depicted. Right: Change of the mean-squared charge radius $\delta\langle r^2\rangle$ for Xe isotopes with respect to $N = 82$ [1] and equideformation lines given by the droplet model for different $\langle\beta_2\rangle$ values.

was chosen, resulting in a resolving power of $R = 5 \cdot 10^5$. With typically 6000 detected ions per isotope a statistical precision in the mass determination of $\delta m/m = 5 \cdot 10^{-8}$ has been achieved. As a conservative estimate of possible systematic uncertainties an additional error of $1 \cdot 10^{-7}$ is added quadratically yielding a total uncertainty for ISOLTRAP mass values of all xenon isotopes of $\approx$ 12 keV. The reliability of the ISOLTRAP measurement can be tested in the cases of the stable isotopes ^{124}Xe and ^{130}Xe, which are known with a mass accuracy of $1 \cdot 10^{-8}$. The deviation of the ISOLTRAP data from those values is $\delta m(^{124}Xe) = 1(12.5)\, keV$ and $\delta m(^{130}Xe) = 3(13)\, keV$, hence excellent agreement is observed.

4 Results

Figure 1 shows a comparison of the masses given in the 1995 Atomic Mass Evaluation (AME 95) [2] and a new evaluation including the ISOLTRAP values. The AME 95 masses marked with # are estimates from systematic trends in the mass landscape [2]. Good agreement of the latter values with the ISOLTRAP data is found. Approaching the valley of stability deviations manifest. Discrepancies with the values for the isotopes with $A = 120, 121$ and 123 are found. For ^{120}Xe the difference is $\delta m = 338\, keV$ corresponding to 7.7 standard deviations. The origin of all deviations could be identified to be incorrect input data from other experiments, arising mainly from misjudgement of beta endpoint energies and corresponding errors from Fermi-Kurie plots or of K/β^+-ratios. Details will be discussed elsewhere [8].

Figure 2 (left) shows the two-neutron separation energies calculated for part of the xenon isotopic chain as a function of neutron number. With the ISOLTRAP data included the trend of the separation energy is very smooth and shows a pronounced curvature. At $N = 82$ the two-neutron separation energy abruptly increases in accordance with the magicity of this closed neutron shell. The right figure depicts the changes of the mean-squared charge radius $\delta\langle r^2\rangle$ as derived from laser spectroscopy experiments [1] for the same chain of isotopes. Also shown are equideformation lines as predicted by the droplet model for different deformation parameter values. Starting with a spherical configuration at $N = 82$, the nuclei become increasingly deformed with the removal of neutrons. A similarly smooth behaviour as for the S_{2n} values is observed which is typical for the transitional nuclear region.

5 Conclusion and Outlook

With the ISOLTRAP spectrometer, recently upgraded by a gas-filled RFQ trap, high-accuracy mass measurements have been performed on neutron-deficient xenon isotopes. For $A = 114 - 123$ nuclear binding energies have been determined for the first time. Details of these measurements and the influence of the ISOLTRAP results on the mass landscape including that due to known Q-value links will be discussed in a forthcoming publication [8].

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