The ISOLTRAP Mass Spectrometer

The ISOLTRAP experiment is a high-precision mass spectrometer which is installed at the on-line isotope separator ISOLDE at CERN [1]. It consists of a beam preparation trap and a tandem Penning trap setup. The tandem Penning trap configuration is made up of a cylindrical Penning trap for the cooling and isobaric cleaning of the ion beam bunch and a hyperbolic Penning trap for the precision mass measurements [2]. The two Penning traps have resolving powers of about 10^10 and about 10^8, respectively. The masses of more than a hundred radioactive nuclides have so far been measured with the ISOLTRAP mass spectrometer.

The beam conditioning stage has been subject to many changes and improvements. Originally, the cooling Penning trap also served as the beam deceleration device. This design gave rise to some problems and restrictions. Its most severe limitation was the fact that it was only able to decelerate and capture the nuclides of surface-ionizable elements, namely the alkali metals and the alkali earths. This restriction was removed by the implementation of a so-called very large Paul trap, which makes use of buffer gas cooling [3]. The linear radio-frequency quadrupole (RFQ) ion trap that is described here is the next-generation beam preparation trap. It was designed to improve the total efficiency of the beam preparation stage by carefully matching its acceptance to the transverse phase space of the ISOLDE beam. The linear RFQ ion trap, which was installed in 1998 and 1999, also uses buffer gas cooling [4].

Schematic Overview of the Principle of the RFQ Ion Trap

The ISOLDE beam enters the structure through the decelerating and the focusing electrodes. In the ion guide, the decelerated beam is radially confined by the pseudopotential of the RFQ field while it is dragged along the axis of the structure by a small axial DC field. The cooled ions are finally trapped in an axial potential well that extends over a few tens of millimeters near the end of the ion guide. The beam bunch is ejected by lowering the potential of the axial trap on the exit side, and the bunch traverses a pulsed cavity in which its potential energy is adapted to ground potential.

Characteristics of ISOLTRAP’s Linear RFQ Ion Trap: Cooling Time

The left figure shows the temporal width of an ejected ion pulse as a function of the storage time. It is seen that the pulse width increases proportionally to the square root of the storage time. The time constant of the decrease is the cooling time \( \tau_{\text{cool}} \) for K+ ions in helium buffer gas at 0.25 Pa (measured at the gauge position just outside the rod structure), the cooling time is \( \tau_{\text{cool}} \approx 0.5 \) ms. The storage time in the trap must be several times \( \tau_{\text{cool}} \) in order to extract only ions that are completely cooled.

The right figure shows cooling times \( \tau_{\text{cool}} \) as a function of the buffer gas pressure. For a very high buffer gas pressure of 1 Pa (again at the gauge position), a cooling time of only a few hundred microseconds is measured [5].

Photograph of the Complete RFQ Ion Trap and Injection System

The assembled four-rod electrode structure of the ISOLTRAP radio-frequency quadrupole ion trap. On the left, one can see the ellipsoidal injection electrode (the outside surface is cylindrical) and the flat focusing electrode. The four quadrupole rods are 18 mm in diameter and about 880 mm long. Each rod consists of 26 axial segments that are separated by ceramic insulators. The rods are mounted onto four support disks whose distance from each other is defined by three sets of spacing rods. Eight solid ceramic rods are placed axially in the gap between the quadrupole rods in order to "seal" the system and maximize the buffer gas pressure inside for a given pumping capacity of the system.

ISOLTRAP Measurements Performed in 1999

- Argon Ar: 33, 34, 42, 43
- Xenon Xe: 114, 115, 116, 117, 118, 119, 120, 121, 122, 123
- Mercury Hg: 182, 183, 197

* Uncertainty reduced
* Not previously measured

Example of a Time-of-Flight Resonance

For the determination of the longitudinal temperature in the trap, the shape of the ejected ion pulse was measured with a micro-channel-plate (MCP) detector. The measured shape was compared to theoretical shapes that were calculated for different temperatures. The good agreement for 300 K suggests that the ions are cooled to the temperature of the buffer gas (left figure). The electrical potentials applied to the trap and the extraction electrodes were used to calculate the energy distribution of the ejected ion bunch (right figure). From this spectrum, a longitudinal emittance of the ion pulse of \( \epsilon_{\text{long}} \approx 10 \times \text{mm mrad} \) for a 60-kV beam, a more than tenfold improvement over the previous value of \( \epsilon_{\text{long}} \approx 100 \times \text{mm mrad} \) can be obtained.

The transverse emittance was measured using a beam observation system with a phosphor screen and a beam scanner. It was found to be \( \epsilon_{\text{trans}} \approx 10 \times \text{mm mrad} \) for a beam bunch energy of 2.5 keV. This corresponds to a transverse beam emittance of about 3 mm mrad for a 60-kV beam, a more than tenfold improvement over the previous value of 30 mm mrad.

Summary and Outlook

The implementation of the RFQ ion guide beam preparation trap has been a highly successful improvement to the ISOLTRAP facility. The total efficiency of the beam preparation stage was increased by three orders of magnitude compared with the previously used very large Paul trap. This increase is efficiency, along with the emittance-improving properties of the buffer gas cooling scheme, has made possible the measurement of the masses of radioactive nuclides very far from stability and with very short half-lives.

Practical experience with the existing system has led to the theoretical development of a novel ion guide design in which the four rods are replaced by a hollow cylinder that is longitudinally cut into wedges [6]. This simpler design whose properties are under study, and simulations appear to show the same characteristics of the current system, but promises to be easier to build, implement, and control.

Contact Information and References

Contact: A. Kelleraus
CERN Division EP
1211 Geneva 23, Switzerland
akelleraus@cern.ch

References
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