Eur. Phys. J. A **25**, s01, 37–39 (2005)
DOI: 10.1140/epjad/i2005-06-070-8

EPJ A direct
electronic only

A MISTRAL spectrometer accoutrement for the study of exotic nuclides

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Received: 20 December 2004 /

Abstract. An ion beam cooler has been constructed to adapt the emittance of the ISOLDE rare isotope beam to the acceptance of the mass spectrometer MISTRAL at CERN. Using $^{20,22}\mathrm{Ne}^+$ beams with an energy of $E_{\text{beam}} = 45$ keV the transmission through the cooler was measured to be $T = 0.25$. An analytical model to describe the transmission as a function of the trapping potential is discussed. By fitting this model to the data, the lateral energy distribution of the radially confined ions was determined to be centered at $E_0 = 1.3(1)$ eV and to have a width of $\sigma_E = 1.6(1)$ eV.

PACS. 29.27.Eg Beam handling; beam transport – 21.10.Dr Binding energies and masses

1 Introduction

The investigation of the nuclear properties of halo nuclei, especially the determination of their binding energies, is a real challenge. The two-neutron halo nucleus ^{14}Be for example can be produced by nuclear reactions at ISOLDE with a rate of only 10/s [1]. This results in a need for ultimate efficiency of any experimental setup. Several years ago the first attempts to adapt the emittance and time structure of an exotic ion beam to the acceptance of the experiments by deceleration and subsequent cooling of the incoming beam were elaborated [2] and are now operational, *e.g.* at ISOLDE [3] and Jyväskylä [4]. To reduce the emittance of an ion beam, a non-conservative interaction is needed. Beam momentum can be dissipated by low-energy collisions with a light, inert buffer gas at background pressures of typically 0.01 mbar. To avoid any loss of the exotic beam particles, linear Paul traps [5] are used for radial confinement.

2 Setup

Even though its short half-life of 4.4 ms renders ^{14}Be inaccessible for investigations at ISOLTRAP [6] it poses no such problem for the mass spectrometer MISTRAL [7,8] at ISOLDE. This transmission, radiofrequency mass spectrometer allows for direct mass measurements of nuclides with half-lives of less than 100 μs and is therefore best suited for very short-lived exotic nuclei. Its acceptance amounts to $3\,\pi$ mm mrad in the horizontal and vertical directions which results presently in the poor transmission of $T_M \approx 10^{-4}$ for the ISOLDE rare isotope beam having an emittance of $\varepsilon_0 = 30\,\pi$ mm mrad.

Therefore, a dedicated 60 keV beam cooler (described in detail elsewhere [9]) is being developed for MISTRAL. First, in order to preserve the initial energy $E_{\text{beam}} = 60$ keV, the beam is decelerated to $E_{\text{kin}} \leq 50$ eV by gaining the potential energy $E_{\text{pot}} = eU_{\text{HV}}$ with the high voltage U_{HV} of the cooler. Subsequently the ions are injected into a He-buffer-gas filled, linear Paul trap [5]. At a buffer gas pressure of 10^{-2} mbar, light ions are stopped during one pass through the radio frequency quadrupole (RFQ) of 504 mm length. The quadrupole rods each consist of 15 electrically isolated segments. Using dc-offsets of typically 1 V between two neighboring segments, a mean axial electric field of 0.25 V/cm can be created which allows for an extraction of the injected ions within 40 μs. In the last part the ions are re-accelerated to the energy $E_{\text{beam}} = eU_{\text{HV}} \approx 59.95$ keV.

3 Measurements

First tests of the cooler were performed at low beam energies. It was shown [10] that a 6 keV Na$^+$ beam could be extracted with a beam emittance of $\varepsilon = 8\,\pi$ mm mrad. This corresponds to $\varepsilon = 2.5\,\pi$ mm mrad at 60 keV and will improve the transmission T through the mass spectrometer MISTRAL by three orders of magnitude [9].

However, a crucial part is the deceleration of the 60 keV ISOLDE beam. Therefore, a new deceleration system has been installed and successfully tested [9] behind

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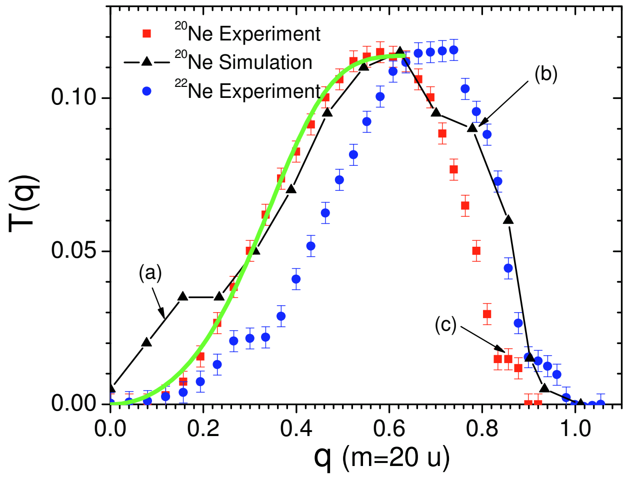

