CHARGE STATE DISTRIBUTION MEASUREMENT IN AN ECR-DISCHARGE BY VUV-SPECTROSCOPY

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The charge state distribution of multiply charged Ar ions in an electron cyclotron resonance (ECR) heated microwave discharge (Bernhardi et al. 1976) was measured by means of VUV-spectroscopy in the wavelength region $\lambda \leq 100$ nm (Marlinghaus 1984). Ion densities were computed from absolute line intensities in a modified corona model. Assuming electron impact excitation of groundstate ions to play the major role and neglecting all other processes leading to excitation, the ion density n_z is given by

$$n_z = \phi_{jo} / (n_e \langle \sigma_z^j \, v_e \rangle \cdot \varepsilon(\lambda) \cdot \Delta\Omega / 4\pi). \qquad (1)$$

In order to obtain ion densities from equ. (1) six quantities have to be measured or calculated absolutely:

1) the electron impact excitation cross section σ_z^j of the transition $j \rightarrow o$ of ion in charge state z,
2) the efficiency ε of the VUV-spectrometer as a function of the wavelength λ,
3) the solid angle $\Delta\Omega$,
4) the volume emission coefficient ϕ_{jo} which is proportional to the count rate integrated over the width of a line,
5) the electron distribution function $f(v_e)$,
6) the electron density n_e.

The excitation cross sections were calculated in a semi empirical Gaunt factor approximation given by Regemorter (1962). The absolute spectrometer efficiency was obtained using the branching ratio method. Calibration in the visible wavelength region was done with a tungsten strip lamp. Using an entrance slit of 10 µm width the geometrical acceptance angle was used in the calculations. Spectra were recorded with a channeltron detector using photon counting techniques. Ar charge states upto Ar VII have been measured. Due to the lack of atomic data (oscillator strength) charge states upto Ar VI were evaluated. The experimental setup is shown schematically in fig. 1.

The electron distribution f(v) parallel to the magnetic field was measured with an electrostatic energy analyser (similar to that described by Puri 1974) in the mirror throat of the discharge. Assuming f(v) to be isotropic, f(v) was evaluated from the second derivative of the probe characteristic. As found earlier by x-ray spectroscopy in the energy region 3 keV $\leq$ E $\leq$ 22 keV (Ziemann 1983) and in the region 10 keV $\leq$ E $\leq$ 350 keV (Bernhardi and Wiesemann 1982)

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the electron energy distribution function f(E) below 2 keV followed a power law $f(E) \sim E^{-s}$, the spectral index s depending on the discharge conditions (pressure, microwave power) and varying from 1 to 4.

