Hyperfine Interactions **132:** 531–534, 2001.

A New Concept for Time-of-Flight Mass Spectrometry with Slowed-down Short-Lived Isotopes

C. SCHEIDENBERGER[1], F. ATTALLAH[1], A. CASARES[2], U. CZOK[2], A. DODONOV[3], S. A. ELISEEV[2], H. GEISSEL[1], M. HAUSMANN[1], A. KHOLOMEEV[2], V. KOZLOVSKI[3], YU. A. LITVINOV[1], M. MAIER[1], G. MÜNZENBERG[1], N. NANKOV[1], YU. N. NOVIKOV[4], T. RADON[1], J. STADLMANN[2], H. WEICK[1], M. WEIDENMÜLLER[1], H. WOLLNIK[2] and Z. ZHOU[2]

[1] *GSI, Planckstraße 1, D-64291 Darmstadt, Germany*
[2] *II.Physikalisches Institut, Justus-Liebig-Universität Gießen, D-35392 Gießen, Germany*
[3] *Institute of Chemical Physics, Chernogolovka, Russia*
[4] *Petersburg Nuclear Physics Institute, St. Petersburg, Russia*

Abstract. A new concept for direct mass measurements of short-lived nuclei with an electrostatic time-of-flight mass spectrometer is described. The spectrometer can be coupled to an in-flight separator such as SHIP or FRS via a gas stopping cell and a gas-filled linear Paul trap. The time required for mass measurement is of the order of a few milliseconds allowing one to investigate nuclei with these short half-lives. A mass-resolving-power $m/\Delta m_{\mathrm{FWHM}} = 50\,000$ has been reached. First results of the range-focusing technique are presented, which is under development for the efficient stopping and extraction of relativistic exotic nuclei.

Key words: time-of-flight mass spectrometer, exotic nuclei, range focusing.

1. Direct mass measurement with electrostatic time-of-flight mass spectrometers

The new concept of slowing-down, stopping, extraction, and re-acceleration of exotic nuclear beams opens up new experimental possibilities to study the gross properties and the structure of short-lived nuclei. One possibility is direct mass measurements with electrostatic time-of-flight spectrometers. A schematic view of the system which is presently under construction is shown in Figure 1. It consists of three main parts:

- A gas-filled stopping cell with an entrance window and an exit nozzle. In this cell the ions are slowed-down to thermal energies and extracted into
- a gas-filled radiofrequency quadrupole, in which the ions are guided and cooled by buffer-gas collisions and which has an electrical potential well at its

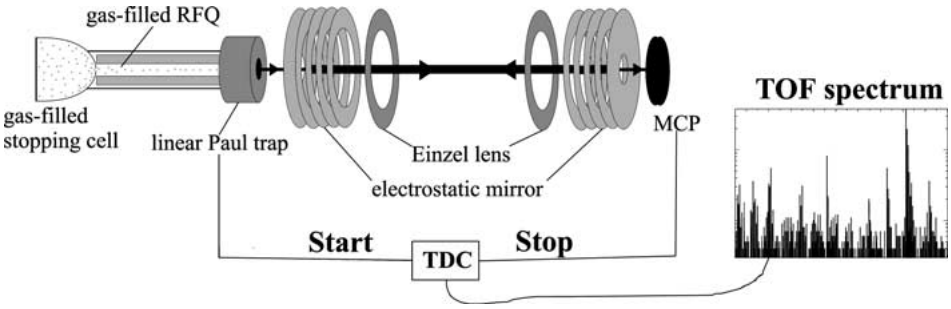


Figure 1. Schematic view of an electrostatic time-of-flight mass spectrometer, which can be coupled to an in-flight separator via a gas stopping cell and a gas-filled linear Paul trap system.

end. In this linear Paul trap the ions can be accumulated, stored, cooled, and bunched. The device acts as ion source, from which the ions are injected into

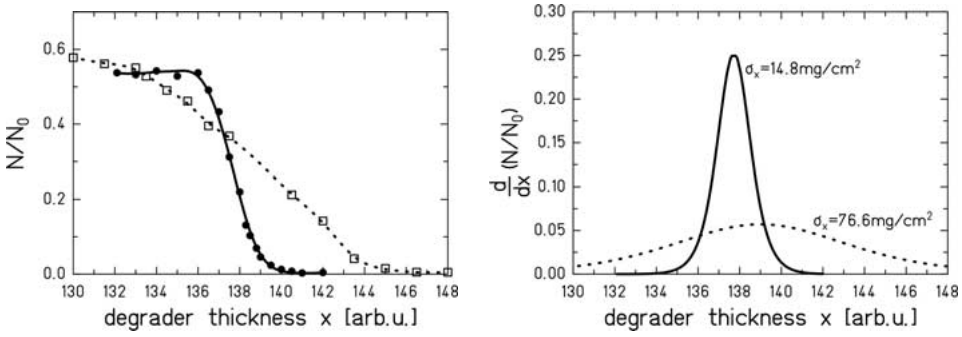
- an energy-isochronous (multiple-) reflection time-of-flight mass spectrometer with electrostatic ion mirrors [1]. In these devices the time-of-flight between ion injection (ejection from the Paul trap) and their arrival at the microchannel plate stop detector (MCP) is independent of their kinetic energy and depends only on their mass. The mass of an ion is obtained by the comparison of its time-of-flight with that of at least two known reference masses.

