Measuring the half-life of n-rich 100Rb with the TITAN MR-TOF-MS

Measuring the half-life of n-rich ^{100}Rb with the TITAN MR-TOF-MS

Measuring the half-life of n-rich ^{100}Rb with the TITAN MR-TOF-MS

I. Mukul[1], C. Andreoiu[2], M. Brodeur[3], T. Brunner[1,4], K. Dietrich[1,5], T. Dickel[6,7], I. Dillmann[1,8], E. Dunling[1,9], D. Fusco[1,10], G. Gwinner[11], C. Izzo[1], A. Jacobs[1,12], B. Kootte[1,11], Y. Lan[1,12], E. Leistenschneider[1,12], M. Lykiardopoulou[1,12], S. F. Paul[1,5], M. P. Reiter[1,6,13], J. L. Tracy Jr[1], J. Dilling[1,12], and A. A. Kwiatkowski[1,8]

[1]TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3, Canada
[2]Department of Chemistry, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada
[3]Department of Physics, University of Notre Dame, Notre Dame, IN 46556, USA
[4]Department of Physics, McGill University, Montréal, Québec H3A 2T8, Canada
[5]Ruprecht-Karls-Universität Heidelberg, Heidelberg D-69117, Germany
[6]II. Physikalisches Institut, Justus-Liebig-Universität, Gießen 35392, Germany
[7]GSI Helmholtzzentrum f:ur Schwerionenforschung GmbH, Darmstadt 64291, Germany
[8]Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia V8P 5C2, Canada
[9]Department of Physics, University of York, York YO10 5DD, United Kingdom
[10]Department of Physics, University of Waterloo, Ontario N2L 3G1, Canada
[11]Department of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada
[12]Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia V6T 1Z1, Canada
[13]School of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3FD, U.K.

E-mail: ishmukul@gmail.com

Abstract. Multiple-reflection time-of-flight mass spectrometers (MR-TOF-MS) have been demonstrated to have a mass resolving power in the range of few hundreds of thousand. The TITAN MR-TOF-MS has been used to separate isobaric impurities and measure masses of many rare isotopes. Recently we have measured the mass and half-lives of neutron-rich Rubidium isotopes with the MR-TOF-MS. This technique is capable of measuring the half-life of rare isotopes in the range of few tens of millisecond. In this proceeding, we present the measurement of half-life of ^{100}Rb that was found to be 50±5 ms, in good agreement with literature value of 48±3 ms.

1. Introduction

Measuring atomic masses precisely is challenging and ion traps have played a crucial role therein [1]. Masses of rare isotopes provide key ingredients for several models defining nuclear structure and nuclear astrophysics [2]. Traditionally, Penning traps have been used for mass measurement of rare isotopes for there highest level of precision, whereas multiple-reflection time-of-flight mass spectrometry (MR-TOF-MS) is rapidly evolving as a new tool for mass measurement of nuclide

away from stability. In comparison to the Penning trap, MR-TOF-MS can provide a quick broadband spectrum which is useful for separating several isobars in a single run, but at the cost of precision. However, this property makes them suitable for cleaning isobaric contaminants. MR-TOF-MS are actively used in different radioactive isotope beam facilities [1, 2, 3, 4, 5, 6, 7].

The half-life provides another important input for validating nuclear models throughout the nuclear chart. Half-life measurements often involve the detection of decay products as a function of time, and identifying the decay products by their γ lines detected in a γ-ray detector. A half-life measurement is also possible by employing an ion trap for decay of mother nuclei and subsequent mass measurement inside a Penning trap mass spectrometer (PTMS) or an MR-TOF-MS [8]. This method often requires a combination of traps where first trap stores ion for longer period. A recent paper describes a similar technique using a combination of cryogenic stopping cell and an MR-TOF-MS [9].

As part of a mass-measurement campaign of neutron-rich Rb and Sr isotopes, we have measured the half-life of ^{100}Rb using the TITAN MR-TOF-MS. The measurement relies on counting the mother as a function of the storage time in a buffer-gas-filled trap and requires identification of the radioactive species in the analyzer section. Our value is in excellent agreement with prior measurements. The technique complements traditional spectroscopy techniques, and it also permits simultaneous identification of the species through its mass. Furthermore, varying the storage time can be used to identify or even to remove shorter-lived species.

