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DOUBLE ION COLLECTOR FOR THE THERMAL IONISATION MASS SPECTROMETER SMIT-1

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Abstract. One of the most important error source, in single collector isotopic analyses by thermal ionisation mass spectrometry, is the fluctuation of the ion current generated by the ion source during the measurement. If the ion currents are successively registered, usually by magnetic scanning, it happens that in the moment *t* when the ion current $i_m(t)$, corresponding to the mass *m*, is recorded, the intensity of the ion current $i_{m-1}(t)$ corresponding to the mass *m-1,* differs from the value $i_{m-1}(t')$,where *t'* is the moment when the *m-1*mass signal was recorded. The use of values registered in this manner to determine isotopic ratios leads to results affected by errors hardly to estimate.

A way to avoid this difficulty is the simultaneous detection of the ion currents of interest. The purpose of this work was to realise the simultaneous detection of the $^{235}U^+$ and $^{238}U^+$ ion currents with the thermal ionisation mass spectrometer SMIT-1.

Introduction

The thermal ionisation mass spectrometer SMIT-1 was designed built and homologated in the Mass Spectrometry Laboratory of our institute. It was meant to cover a wide range of isotopic analyses with a medium precision and was equipped with a single ion collector based on a secondary electron multiplier.

In order to realise a simultaneous detection of two ion currents, the right positions of the two definition slits has to be determined and an ion optical solution has to be found, to incorporate two rather bulky secondary electron multipliers at the end of the detection chains.

Determining the right position of the definition slits.

The geometric parameters of the ion optics structure of the mass spectrometer are shown in the figure 1. The analyser is a magnetic prism with homogeneous field, a deflection angle of 90º and a curvature radius of the ion trajectories of 238 mm. The incidence - emergence angles of 28.167°, field free regions of 515,46 mm and a curvature radius of 419,65 mm at the field boundaries ensure the stigmatism and a dispersion coefficient of about 2.

In a geometrical approach, the calculation was carried out in the plane of the central ion trajectory, assuming a 1°-divergence angle of the ion beam. The ion trajectories delimiting the ion beam were calculated as follows:

- the coordinates of the crossing points of these trajectories with the entrance limit of the magnetic field were determined,

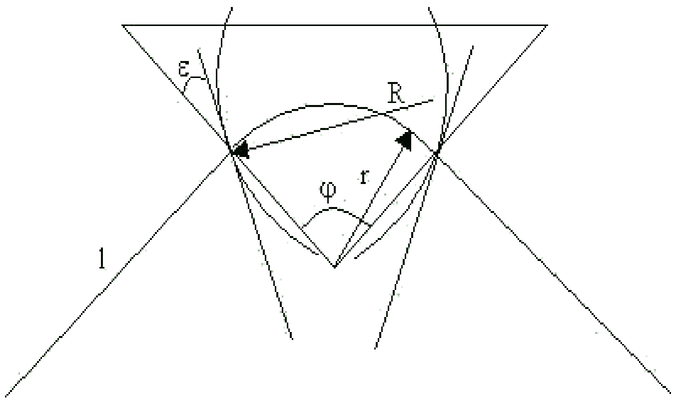

Figure 1. Schematic representation of the geometry of the magnetic analyser
r=238 mm; φ=90°; ε=28.167°; R=419.654 mm; l=515.462 mm

- the curvature radius of the $^{235}U^{+}$ ion trajectory was calculated, assuming that the main trajectory corresponds to the $^{238}U^{+}$ ion,
- the coordinates of the crossing points of the trajectories corresponding to the two ions taken into account, with the exiting limit of the magnetic field, were determined,
- the crossing points of the trajectories delimiting the two emerging ion beams were calculated,
- The relative position of the two images was established (the radial and axial distances between them)

A 6.3 mm distance between the two beams, in radial direction and a 20.7° inclination angle of the image plane towards the central axis of the ion-optics system were found.

A numerical modelling of the magnetic analyser of the SMIT-1 mass spectrometer was also performed, using the "SIMION 3D" software. This application calculates the electrostatic potentials in a 3D array of points, via a numerical first order approximation of the Laplace equation, the electrodes, respectively the poles defining the boundary conditions. Though SIMION isn't a program meant to solve magnetic configurations, the authors have introduced the fictive notion of "magnetic potential" (*Mag defined as gauss·grid unit*) which enables the modelling of magnetic field configurations too.

A 3D array with a grid unit of 2 mm was "built" in which the magnetic poles of the magnetic analyser were placed. The "magnetic potentials" were determined and the trajectories of a set of ions having energies and masses prescribed by the operation conditions of the mass spectrometer (m/z=238, respectively 235 and EK=7000 eV).

Figure 2 shows these trajectories in the collector region of the analyser.