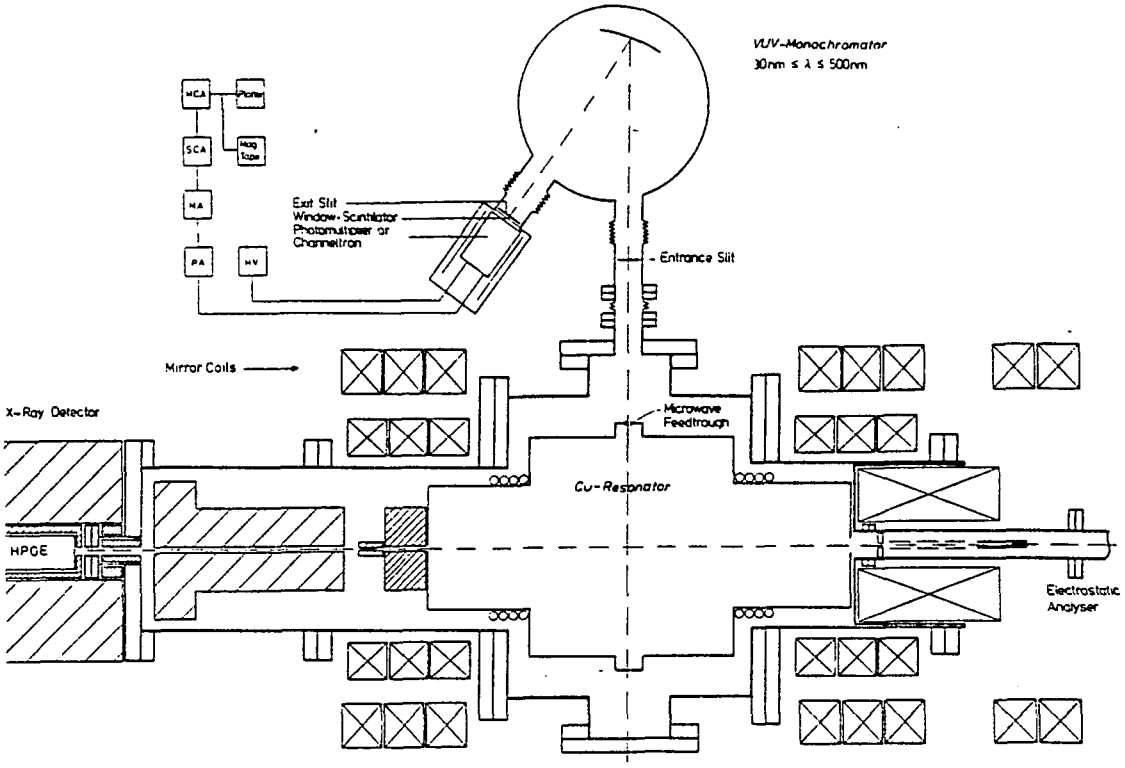

Fig. 1 Experimental setup of the ECR-experiment
Abbreviations are PA, MA = pre-,main amplifier, SCA, MCA = single-multichannel analyser, HV = high voltage power supply

Using Regemorter's cross sections and the measured distribution functions, excitation rate coefficients were calculated by numerical integration (Marlinghaus 1984). Electron density n_e was deduced from the condition of quasineutrality of the plasma

$$n_e = \sum_z z\, n_z . \qquad (2)$$

A typical measured charge state distribution is shown in fig. 2. The highest density is that of the Ar^{2+} ion. Assuming a homogenous stationary plasma it follows from particle balance calculations, that the plasma is fully ionised (Hesse 1983). Processes which are included in these calculations are

i) single, multiple and step-ionisation of atoms and ions by electron impact,
ii) charge exchange collisions between Ar atoms and ions and
iii) diffusion of ions to the wall.

The solution of the balance equation was fitted to measured

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ion densities by varying two fit parameters $n_o/n_e\sqrt{kT_i}$ and $n_e\tau$ (n_o = density of the neutrals, kT_i = ion temperature, $\tau = \tau_z$ = the ion's mean diffusion time to the wall). The first parameter gives a measure for the influence of charge exchange collisions, the second parameter describes the role of step-ionisation via the plasma life time τ. Results are plotted in fig. 2.

