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New Test Facility for Solar Wind Instrumentation

P. Wurz, A. Marti, and P. Bochsler
Physikalisches Institut, Universität Bern, Sidlerstr. 5, CH-3012 Bern, Switzerland

First experimental results from our new test facility for solar wind plasma particle instrumentation are presented. The test facility consists of an electron-cyclotron resonance ion source operating at 2.45 GHz using permanent magnets and an accompanying ion-optical system for ion beam analysis, definition, and delivery. Ion beams can be produced from elements in gaseous as well as solid form. A simple model to explain the observed ion charge state distributions is also introduced.

For the development, testing, and calibration of solar wind plasma instruments, test facilities providing highly charged ions beams for all elements from hydrogen up to iron are needed. Although ion sources for the desired ions have been available for some time [1, 2], the special demands of space instrumentation made it necessary to build a dedicated facility in house, which also alleviates many logistic problems encountered during calibration campaigns.

We built an electron-cyclotron resonance (ECR) ion source operating at 2.45 GHz using only permanent magnets [3]. The design of this ion source was based on an earlier design from the University of Giessen [4], which we adapted for our needs. We also added a high temperature furnace closely attached to the ion source at the location where the plasma is burning. Ions can be produced from elements in gaseous and solid phase. The latter are formed from vapor released from the high temperature furnace and introduced into an auxiliary plasma (H_2 or He). With furnace temperatures up to 2000°C all elements observed in the solar wind can be provided by this facility. Ions are extracted from the ECR ion source by a mechanically adjustable extraction electrode system to

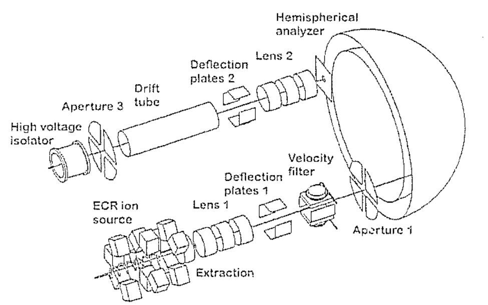

Figure 1: Schematics of the ECR ion source and the ion optical system of the new facility.

optimize the electric field for ion extraction for the particular m/q of the ion of interest in the space charge limited region of the initial ion acceleration. The ion optical system comprises an Einzel lens, a set of deflection plates, a Wien-filter, a 180° hemispherical energy analyzer, a second Einzel lens and a drift tube before the ions exit through the exit aperture (see Figure 2). The ECR ion source with the accompanying ion optical elements are installed on a high-voltage platform allowing for post-acceleration potentials of up to 100 kV. The post-acceleration is applied after the exit aperture, across the high-voltage isolator, and then the ions enter into the main chamber toward the instrument to be tested. Further experimental details of this new facility are given in [3, 5].

So far, beams of highly charged ions have been produced from various gaseous elements

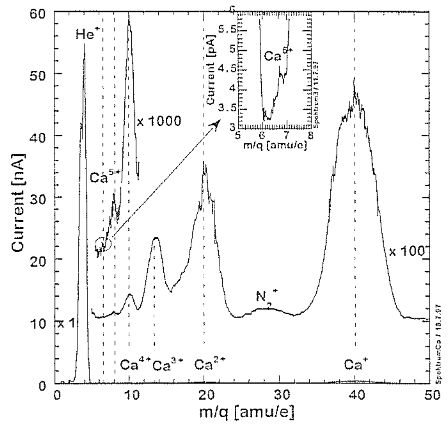

Figure 2: Charge state spectrum of a Ca ion beam. Ca was added to the auxilary He plasma through an atomic beam emitted from a high temperature oven. The ion source parameters were optimized for higher Ca charge states.

and from a few solid elements. As an example of an ion beam produced from a metallic element we show in Figure 2 the recorded charge state spectrum for a calcium ion beam. The dominating ion in the charge spectrum is the He^+ from the auxiliary discharge necessary to maintain a plasma when the element to be ionized is furnished from the high temperature furnace. The oven was kept at 475°C, which gives a Ca vapor pressure of about $1.6\ 10^{-4}$ mbar. The Ca^+ ion (at $m/q = 40$) is about a factor of 100 less intense than the He^+ ion in the ion beam. We can also identify the higher charge states of calcium Ca^{2+}, Ca^{3+}, ... Ca^{6+} at the m/q values 20, 13.3, 10, 8, and 6.7 in the ion beam. At the highest observed charge state for this run, Ca^{6+}, the ion current was still 0.5 pA, which is more than is required for the calibration of solar wind instruments.

In order to understand and predict the formation of multiply and highly ionized elements in the plasma of our ECR source, we devised a simple model consisting of a set of rate equations,

$$\frac{d}{dt}N_0(t)=N_e\{-N_0(t)C_0+N_1(t)R_1\}$$

$$\vdots$$

$$\frac{d}{dt}N_i(t)=N_e\{N_{i-1}(t)C_{i-1}-$$
$$-N_i(t)\left(C_i+R_i\right)+N_{i+1}(t)R_{i+1}$$

$$\vdots$$

$$\frac{d}{dt}N_8(t)=N_e\{N_7(t)C_7-N_8(t)R_8\}$$

where N_i denotes the ion density of an element in charge state i, N_e denotes the electron density, and C_i and R_i are the ionization and recombination constants for an element in the ionization state i in an electron gas of the temperature T_e, i.e. $C_i = C_i(T_e)$ and $R_i = R_i(T_e)$ [6]. Our model relies on the facts that the formation of multiply charged ions is a step-by-step process, and the actual ionization process is electron impact ionization. To obtain the ion densities N_i we integrated the set of rate equations over time, with the upper integration limit being the confinement time τ_C of the ion in the magnetic bottle of the ion source. The integration was performed for several sets of the parameters N_e, T_e, and τ_C in order to best reproduce the measured data, assuming a degree

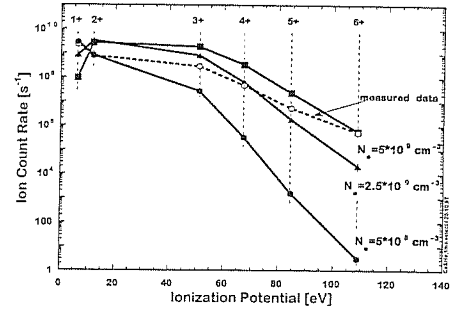

Figure 3: Calculated charge distribution for Ca ions in an ECR plasma for three electron densities and an electron temperature of 100 eV.

of ionization in the plasma of 10%. The best agreement with the measured data is found for an electron temperature T_e= 100 eV, an electron density $N_e = 5\cdot10^9$ cm^{-3} and a confinement time τ_C = 1 ms. Figure 3 shows three results of the calculations for Ca together with the measured charge state distribution. The agreement between our model and the measured data is reasonably good given the simplicity of our model. Also, charge state fractionation will occur in the ion optical system, and the measured charge state distributions is probably different from the charge state distribution in the plasma.

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