Eur. Phys. J. A **25**, s01, 59–60 (2005)
DOI: 10.1140/epjad/i2005-06-132-y

EPJ A direct
electronic only

The LEBIT 9.4 T Penning trap system

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Received: 21 January 2005 / Revised version: 14 March 2005 /
Published online: 5 July 2005 –

Abstract. The initial experimental program with the Low-Energy Beam and Ion Trap Facility, or LEBIT, will concentrate on Penning trap mass measurements of rare isotopes, delivered by the Coupled Cyclotron Facility (CCF) of the NSCL. The LEBIT Penning trap system has been optimized for high-accuracy mass measurements of very short-lived isotopes.

PACS. 21.10.Dr Binding energies and masses – 32.10.Bi Atomic masses, mass spectra, abundances, and isotopes – 07.75.+h Mass spectrometers

1 Introduction

The primary experimental goal of the LEBIT project is to make high-precision mass measurements of rare isotopes produced by projectile fragmentation. For this purpose, relativistic rare isotope beams are converted into low-energy beams with excellent quality by using gas stopping and advanced ion guiding, cooling, and bunching techniques, as discussed in more detail in [1]. For the mass measurements a high-performance Penning trap mass spectrometer has been designed and built.

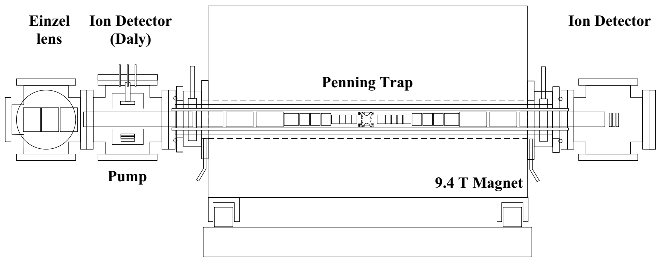

Fig. 1. Schematic layout of the LEBIT Penning trap system.

2 The LEBIT 9.4 T Penning trap system

2.1 Experimental setup

Figure 1 shows the layout of the experimental setup of the LEBIT Penning trap mass spectrometer. The magnetic field is provided by an actively-shielded persistent superconducting magnet (Cryomagnetics). The magnet system has been upgraded by additional external-field compensation coils, which reduce the effect of external field changes, as they occur in an accelerator environment. The employment of a 9.4 T field, as compared to ~ 6 T which is typical of current systems, has the advantage that a given precision can be achieved in about half the measurement time. A precisely machined vacuum tube, mounted inside the room-temperature bore of the magnet, serves as an ion optical bench for optics components and the trap electrode system. Two ion-optical packages, one containing the injection optics and Penning trap and the other containing the ejection optics, are inserted into opposite ends of this bore tube. The ion trap and optics elements in its vicinity can be cooled with the help of a cryogenic shield. This aids the creation of an ultra-high vacuum in the center of the bore tube, which is pumped by two turbomolecular pumps located on either end of the magnet. Ion bunches that are delivered by the LEBIT buncher/cooler [2] are focused and injected into the magnetic field and captured in the Penning trap. For the mass determination via cyclotron frequency determination the ions are driven by a radiofrequency (RF) field, ejected out of the trap and their time of flight to a detector is measured. Currently a micro channel plate detector located down-stream of the trap is used. In the near future it is planned to eject the ions upstream and to use a Daly detector, mounted perpendicular to the beam axis, as indicated in fig. 1. This would free the back side of the ion trap, allowing for example detectors for in-trap decay studies to be installed.

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Fig. 2. The LEBIT high-precision Penning trap with the end-cap electrode removed.

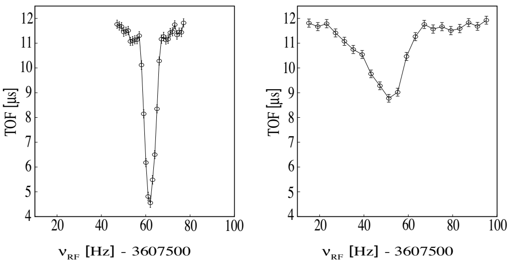

Fig. 3. Two resonance curves obtained with dipole excitation at the reduced cyclotron frequency. Optimized correction voltages (left) and incorrect values (right). The same scale is used in both panels. Lines are to guide the eye only and not a fit.

2.2 Penning trap design

The LEBIT Penning trap's electrodes (see fig. 2) are constructed of high-conductivity copper and plated with gold. The insulators are made of aluminum oxide. The ring electrode is eightfold segmented. This allows not only for the creation of a quadrupole RF field, as required for the excitation of the ion motion at the ion's cyclotron frequency ω_c, but also the application of an octupole RF field. Such a field should allow one to drive the ion motion at $2\omega_c$ and provide a higher resolving power. This new excitation mode is presently under study at LEBIT. Extensive numerical calculations have been performed for the minimization of electric and magnetic imperfections and the optimization of the trap design. To avoid introducing systematic errors in mass measurements both the electric quadrupole and magnetic dipole field inside the trap must be free of imperfections. Magnetic field imperfections introduced by the susceptibility of the chosen materials can be strongly minimized by using thin electrodes and by optimizing the material distribution. Deviations from the electric quadrupole field are due to finite electrodes, and holes and segments in the electrodes. Two pairs of correction electrodes are used to provide efficient compensation of these effects. The importance of using such correction electrodes and appropriate voltages applied to them is illustrated in fig. 3. Poorly chosen correction voltages lead to frequency shifts and broadened and asymmetric shapes of the resonance curves. Most sensitive for these tests are resonances of the reduced cyclotron motion, which can be excited with dipole RF fields and which have been used in the example shown here.

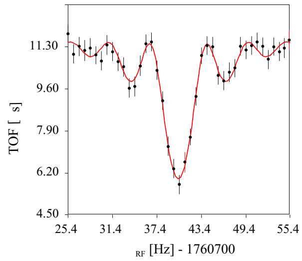

Fig. 4. Cyclotron resonance curve of $^{82}Kr^+$ ions with a fit of the theoretical line shape. An excitation time of 200 ms has been used in this measurement [4].

2.3 The Lorentz steerer

Mass measurements using the LEBIT Penning trap system are based on a cyclotron frequency determination achieved via the excitation of the ion motion with an azimuthal quadrupole RF field [3]. In this scheme the ions must be prepared to perform a magnetron motion prior to this excitation. The usual method involves driving the ions resonantly at their magnetron frequency. To eliminate this step, thus saving time, we have developed a new technique. A cylindrical tube which has been segmented into four pieces is located in front of the trap in the high-field region. This arrangement is used to create an electric field perpendicular to the magnetic field. Passing through this field combination the ions perform an $\mathbf{E} \times \mathbf{B}$ drift motion, leading to an off-axis capture of the ions inside the Penning trap and resulting in the desired magnetron motion.

3 System performance

The LEBIT Penning trap has been commissioned with stable beams. Already after a few month of system tuning very good performance is observed. For the transfer of ions from the buncher into the Penning trap an efficiency of ~ 50–70% is typically achieved. Excellent line shapes and high resolving powers are obtained. A sample cyclotron resonance curve with $R \sim 450000$ for a 200 ms excitation time is shown in fig. 4. Perfect agreement is observed between the data points and the fit with the theoretical line shape [4]. The highest resolving power observed so far is about 3000000 for a 1 s excitation time. Test measurements have also been performed to assess the achievable accuracy. Already in the first mass comparisons between stable krypton and argon isotopes a mass accuracy of better than 10^{-7} has been verified [1].

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