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

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Abstract

The masses of the Xe isotopes with $124 \geq A \geq 114$ have been measured using the ISOLTRAP spectrometer at the on-line mass separator ISOLDE/CERN. ISOLTRAP consists of two Penning traps and a recently added linear radio frequency quadrupol trap for retardation, cooling and bunched ejection of the ISOLDE beam into the Penning trap section. A resolving power 10^6 was chosen resulting in a mass accuracy for all isotopes investigated of $\delta m \approx 12\,keV$. Strong conflicts with existing mass data of up to 7.7 standard deviations could be solved.

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

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1 Introduction The masses of neutron-deficient xenon isotopes were not very well known before. For the isotopes far away of the valley of beta stability only approximations from systematic trends could be given in the Atomic mass Evaluation (AME) of Audi and Wapstra in 1995 (1). Direct mass measurements on those exotic noble gases have been very difficult in the past and the standard way to determine those was either by Q_β-links or by measuring

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the ratio of electron capture to β^+. A new direct method became recently possible with the ISOLTRAP triple trap spectrometer where a Penning trap time-of-flight technique is applied.

2 Set-Up The ISOLTRAP mass spectrometer is installed at the on-line facility ISOLDE/ CERN (4) in Geneva. It consists of a recently added linear radio frequency (RFQ) trap (5; 6) and two Penning traps (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 buffergas collisions, bunched and extracted at low energy. The ions at typical 2.5 keV energy are transferred to the first Penning trap where mass selective buffer gas cooling is applied (8) to further cool and isobarically clean the ion sample. Subsequently these ions are delivered to the precision Penning trap. Here, only very few ions are accumulated and their cyclotron frequency is determined by interaction with radio frequency and by use of a time-of-flight technique (7). Masses are determined by the relation $\nu_C = B/2\pi \cdot m/q$, where ν_C is the cyclotron frequency and m, q are the mass and charge of the ion. The magnetic field B is determined by using the well known mass of ^{133}Cs as reference from an off-line ion source.

3 Measurements The mass measurements of stable and neutron-deficient Xe isotopes reported in this paper were taken in one run. Reference measurements with ^{133}Cs were done regularly during the run. All high-accuracy mass measurements of the Xe isotopes were performed within 29 hours. The typical duration of the determination of one mass was about 40 min. For the overall efficiency $\eta = 4 \cdot 10^{-4}$ was found. Only very few ions were accumulated in the precision trap for the mass determination procedure to ensure a pure sample. Most masses were determined with only one ion at a time in the trap, excluding in this way systematic frequency shifts due to contaminations (9). In figure 1. on the left the resonance curve of ^{120}Xe is depicted together with the fit of the data points to the theoretical model. The cyclotron resonance frequency was determined to be $\nu_C(^{120}Xe) = 758571.355(29)Hz$. By choosing the excitation time of the ions by RF to be $T_{RF} = 0.9$ s the resulting linewidth is $\Delta\nu_C(FWHM) = 1.5\,Hz$. This is leading to a resolving power of $R = \nu_C/\Delta\nu_C(FWHM) = 1 \cdot 10^6$. The statistical precision is $\delta\nu_c/\nu_c = 5 \cdot 10^{-8}$. For the final values of the frequency ratios a conservative estimate of possible systematic errors of $\delta\nu_c = 1 \cdot 10^{-7} Hz$ is added. Masses of the stable isotopes ^{124}Xe and ^{130}Xe were re-measured which were known before on a $1 \cdot 10^{-8}$ accuracy level. The deviation of the ISOLTRAP data from those values is $\delta m(^{124}Xe) = 1(12.5)\,keV$ and $\delta m(^{130}Xe) = 3(13)\,keV$ This agreement with the stable masses already known with better accuracy demonstrates the high performance of the ISOLTRAP mass spectrometer.