Figure 1 shows a schematic view of a system which can be used for multiple reflections. With such a spectrometer of 35 cm length and ions with kinetic energies of 6 keV up to hundred reflections have been observed at a residual gas pressure of the order of 10^{-7} mbar, the efficiency was 20% [2]. The remarkable property and the potential of these spectrometers is that a mass resolving power of 50 000 is reached after 31 reflections and the measurement time is less than 800 μs for ions with mass number $A = 28$ [2]. Using different stable Kr and Pb isotopes a relative mass accuracy $\delta m/m = 2\text{–}3 \cdot 10^{-6}$ corresponding to 100–600 keV has been reached. Presently several applications are considered and their feasibility is under investigation:

- The spectrometer can be used for mass determination and identification of the extracted ions and/or molecules created in the stopping cell. It can also serve as mass filter, when the ejection mirror is properly pulsed to transmit only ions within a certain mass range.
- Direct mass measurements on short-lived nuclei with half-lives of the order of milliseconds are feasible because the time for stopping, extraction, cooling, and mass determination is of the same order of magnitude [3–5]. Coupled for instance to the SHIPTRAP [6] facility, the spectrometer can complement the planned Penning trap mass measurements on transuranium elements.
- Decay-spectroscopy experiments with mass-separated exotic nuclei are possible if a position-sensitive detector is used as stop detector and the ions' flight time and position is recorded event-by-event.

2. Slowing down and range focusing of relativistic exotic nuclei

One source for short-lived nuclei are fragmentation and/or fission reactions of relativistic projectiles and in-flight separation with, e.g., the FRS [7]. The fragment beams are characterized by a broad energy distribution due to the nuclear reaction process and the energy-loss straggling in the production target. For these nuclei range focusing [8], which is achieved by using a dispersive magnetic dipole stage and a wedge-shaped degrader, is essential in order to reach fast slowing down and efficient extraction from the gas stopping cell. Typically they have specific kinetic energies of several hundred MeV/u and ranges of several g/cm^2. For instance, a monoenergetic beam of 360 MeV/u $^{56}Ni^{28+}$ ions has a calculated mean range of 4150 cm and a range straggling of 14 cm (FWHM) in Ar gas at normal temperature and pressure. The range-focusing technique [8] has been developed at the FRS [9], which yields a small spatial distribution of the stopped fragments, see Figure 2. This is an essential prerequisite to obtain high collection and extraction efficiency. As can be seen from Figure 2, the range-focusing technique can reduce the range straggling by a factor five as compared to the conventional slowing down in homogeneous degraders. In this measurement the ^{56}Ni fragments had a relative momentum spread of 1% and the achieved range straggling of the stopped ^{56}Ni fragments of 14.8 mg/cm^2 in P-10 gas at normal temperature and pressure corresponds to 9 cm. The same value has been measured with a ^{58}Ni primary beam having a momentum width of less than 10^{-3}.



(a) (b)

Figure 2. (a) Number–distance curve of 360 MeV/u ^{56}Ni fragments stopped in P-10 gas (90% Ar, 10% CH_4) at normal temperature and pressure [9]. In one case (open squares, dotted line) the ions are slowed down with a homogeneous degrader, in the other case (full dots, solid line) the ions are slowed down using the range-bunching scheme described above. The fragments cover a momentum width of ±0.5%. The range straggling of the ions (b) is obtained from the derivative of the number–distance curve shown in (a).

3. Summary and conclusion

The concept of slowing down, stopping and extraction of in-flight separated ions opens up a new access to experiments with low-energy exotic nuclear beams. Two possible scenarios have been described: direct mass measurements of exotic nuclei with half-lives in the ms region using electrostatic time-of-flight spectrometers and decay spectroscopy with mass-separated exotic nuclei. For direct mass measurements the presently reached mass accuracy has to be improved by about one order of magnitude to be able to compete with other mass measurement techniques for short-lived nuclei [10, 11].

References

1. Wollnik, H., *J. Mass Spectrom.* **34** (1999), 991.
2. Casares, A. *et al.*, *Internat. J. Mass Spec. Ion Proc.*, accepted for publication.
3. Savard, G. *et al.*, this issue, 223.
4. Maier, M. *et al.*, this issue, 521.
5. Engels, O. *et al.*, this issue, 505.
6. Marx, G. *et al.*, this issue, 463.
7. Geissel, H. *et al.*, *Nucl. Instrum. Methods B* **70** (1992), 286.
8. Weick, H. *et al.*, *Nucl. Instrum. Methods B* **164/165** (2000), 168;
   Scheidenberger, C. *et al.*, In: *Proc. STORI'99*, Bloomington, IN, AIP Conference Proceedings 512 (2000), p. 275.
9. Nankov, N., Thesis in preparation, University of Gießen.
10. Lunney, D. *et al.*, this issue, 299.
11. Hausmann, M. *et al.*, this issue, 291.