

# DETERMINATION OF THE ATOMIC MASS CONSTANT BY ION ACCUMULATION

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**Abstract:** An experiment for the direct measurement of the atomic mass unit is under way by accumulating ions from an ion beam up to a weighable mass. The aim of this experiment is to find an alternative approach for the redefinition of the SI unit kilogram. In a recent experiment a mass of about 300 mg bismuth was accumulated and the atomic mass unit could be determined with a relative uncertainty better than  $1.0 \times 10^{-4}$ .

**Keywords:** Definition of SI-Unit Kilogram, heavy ion beams, ion collector

## 1. INTRODUCTION

An experiment for the direct measurement of the atomic mass unit was proposed in [1]. The main idea is to produce a sufficiently intense heavy ion beam and to guide it into a collector where the total charge and mass of the accumulated ions can be measured. If the mass to charge ratio of a single atom,  $m_a/e$ , is assumed to be equal to the mass to charge ratio of all the collected ions,  $M/Q$

$$\frac{m_a}{e} = \frac{M}{Q}, \text{ with } m_a = m_u \cdot A, A = \text{mass number}$$

one can determine the atomic mass unit,  $m_u$ , by means of a measurement of the total mass,  $M$ , and the ion current,  $I$ :

$$m_u = \frac{e \cdot M}{A \cdot Q} = \frac{e \cdot M}{A \cdot \int I(t) dt}$$

Thereby the charge,  $Q$ , was replaced by the integration of the ion current over the accumulation time,  $t$ . This idea can be realized with an experimental setup consisting of an ion source, followed by a magnet which separates the ions according to their mass to charge ratio, the ion collector and finally a high-sensitive balance.

## 2. EXPERIMENTAL SET UP

In order to accumulate a weighable mass in a manageable time ion currents around 5mA are needed. Therefore the so called *Cold* or *Hot Reflex Discharge Ion Source* (CHORDIS) [2] was used, which can be operated in a gas-, a sputter- or in an oven version. For the production of singly charged bismuth ions the oven version was used, since due to the relatively low melting point of bismuth (271 °C) sufficient vapor pressures can be obtained already at temperatures between 600 °C and 800 °C. The extraction voltage is usually between 20 kV and 30 kV.

Behind the source the ion current can be measured with a dc current transformer (Bergoz MCP). In addition the pressure at the working gas entry of the source and behind

the source is controlled by pressure sensors (Pfeiffer-Vacuum PKR 256/251). The ion beam enters a double focussing dipole magnet 50cm behind the source, where the ions are separated according their mass to charge ratio. At the entrance aperture of the magnet a four fold segmented stainless steel blend is mounted to check the horizontal and vertical ion beam position in respect to the magnet gap. In order to match the beam emittance in respect to the magnet acceptance we can vary the working gas pressure through a needle valve in the range of  $0.5 - 4.3 \cdot 10^{-4}$  mbar measured behind the source. The pressure in the source influences strongly the so called plasma meniscus which mainly influences the ion optic through the extraction system. Behind the magnet the beam current can again controlled via a second dc current transformer and a moveable water cooled faraday cup. The faraday cup is mounted on top of a chamber 50 cm behind the magnet. A turbo pump (Varian, 1800 l/s) is mounted on the bottom of the chamber and provide a vacuum of approximately  $8 \cdot 10^{-8}$  mbar without beam, measured directly above the pump. After this chamber the beam line can be separated by a gate valve to isolate the collector part from the beam line. Behind the valve another chamber is mounted equipped with a further turbo pump (Varian, 1000 l/s) on the bottom, a wire monitor on the top and a residual gas analyzer on a side flange. The wire monitor is needed to adjust the magnetic field to a certain ion species. By varying the magnetic field and measuring the corresponding beam current on the wire a mass spectrum can be obtained from which the right magnet setting can be determined. The rest gas analyzer is used to monitor a possible desorption from the collector during the accumulation process. After this second chamber a T-like beam pipe is mounted where the collector is housed.