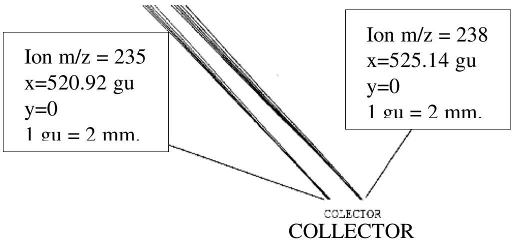

Figure 2. Numerical modelling. Trajectories in the collector region of the SMIT-1 mass spectrometer

From the numerical modelling, the distance between the two beams appears to be 6.5 mm, in a reasonable agreement with the geometrical treatment.

The deflection system

To achieve the simultaneous detection of the two ion beams, a solution had to be found, to place, along the axis of each ion beam, a detection system based on a secondary electron multiplier.

The simplest detection system, the Faraday cage, may be realised at very small sizes, but its sensitivity is limited. For the ion currents of very low intensity, secondary electron multipliers are used. For ions of some KeV kinetic energy (7 KeV for the SMIT-1), these devices are bulky and the constraint of ensuring only 6.3 mm between their axis may seem prohibitive.

A numerical modelling was performed for a double electrostatic deflector enabling the deviations of the two beams in opposite directions, so that secondary electron multipliers could be still used. (Figure 3) This permitted the determination of the constructive parameters: the curvature radius of the central trajectory 20 mm., the

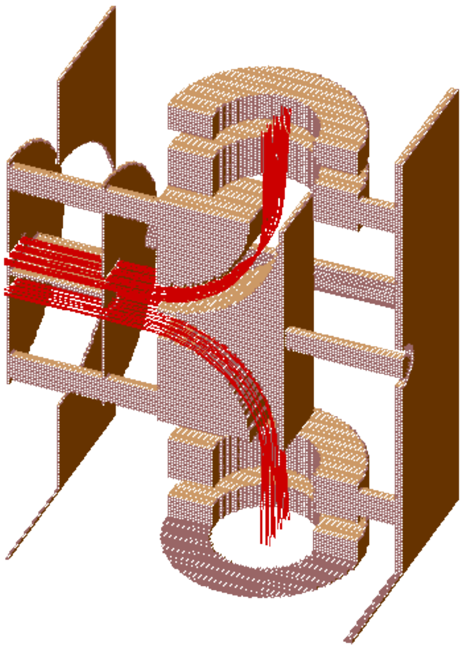

Figure 3.3D Numerical modelling of a double electrostatic deflector

distance between the electrodes of the deflector 4 mm., the electric potential of the deflecting electrode 2250 V.

The double collection system was physically realised and was mounted in the structure of the SMIT-1 mass spectrometer. (Figure 4 and 5). An electrometric system connected to a PC computer was designed and realised and the necessary software was elaborated. The system allows the complete monitoring via the PC of the main parameters: magnetic field in the analyser, sensitivity and range of the two measuring channels, the acquisition and processing of data.

Figure 4. The double deflector mounted on his flange.

Figure 5. The double collector system inserted in the structure of the SMIT-1 spectrometer.

Collector testing

$^{235}U^+$ and $^{238}U^+$ ion currents generated by a natural uranium sample were used. Figure 6 shows the simultaneous recording of the two peaks.

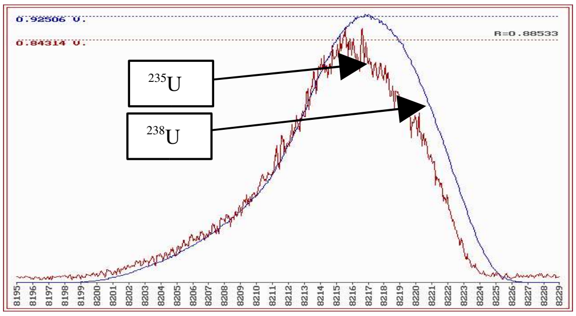

Figure 6. The simultaneous recording of the $^{235}U^+$ and $^{238}U^+$ ionic currents

One may observe that, the peaks have a gaussian shape slightly altered in the lower masses region One may observe also, a small simultaneousness default, meaning that the $^{235}U^+$ ion reaches the collector 1.5 Gauss "sooner" than the $^{238}U^+$ ion. This means that, the distance between the entrance slits of the two channels is 0.05 .. 0.1 mm. smaller as it should be.

Conclusions

The deviation of 1.5 Gauss in what concerns the simultaneousness detection of the two peaks represents 0.018% from the magnetic induction in the gap of the magnetic analyser. There are at lest two ways to compensate this error:

- The use of larger definition slits and larger spaces between the deflector electrodes in order to obtain flat top peaks. This would imply a new design for the double deflector and the results are hardly to estimate.
- The use of an Einzel lens of large aperture in front of the slits. It would permit to achieve slight adjustments on de distance between the ion beams of interest and would perhaps allow double collection on other ion pairs too.

References

[1] David A. Dahl *SIMION 3D version 7.0, user's manual* Idaho National and Environmental Laboratory, INEEL-95/0403, Rev. 5, February 2000.