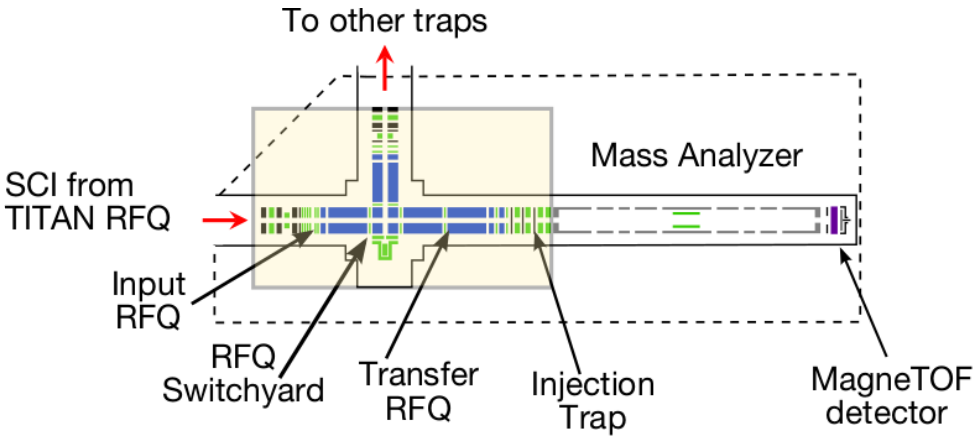

Figure 1. A pictorial representation of the TITAN multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS). The shaded part depicts gas-filled section that contains RFQ traps. The mass analyzer section is a field-free section, separated by electrostatic mirrors, where ions perform isochronous multiple turns for isobaric separation based on time of flight. Ion bunch of singly charged ions (SCI) from the TITAN RFQ is stored in gas-filled sections for variable time and sent to mass analyzer for isobaric cleaning, mass measurement or half-life measurement. See text for more details.

2. Experimental details

The TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) [10, 11] facility is located in the ISAC-I hall [12] of TRIUMF. TITAN consists of five traps: (a) a radio frequency quadrupole

cooler and buncher [13, 14] for accumulation, cooling and bunching of the ion beam, (b) a MR-TOF-MS [7] for cleaning isobaric contaminations and broadband mass measurements, (c) an electron beam ion trap (EBIT) for charge breeding [15], (d) a cooler Penning trap for sympathetically cooling highly charged ions, and (e) a measurement Penning trap (MPET) for high-precision mass measurements. Except the cooler Penning trap, all other traps can work independently or in conjunction with one another as desired.

Radioactive ion beam of Rb was produced by bombarding 480 MeV protons at 9.8μA current on the UCx target [12]. The ion species of interest were mass separated by a dipole magnet and delivered to TITAN at 20 keV of kinetic energy. The singly charged ion (SCI) beam was bunched in the TITAN RFQ cooler-buncher, pulsed down to 1.3 keV and sent to the MR-TOF-MS for mass measurement. Other traps were not used in this measurement.

The MR-TOF-MS at TITAN (Fig. 1) consists of a buffer-gas-filled section and a mass-analyzer section. The former to prepare the ions, and the latter to determine the mass. The gas-filled section contains several RFQ ion guides and traps. Relevant to the half-life measurement is the transfer RFQ. TITAN RFQ cooler buncher, operated at 20 ms duty cycle, provided SCI bunch that were stacked in the transfer RFQ. An aperture electrode in the middle of transfer RFQ acted as the trapping barrier and accumulated ions for several accumulation time (t_{ac}) counted over many cycles. During the stacking of ions inside the transfer RFQ, mass-analyzer continued its operation cycle at 20 ms, without any ion bunch. After a total time t_{ac}, stacked ion bunch was injected into the mass analyzer section. The analyzer then separated the isobaric species by TOF for identification.

If a radioactive species decays in the gas-filled section, it can be lost since the maximum recoil energy for ^{100}Rb si 1026 eV , which exceeds the trap confinement (20 V pseudo potential) and cooling capabilities. Furthermore, the doubly-charged daughter will not be observed unless it charge exchanges with the buffer gas. To understand trap losses, the trapping efficiency has been measured with stable beams and found to be constant for $t_{ac} \leq 10$ s; as such trap losses do not affect the half-life measurement.