## 2. ACCUMULATION EXPERIMENT

The main task of the accumulation process is to collect all singly charged bismuth ions without losses of mass and charge in a collector.

Presently a cylindrical aluminum collector (Fig.1) with a length of 20 cm, a diameter of 8 cm and an entrance hole of 3 cm is used. The collector is placed on four stainless steel balls mounted on a special table in the vacuum chamber to minimize mass changes due to surface contacts. The table itself is electrically isolated from the surrounding vacuum chamber to guarantee correct current measurements. For adjustment purpose the table can be rotated and vertically moved. In front of the collector a segmented entry blend is mounted to steer the beam into the collector. Just after this blend a further blend is needed to suppress secondary

electrons which will be produced by stopping at the collector bottom. Figure 1 shows in addition some representative ion trajectories.

After the accumulation process the collector was dismantled out of the vacuum chamber and placed manually in the special designed vacuum balance which is located in a room very close to the experimental area.

The mass which was measured on this balance was 314.55 mg. The relative measurement uncertainty of the accumulated mass was  $9.2 \cdot 10^{-5}$ . To accumulate this amount of mass we had to produce a DC  $\text{Bi}^+$  ion beam of 2.5-3.0 mA for about 25 hours.

The charge determination was done offline via current integration using the Simpson-Algorithm. Approximately every 60 ms a current was measured using a digital multimeter (HP3458A) with  $7\frac{1}{2}$  digits. All together there was collected a charge of 149.19C.

The error of the charge is determined through the sum of the individual integration samples in the Simpson formula which are mainly depend from time interval between two current measurements. The relative uncertainty of the charge determination was calculated to  $7.3 \cdot 10^{-6}$ .

The ions hitting the collector bottom remove atoms from the aluminum surface. This process is called sputtering and is mainly dependent from the ion energy and mass. The sputter process is characterized by the sputter-yield which is the ratio between the numbers of removed particles from the surface to the number of incoming (primary) ions. The sputter yield of bismuth ions with a kinetic energy of 25 keV on aluminum is approximately 14. Most of the sputtered particles leave the surface under an angle of  $50 - 60^\circ$ . If the collector is long enough most of the sputtered particles will be collected at the cylinder-wall and only a small amount is scattered into the direction of the entry hole. In order to get a handle of the losses through the entry hole a polished stainless steel ring is mounted on the backside of the entry hole during the accumulation experiment. On this ring a mass accretion caused by the sputtered atoms can be measured by weighting. In addition the sputter distribution along the collector tube was measured and could be very well reproduced by Monte Carlo simulations. The ratio between the particles which will be collected on the ring to this which will lost through the entry hole can be calculated using this Monte Carlo Model. In summary roughly 2.5% of the hole accumulated mass will be lost by sputtering. A quantitative analysis of the sputter losses as well as the main result of the atomic mass constant will be given at the conference.

#### 4. CONCLUSION

An accumulation of a heavy ion bismuth beam up to a weighable mass in a collector was performed. DC bismuth ion currents up to 3 mA are sufficient to accumulate a mass of about 320mg in a period of 25h. With the described procedure we achieved a relative accuracy of better then  $3 \times 10^{-4}$  for the atomic mass unit.

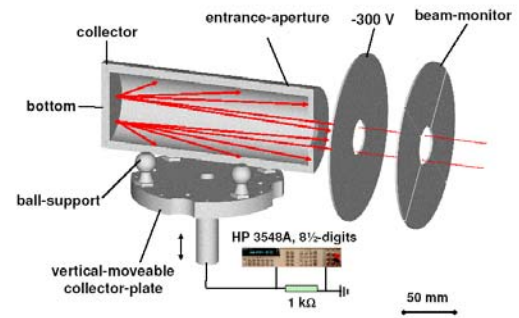


Fig.1. Collector Set-up consisting of collector cylinder, table holder, electron suppressor blend and segmented entry blend.

#### REFERENCES

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