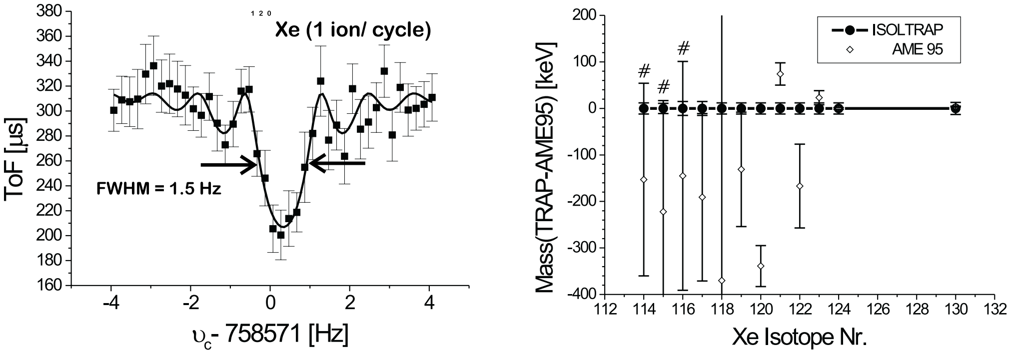

Fig. 1. Left: Measurement of the cyclotron frequency resonance of ^{120}Xe. The time of flight of the ions from the precision trap to a particle detector is plotted as a function of applied radio frequency (RF). The solid curve represents a fit to the data points by the theoretical line profile. Right: Comparison of the ISOLTRAP data with the Atomic Mass Evaluation 1995 (AME 95) (1) values for xenon isotopes. The ISOLTRAP data are set to zero and the difference to the AME 95 data is plotted. Isotopes marked with #: the masses of which have been estimated from extrapolations of systematic trends (1). The error for ^{118}Xe is $\Delta m = \pm 1000\,keV$.

5 Results Figure 1. on the right shows a comparison of the ISOLTRAP masses with the values given in the 1995 Atomic Mass Evaluation (AME 95) of Audi and Wapstra (1). All masses measured by ISOLTRAP have an uncertainty of $\delta m \approx 12\,keV$. The ISOLTRAP data are set to zero and the difference is shown. The AME 95 data marked with # are approximations from systematic trends in the mass landscape (1). Good agreement of the latter values with the ISOLTRAP data is found. Approaching the valley of stability deviations manifest. Strong discrepancies with the values for xenon for $A = 120, 121$ and 123 are found. For example for ^{120}Xe the difference is $\delta m = 338\,keV$ corresponding to 7.7 standard deviations. All conflicts could be solved and are discussed in more detail elsewhere (11). Figure 2. shows on the left the two-neutron separation energies for some xenon isotopes as a function of neutron number. The difference in these values with and without ISOLTRAP data is shown. A linear function, describing the general trend is subtracted. On the right the mean charge radii $<r^2>$ derived from laser spectroscopy experiments, taken from (10) are depicted for the same chain of isotopes. Quantify both picture show the same trend in deformation of the core. In the mean charge radii the smooth change in deformation which is typical for the transitional nuclear region can be seen. The same behavior is reflected in the two-neutron separation energies and the improve data set now also shows that smooth development.

5 Conclusion and Outlook The upgrade of the ISOLTRAP spectrometer with the gas-filled RFQ trap allowed for the first time to measure directly the

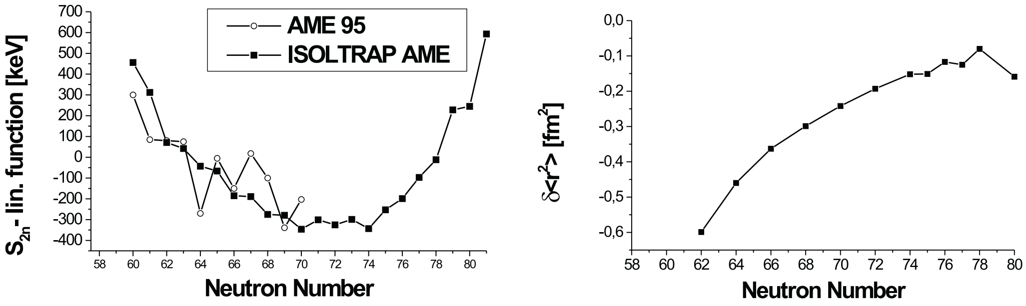

Fig. 2. Left: Two neutron separation energy for some Xe isotopes as a function of neutron number. A linear function, that describes the linear trend, has been subtracted. The values with and without ISOLTRAP data are depicted. Right: Mean squared charge radii <r^2 > of the same chain of Xe isotopes. Taken from (10).

mass of the exotic noble gas xenon isotopes ^{114}Xe - ^{123}Xe. All values are measured with an typical accuracy of $\delta m \approx 12\,keV$. The achieved masses improved the existing values of the AME 95 significantly and will be included in the new edition AME 2000. The influence of those results on the mass landscape e.g. due to known Q-value links and the general impact is discussed in the following publication (11).

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