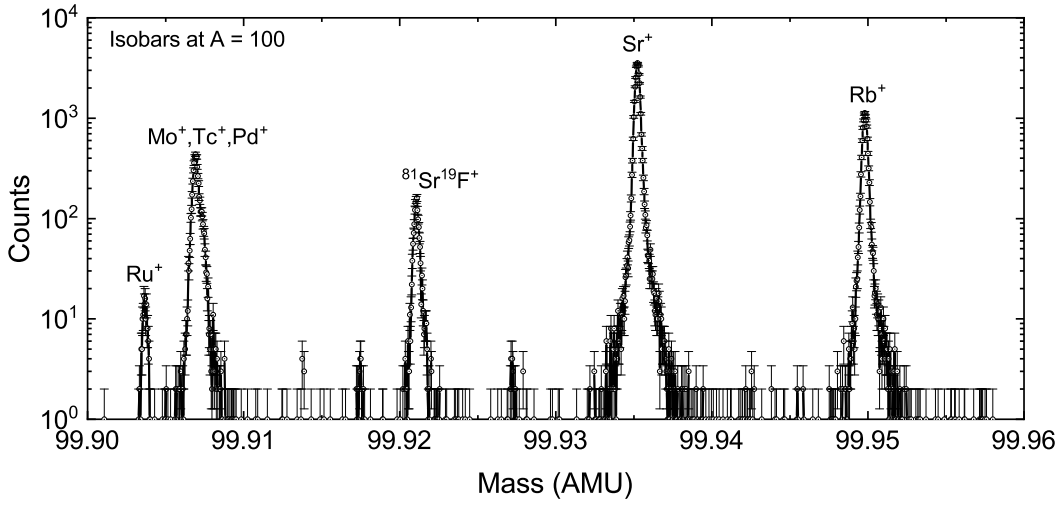

Figure 2. A time-of-flight spectrum (TOF) at mass number A=100 recorded for 30 min. The spectrum has been converted to mass from TOF, see section 3.1 for details. ^{100}Ru^{+} ion was used for calibration of spectrum and identification of other peaks.

3. Results

In this section, we describe the results of half-life measurement of ^{100}Rb. The first step involves identification of isobars, and the next step involves storing mother nuclei in the gas-filled traps for variable times for the half-life measurement. The following sub-sections describes these two steps.

3.1. Identification of isobars

A typical TOF spectrum at A=100 recorded for 30 min. is shown in Fig. 2. The TOF spectrum represents a flight time of 7.8 ms that gave a mass resolving power of nearly 250,000. A time-to-mass conversion was performed using a calibration function, $m/q = c\ (t - t_0)^2/(1 + b\ N)^2$ [17], where c, b and t_0 are the calibration parameters, and m, q, t and N are the mass, charge state, time of flight and number of turns of the ion of interest. Parameters c and t_0 were calculated before the experiment using stable ions of ^{85,87}Rb$^+$ and ^{133}Cs+. In the spectrum in Fig. 2, the charge state is 1 for all peaks and N is 397. A typical peak shape has a central Gaussian part with an exponential tail, which is 3 orders less than the Gaussian part, and hence negligible for fitting well separated peaks. The peaks were fitted using a single Gaussian function and their centroids were used for the mass calculation. We used ^{100}Ru$^+$ as the calibrant, calculated b, and identified other species in the spectrum, namely, atomic ^{100}Sr$^+$, ^{100}Rb$^+$, ^{100}Mo$^+$, ^{100}Tc$^+$, ^{100}Pd$^+$ and molecular $(^{81}$Sr^{19}F$)^+$.

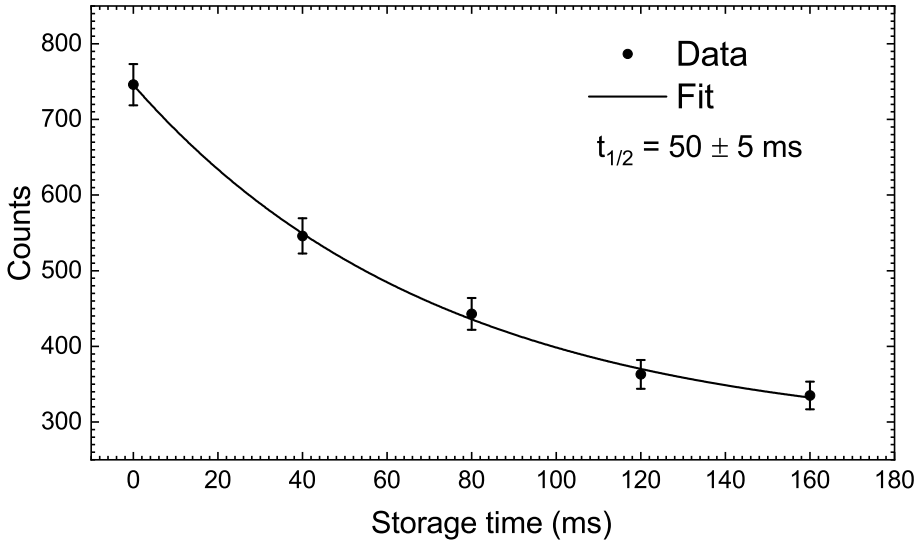

Figure 3. Number of Rb ions recorded as a function of storage time. The error bars on data correspond to statistical error. Solid line represents the exponential fit to data. Half-life obtained from fit agrees with previous value [18, 19].

