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A multi-reflection time-of-flight mass spectrometer for mass measurements of short-lived nuclei

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Abstract

In order to determine binding energies of short-lived nuclei we have developed a time-of-flight mass spectrometer of high mass resolving power $m/\Delta m$. This spectrometer achieves a very long ion flight path by repeatedly reflecting ions between two electrostatic ion mirrors. The nuclei to be investigated are produced in heavy ion fragmentations and separated in-flight by a fragment separator. These energetic ions are thermalized in a catcher gas cell injected into an RF ion-guide and then into an ion trap to be cooled, bunched and entered into the time-of-flight spectrometer. This technique should allow to determine the masses of short-lived nuclei with high efficiency. Using stable ions, the so far achieved mass resolving power $m/\Delta m$ exceeded 65,000.

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Keywords: Time-of-flight mass spectrometer; Precise mass measurement; RF ion-guide

1. Introduction

The masses of stable and long-lived nuclei are known with good accuracy, while information is scarce in the regions far from β-stability. However, the masses of nuclei in these regions are of considerable interest because of their role in astrophysical processes, and because the predictions of various mass models differ greatly from each other.

Though such exotic nuclei are produced at high energies they can be stopped in a catcher gas cell and be extracted to a high vacuum region by using superimposed dc and rf electric fields [1]. After cooling and bunching we plan to inject these ions into a multi-reflection time-of-flight mass spectrometer (MR-TOF-MS) [2] of high mass resolving power.

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2. Mass measurements with the MR-TOF-MS

Exotic nuclei can be produced at RIKEN separated in-flight by the projectile fragment separator (RIPS) [3] or later by BigRIPS in the RIKEN RI-beam factory project [4]. These ions are passed through a degrader to decrease their kinetic energies and are then injected into a large He gas cell to be thermalized.

2.1. The RF ion-guide system

In this He gas cell, a static electric field drives the ions towards an exit hole. Around this exit hole fine concentric ring electrodes are placed whose RF and DC potentials keep the ions away from the electrodes. The extracted ions are then transported by a multipole ion guide [5] to the ion trap and the MR-TOF-MS.

This RF ion-guide system has been tested with 100-MeV/u ^{8}Li ions from RIPS using a primary beam of 100-MeV/u ^{13}C and a 10-mm thick Be target. The ^{8}Li ions were recorded by α-particles emitted after β-decay. Using 100 Torr He gas in the cell we have achieved a maximum efficiency of 5%.

2.2. The linear RF ion trap

Before ions can be injected into the MR-TOF-MS they must be well confined in phase space to ensure small energy and time spreads. For such ions the MR-TOF-MS can compensate the residual energy spread when the geometry and the potentials of the mirror electrodes are chosen properly [6,7]. This ion beam is formed by a "six-pole RF ion-guide" and a "linear RF ion trap". In the six-pole guide the ions are cooled and then trapped in a potential depression which is formed by the potential of a ring electrode placed around the six-pole electrodes [8].

A "quadrupole ion trap" that consists of two endcap electrodes with a ring electrode and a "linear ion trap" have been considered. We have chosen a "linear ion trap" since it has a greater phase-space acceptance according to Clark et al. [9] who found that typical efficiencies were 15% with a "quadrupole trap" and more than 80% with a "linear trap".

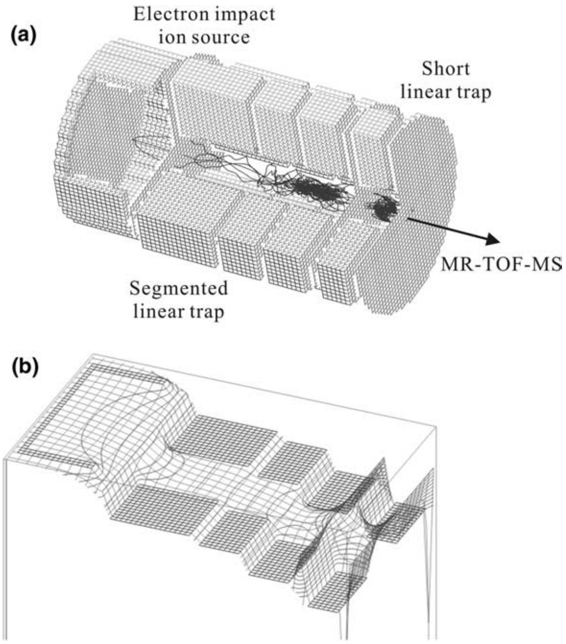

Fig. 1. (a) Calculated trajectories of singly charged ions of mass 100 and (b) the DC potential distribution in the linear trap as determined by SIMION.