Fig. 1. Transmission $T = I_{\mathrm{CF2}}/I_{\mathrm{CF1}}$ as function of q (m = 20 u). Amplitudes of experimental curves were multiplied by a factor 0.7 for better comparison. The full line is a best fit to the data, see text.

the mass separator SIDONIE [11] at Orsay. To determine the transmission T, the currents of $^{20,22}\mathrm{Ne}^+$ beams have been measured with Faraday cups before (I_{CF1}) and behind the cooler (I_{CF2}). To avoid the charging of insulators by scattered and deflected ions, the ion current $I_S = 3$ μA delivered from the separator was reduced with slits to $I_{\mathrm{CF1}} = 400$ pA. The gas flow of the He-buffer gas amounted to 0.6 mbar l/s and corresponds to a calculated mean gas pressure of $p = 0.01$ mbar. Figure 1 shows $T(q)$ as a function of the Mathieu parameter $q = \frac{4eA_{\mathrm{RF}}}{m(r_0\omega)^2}$ [5] which is plotted for the mass $m = 20$ u, the RF angular frequency $\omega = 5 \times 10^6$ /s and the inner radius $r_0 = 7$ mm of the rod system. The elementary charge is denoted by e. The parameter q was varied by selecting the RF amplitude A_{RF}. To obtain $q = 0.9$ at the end of the transmission curve of ^{20}Ne due to the instability of the trajectories [5], the measured A_{RF} was multiplied by a factor 1.3. This correction is necessary since A_{RF} decreases during its measurement using a capacity probe of an oscilloscope.

4 Results and conclusion

For $q < 0.5$ the potential energy of the trapped ions can be approximated by $E(q) = cq^2\left(\frac{r}{r_0}\right)^2$, $c = \frac{m(r_0\omega)^2}{16}$ [4,12]. The maximal transversal energy of the ions $E_{\max} = E_0 + 2\sigma_E$ must thus be smaller than $E(q)$ and limits the transmission of the ions. If we assume a Gaussian for the transversal energy distribution $I(E)$ with the center E_0 and the width σ_E, $T(q)$ can be calculated for $r = r_0$: $T(q) = A\int_0^{E(q)} I(E)\mathrm{d}E = A\int_0^q \frac{1}{\sqrt{2\pi}\sigma_E} e^{-\frac{(E_0(q')-E(q'))^2}{2\sigma_E^2}} 2cq'\mathrm{d}q'$. The constant $A=1.3(1)$ was used to fit the experimental data; see fig. 1. This fit yields $E_0 = 1.3(1)$ eV and $\sigma_E = 1.6(1)$ eV. The model describes the experimental data very well up to $q \approx 0.55$. Beyond this value the transmission decreases due to RF-heating and subsequent destabilization of the trajectories [2]. At $q = 0.55$ the trapping potential amounts to $E(q = 0.55) = 4.8$ eV and coincides with the deduced maximal transversal energy of the ions $E_{\max} = 4.5(2)$ eV. This leads to the assumption that the transmission $T \approx 0.11$ is limited by the trapping potential. Simulations using the software package SIMION7 [13] confirm this interpretation. The absolute transmission, as well as the shape of the curve are well reproduced by the simulation; see fig. 1. Collisions in the region of the fringing field at the entrance of the quadrupole can provoke losses of ions. This may explain the onset of the transmission at higher q values (a) with respect to the simulations in which the buffer gas interaction was omitted. This may also explain why the step in the transmission function of the ^{20}Ne ions at $q = 0.86$ (c) appears in the simulation already at $q = 0.8$ (b). This step may be explained by the radius of the macro motion in front of the exit cone which varies with q [14] and may exceed the radius of the latter. By increasing the angular frequency to $\omega = 1.3 \times 10^7$/s, the trapping potential amounts to $E(q = 0.55) = 32$ eV and the simulations yield a transmission of $T = 0.3$. This was confirmed in a test experiment using $\omega = 0.9 \times 10^7$/s where a transmission of $T = 0.25$ was observed.

An unambiguous identification of the ions was possible by recording the transmission curves for different isotopes; see fig. 1. The transmission curve of ^{22}Ne is displaced with respect to ^{20}Ne by $\Delta q/q = 0.1$ corresponding exactly to 2 mass units, as expected, and therefore excludes the observation of ionized buffer gas impurities.

To increase the transmission, a reduction of the quadrupole capacitance is planned which will allow for a higher amplitude $A_{\mathrm{RF}} = 235$ V at $\omega = 1.3 \times 10^7$/s and thus $E(q = 0.55) = 32$ eV. After final emittance measurements of the extracted beam, the set up will be installed at ISOLDE.

This work has been supported by the French IN2P3 and the EU-network NIPNET under contract HPRI-CT-2001-50034.

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