3.2. Half-life measurement

As described earlier, the half-life measurement depended on varying the accumulation time (t_{ac}), here in 20 ms increments. The mass-analyzer was run with a resolving power of 250,000 to separate the ^{100}Rb$^+$ (Z=37) from any other radioactive species. No ^{100}Kr$^+$ (Z=36) was observed and it would be unlikely to surface ionize during beam production. Hence, we are confident

that the variation in $^{100}Rb^{+}$ counts was only due to its radioactive decay. The daughter, $^{100}Sr^{+}$ (Z=38), could be produced both by decay of the $^{100}Rb^{+}$ as well as during beam production by ISAC; as such its half-life measurement was not performed.

In Fig. 3, the $^{100}Rb^{+}$ counts are plotted as a function of storage time. Due to stacking of ions over each accumulation cycle, the ion count from undecayed ions from previous cycles converge to a constant value. The data points can be fit with a modified exponential decay function that accounts for simultaneous accumulation and decay of ions inside the transfer RFQ. The half-life was thus calculated from the decay constant obtained from the fit. The TITAN value of 50(5) ms for half-life agrees well with the literature value of 48(3) ms [18, 19].

4. Summary

The MR-TOF-MS at TITAN has been successfully used in several mass measurement experiments. In this paper, we demonstrate a method to measure half-lives of short-lived nuclei, e.g. ^{100}Rb, by utilizing the transfer RFQ and the mass analyzer of the MR-TOF-MS. The ions were stacked inside RFQ trap for different accumulation times and underwent nuclear decay. The undecayed nuclei were identified with mass analyzer and provided the half-life. This technique permits the determination of the half-lives of tens of millisecond.

Acknowledgment

The authors acknowledge support from the TRILIS group, the ISAC Beam Delivery group, and M. Good for their contributions to realizing this experiment. This work has been supported by the Natural Sciences and Engineering Research Council of Canada (NSERC), and the National Research Council of Canada that provides federal funding to TRIUMF via a contribution agreement. E.D. acknowledges financial support from Canada-U.K. foundation. T.D. thanks support from JLU and GSI under the JLU-GSI strategic Helmholtz partnership agreement.

References

[1] Dilling J, Blaum K, Brodeur M and Eliseev S 2018 *Ann. Rev. Nucl. Part. Sci.* **68** 45–74
[2] Blaum K, Dilling J and Nörtershäuser W 2013 *Physica Scripta* **T152** 014017
[3] Wolf R N 2013 Int. *Jour. Mass Spec.* **349-350** 123-133
[4] Dickel T et al. 2015 *Nucl. Inst. Methods* A **777** 172 – 188
[5] Schury P, Okada K, Shchepunov S, Sonoda T, Takamine A, Wada M, Wollnik H and Yamazaki Y 2009 *Eur. Phys. Jour.* A **42** 343
[6] Hirsh T Y et al. 2016 *Nucl. Inst. Methods* B **376** 229 – 232
[7] Jesch C et al. 2015 *Hyperfine Interactions* **235** 97–106
[8] Wolf R N et al. 2016 *Nucl. Inst. Methods* B **376** 275-280
[9] Miskun I et al. 2019 *Eur. Phys. Jour.* A **55** 148
[10] Kwiatkowski A A et al. 2014 *Hyperfine Interactions* **225** 143–155
[11] Dilling J et al. 2006 *Inter. Jour. of Mass Spec.* **251** 198 – 203
[12] Dilling J, Krücken R and Merminga L *ISAC and ARIEL: The TRIUMF Radioactive Beam Facilities and the Scientific Program* (Springer Netherlands)
[13] Brunner T et al. 2012 *Nucl. Inst. Methods* A **676** 32 – 43
[14] Smith M, Blomeley L, Delheij P and Dilling J 2006 *Hyperfine Interactions* **173** 171
[15] Lapierre A et al. 2010 *Nucl. Inst. Methods* A **624** 54 – 64
[16] Wollnik H and Przewloka M 1990 *Inter. Jour. of Mass Spect. and Ion Processes* **96** 267 – 274
[17] Andrés S A S et al. 2019 *Phys. Rev. C* **99** 064313
[18] Nishimura S et al. 2011 *Phys. Rev. Lett.* **106** 052502
[19] Audi G, Kondev F G, Wang M, Huang W and Naimi S 2017 *Chin. Phys.* C **41** 030001