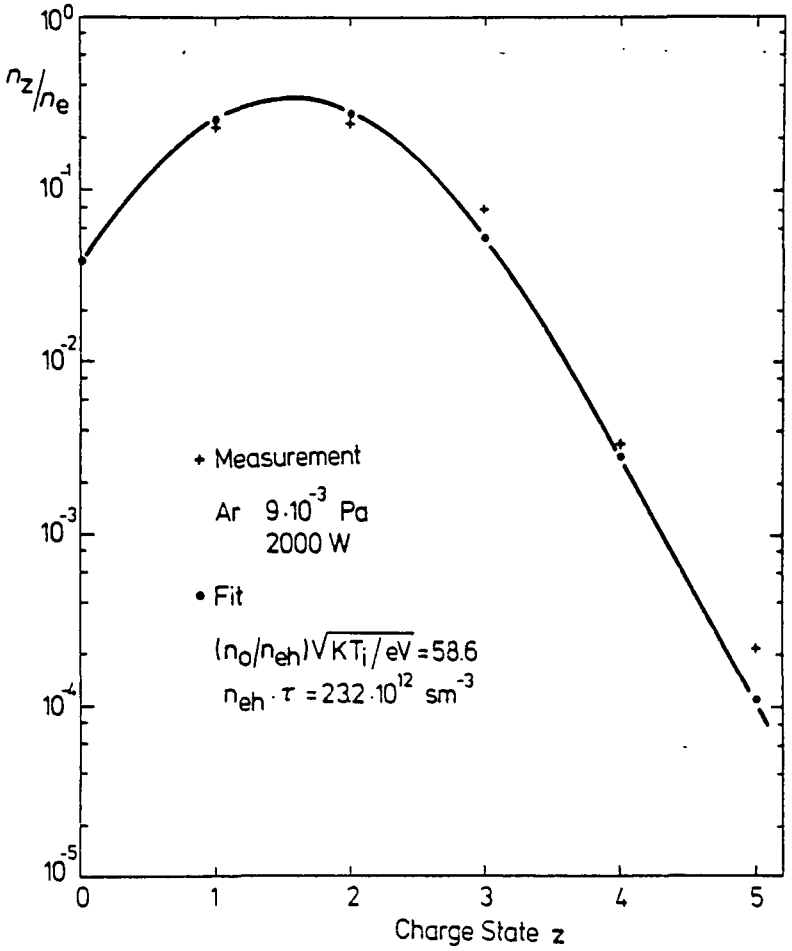

Fig. 2 Typical measured (crosses) and calculated (dots) charge state distribution. For simplicity absolutely measured ion densities are normalized to electron density. The fit yields for the neutrals $n_o/n_e = 0.04$.

Electron density is determined from (2) as $n_e = 1.1\cdot10^{17}m^{-3}$. Assuming $n_o/n_e = 0.04$ as given by the fit, one would be forced to assume unreasonably high ion temperatures. Spectroscopic measurements of the neutral density n_o yield $n_o = 1.3\cdot10^{18}m^{-3}$, pressure measurement yields $1.6\cdot10^{18}m^{-3}$. From these values one obtains $(n_o/n_e)_{exp} \sim 15$ in spite of $(n_o/n_e) = 0.04$ from the fit. From this figure an ion temperature of $kT_i \sim 15$ eV is deduced which is reasonable. The solution of this contradiction is obtained by considering the time behaviour of the plasma.

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Time resolved measurement show, that about 10 ms after ignition of the plasma the concentration of wall material (Cu) increases strongly while the Ar ion densities go sharply down. So we believe, that a short living fully ionised plasma is driven by an instability to the wall, sputtering wall material. Since the plasma Ar ions are neutralized at the wall, there will be a cold plasma wall boundary containing essentially neutral Ar and neutral Cu atoms. When ions from the hot plasma drift through this cold boundary layer, charge exchange reactions may become important as shown earlier (Marlinghaus et al. 1983).

The uncertainty of the ion densities is determined by the uncertainties of the quantities listed below equ. (1) and is estimated by ± 45 % relative and a factor of 2.5-3 absolute. The main contributions come from the spectrometer efficiency (± 30 % relative, factor 2 absolute) and the excitation rate coefficients. Regemorter estimates the absolute uncertainty of his excitation cross sections by a factor of 2 in the threshold region. Because of the flat form of the measured electron distribution functions (power law), the low energy contribution to the rate coefficients is small. For the same reason the influence of putting the effective Gaunt factor for ions $\bar{g}$ = 0.25 or 0.3 instead of 0.2 as discussed by Regemorter is small (± 3 %, + 13 % resp.). We estimate the uncertainty of rate coefficients ± 30 %, but the uncertainty of the oscillator strength used in the calculation (± 25...± 50 %) has to be added. It would be highly desirable that f-values for more lines were known with higher accuracy.

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