We have operated our RF ion trap with 1×10^{-3} Torr He gas. Differently from its normal use we have divided this trap in a 25 mm long loading section and a 5 mm long extraction section. To determine the appropriate parameters of this ion trap we have calculated ion trajectories (see Fig. 1) by SIMION [10]. By doing so we found that it seems feasible to efficiently load the pulsed ions from the RF ion-guide system by switching the voltage of the endcap of the trap, and to extract most of the ions without a gas collision after transmitting them to the extraction section.

3. Experimental tests of the MR-TOF-MS and the linear trap

For experimental tests of the MR-TOF-MS and the linear trap stable ions were produced in an electron impact source, extracted by an electric field of ~5 V/mm and stored in the loading part of the trap. Here they were cooled by gas collisions in the He buffer gas, and then transferred to the extraction section. After being cooled again, the ions were extracted by an electric field of ~100 V/mm and then accelerated to 1500 eV. This system provided ion pulses of <10 ns duration with repetition rates of 500 Hz.

Injecting CO-ions of mass 27.9949 u and N_2-ions of mass 28.0061 u into the MR-TOF-MS they appeared to be well separated after 641 laps as is shown in Fig. 2. The peaks have long tails and do not look like Gaussian shapes. However, a Gaussian curve was fitted only to the upper half of the peak. As a result, one can determine a FWHM mass resolving power of the spectrometer of $m/\Delta m \approx 66{,}000$. This is better than the value of $m/\Delta m = 40{,}000$ reported in [2] after 510 reflections. Also, the signal-to-noise ratio in the spectrum was higher.

The recorded intensity of ions after N laps is shown in Fig. 3 relative to the intensity recorded after a single pass. Since the acceptance of the MR-TOF-MS is smaller than the emittance of the ion source one observes some initial losses but thereafter a transmission of >20% that is more or less independent of the number of laps. Since one must expect losses due to collisions between ions and residual gas molecules Fig. 3 also shows the transmission for gas pressures of 1×10^{-7} Torr and 3×10^{-8} Torr in the MR-TOF-MS. In the case that RF power was applied to the ion trap while ions were flying in the MR-TOF-MS, a small decrease of the ion count can be seen in Fig. 3. To determine masses of short-lived nuclei the MR-TOF-MS and the linear trap will be connected to the gas cell soon.

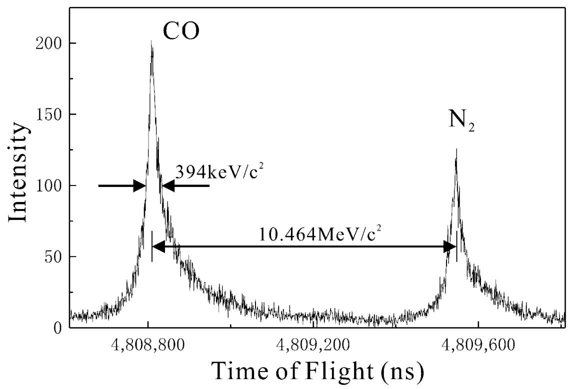

Fig. 2. The obtained mass spectrum of the CO–N_2 mass doublet after 641 laps.

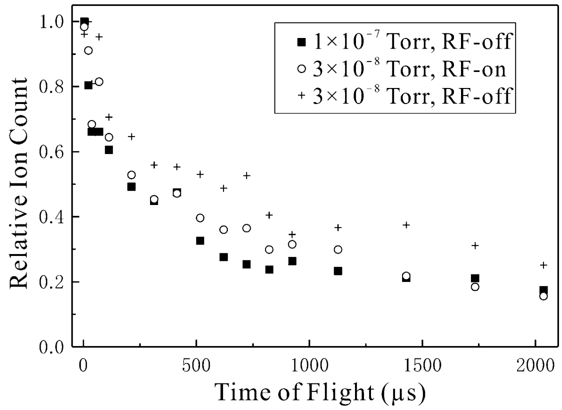

Fig. 3. The recorded ion intensity as a function of ion flight time relative to the intensity after one pass. Squares and crosses denote the ion count rate at residual gas pressures of 1×10^{-7} as well as 3×10^{-8} Torr with no RF power being applied to the ion trap when the ions were flying in the MR-TOF-MS. Circles denote the ion count rate at 3×10^{-8} Torr when RF power was applied which locally increased the residual gas pressure.

Acknowledgments

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