TAMUTRAP commissioned: 1st mass measurement using a uniquely-designed cylindrical Penning trap

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The Texas A&M Unviersity Penning Trap faiclity (TAMUTRAP) facility was commissioned with a prototype cylindrical Penning Trap by performing high precision mass measurement of stable isotope of sodium (^{23}Na). The electrode structure is based on our novel design [1] with a much larger radius-to-length ratio compared to any other existing trap [1]. The details of the prototype Penning trap system have been discussed in our previous year annual report [2, 3].

Mass measurements in a Penning trap are based on a comparison of the cyclotron frequencies of the ion of interest and that of a mass reference ion. It is here assumed that the change in the magnetic field can be neglected during the time the cyclotron frequencies of the two ion species are measured. If the reference ion is denoted by subscript 1 and the ion whose mass is to be measured by subscript 2 the following relation is obtained:

$$\omega_{c1}(2\pi f_1) = \frac{q_1 B}{m_1};\ \omega_{c2}(2\pi f_2) = \frac{q_2 B}{m_2}\ ;\ \frac{f_1}{f_2} = \left(\frac{q_1}{q_2}\right)\left(\frac{m_2}{m_1}\right)$$

In our case, we used ^{39}K as our reference mass (f_1) and performed mass measurement of ^{23}Na (f_2). As mentioned in previous annual reports [2], the mass of an ion is determined via its cyclotron frequency. At the TAMUTRAP facility, we measured the cyclotron frequency by the time-of-flight ion cyclotron resonance method (TOF-ICR). The TOF-ICR is a destructive technique in the sense that the trapped ion is lost in the detection process and the trap has to be reloaded in each cycle. The technique involves manipulating the ions eigenmotions and probing the cyclotron frequency using an external radiofrequency field and measuring the flight time of the ions ejected from the trap to a detector. Within the TOF-ICR technique, a resonant quadrupolar radiofrequency excitation signal with properly chosen amplitude and duration is applied on the four fold segmented ring electrode. The radial motions couple and the magnetron motion is completely converted into the modified cyclotron motion leading to a large increase in radial energy. The excited ions are ejected from the trap towards a counting detector. While travelling through the fringe field of the magnet, the ions get accelerated due to the gradient force. Thus the radial energy of the ions is the largest at resonance. This energy gain is directly transformed into a change in time of flight, and for optimum energy conversion into the cyclotron motion a minimum in flight time is observed at the frequency of the unperturbed cyclotron frequency.

A MCP detector with an active area of 32 mm was placed 1.5 m downstream from the center of the trap to detect the ions ejected from the trap. As a first step towards the mass measurement, we optimized the cooling time before the excitation by recording timing spectrum for different trapping time. A Gaussian shape timing spectrum was observed for trapping time more than 250 ms, which indicated that the ion motion were cooled by collision with background buffer gas (He) atoms present in the beam line. After estimating the cooling time, ion motion were manipulated by applying a quadrupole excitation for 20 ms. The quadrupole excitation was applied to four-fold segmented ring electrode, where the RF voltage was applied to one pair of opposite segments is phase-shifted by 180 degree with respect to the RF voltage applied to the other pair of opposite segments. The TOF was recorded for 30 different frequencies close to the resonance value in steps of 10 Hz. We started the measurement with ^{39}K and switched to ^{23}Na. The first frequency scan for both the masses was carried out in less than 8 hours. Fig. 1 shows our first resonance curve observed for ^{23}Na and ^{39}K.

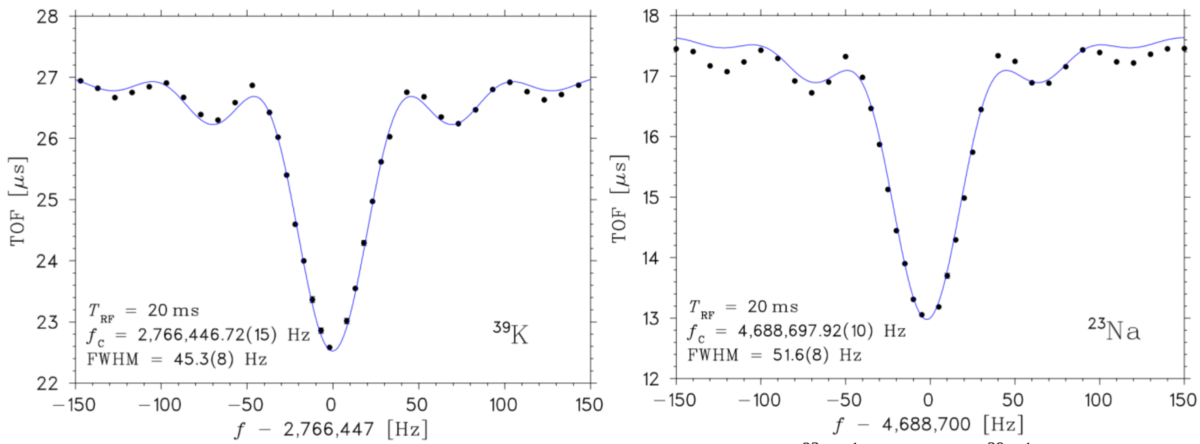

FIG. 1. Ion time-of-flight as a function applied cyclotron frequency for $^{23}Na^{1+}$ (left) and $^{39}K^{1+}$ (right) with an excitation time of 20 ms. The TOF is minimum at cycltron frequency, f_c. The mass resolving power of this resonance corresponds to 10 ppm.

We further performed the mass measurement with exciation time of 100 ms. For longer exciation time, we had slightly different configuration of quadrupole excitation. We first applied a dipole excitation at the magetron frequency ($f_{magnetron}$ = 830 Hz, excitation time t_{exc} = 10 ms, and amplitude V_{pp} = 6.25 V) by applying RF voltage to one of the segment of ring electrode, and then the quadrupole excitaiton was applied for 100 ms by applying the RF voltage with same phase to one pair of opposite segments. There was no RF voltage applied to the fourth segment of the ring electrode. So far, we have performed around 10 mass scan with excitation time of 100 ms. During these scans the parameters of the Penning trap were set to 350 ms for cooling time , 10 ms t_{exc}, and 6.25 V_{pp} for the magnetron excitation, while 100 ms t_{exc} and 3 V_{pp} were used for the cyclotron excitation. The trap depth for all these scans was set to 200 V and the trapped ion energy was around 150 eV. After the quadrupole excitation, ions were ejected immediately without any additional cooling and that allowed for a better transport of ions to the detector. The mean value of the measured atomic mass value of ^{23}Na is:

$$m(^{23}Na) = 22.9897695\ (10)\ u$$

The measured mass of ^{23}Na agrees with the literature value within a precision of 1.2×10^{-8} with measurement precision of $\delta m/m = 4\times10^{-8}$.

With the prototype trap commissioned and abiltiy to perform mass measurements demonstrated, we will be installing the TAMU Penning trap which is twice the dimension of the prototype Penning trap by end of June 2018.

[1] M.Mehlman *et al.*, Nucl. Instrum. Methods Phys. Res. **A712**, 11 (2010).

[2] E. Bennett *et al.*, Progress in Research, Cyclotron Institute, Texas A&M University (2015-2016), p.I-62.

[3] B.Fenker *et al.*, Progress in Research, Cyclotron Institute, Texas A&M University (2015-2016), p.I-50.