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A RELAXATION EXPERIMENT WITH AN INDUCTIVELY COUPLED ARGON PLASMA.

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Inductively coupled plasmas (ICP) are created in a load coil supplied by a RF generator [1]. We operate with a 100 Mhz Philips generator designed for spectrochemical purpose.

A point of recurrent discussion is the presence of (near-) local thermal equilibrium (LTE) in the argon ICP. This discussion has three aspects.

1) In how far does the equality $T_e = T_h$ holds in which T_e is the electron temperature and T_h the temperature of the heavy particles?

2) In how far are the atomic levels populated according to Saha [1]?

3) What is the correct form of the Saha density if $T_e \neq T_h$ [2]?

A technique to tackle these questions experimentally is the use of a relaxation technique a.o. described by [3,4] and applied to the ICP by [5]. The generator is switched off during a short period (typically 100 μs) by which 4 relaxation mechanisms are induced in the plasma.

This will be discussed in view of the density of a highly excited state p for which we assume that, at any moment, the population density n(p) is determined by the balance of ionization and 3 particle recombination; which means that the density is given by the Saha equation [2]

$$\frac{n^s(p)}{g(p)} = \frac{n_e}{2}\frac{n_+}{g_+}\cdot\frac{h^3}{(2\pi m_e k T_e)^{3/2}}\cdot\exp[I_p/kT_e] \quad (1)$$

where n_e and n_+ are the electron and ion density, g_+ and $g(p)$ the statistical weight of the ion groundstate and the level p, whereas I_p is the ionization energy of the level p.

The response of the density $n^s(p)$ on the switch off and on procedure can be described by the following scenario (cf. figs 1 and 2):

1) *Cooling*: Immediately after the switch off the electrons will be cooled by the heavy particles such that T_e changes into T_h in a cooling time $\tau_E \approx 10^{-6}$s. This means a.o. an increment of the slope of the Saha plot and thus a jump in $n^s(p)$, cf fig.2.

2) *Recombination*. The electrons and ions will recombine in a time $\tau_n \approx 10^{-4}$s which means that the Saha line will descend retaining its slope. Thus $n^s(p)$ decreases slowly.

3) *Heating*. If the RF generator is switched on the slope of the curve decreases resulting in a sudden decrease of the density ($\tau \approx \tau_E$).

4) *Ionization*. Since n_e and n_+ increase in a time τ_n we find a relatively slow increase of the density to its original value before the switch off.

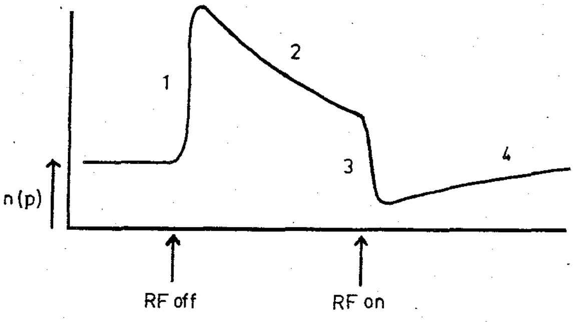

Fig 1

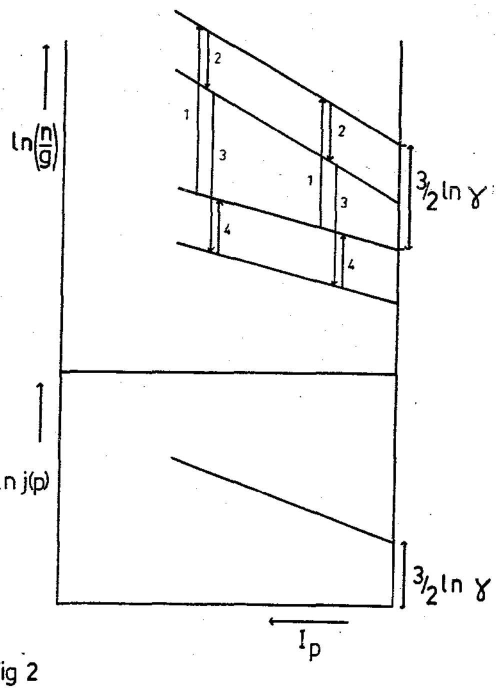

Fig 2

Let us consider the cooling mechanism during which $n^s(p)$ changes with the jump factor $j^s(p) = n^s(p;n_e,T_h)/n^s(p;n_e,T_e)$.
The jump can be related to $\gamma \equiv T_e/T_h$ by the relation

$$\ln j^s(p) = \frac{3}{2}\ln\gamma + I_p[\gamma - 1]/kT_e \qquad (2)$$

which is obtained using eq(1) for T_h and T_e and realizing that since $\tau_E \ll \tau_n$, the value n_e and n_+ will remain constant during the cooling process. The arrows labeled "1" in fig. 2 represent the jump factor and are plotted against I_p in the bottom of fig. 2. The intersection of this curve with the axis gives the ratio $\gamma \equiv T_e/T_h$ while the slope equals $1/T_e$.

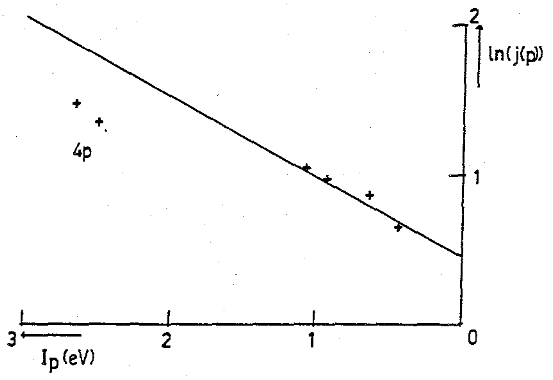

Fig 3

Figure 3 presents preliminary results obtained from relative line intensity measurements of several atomic transitions in the active plasma zone between the windings of the load coil. To obtain the jump for a given line we used the ratio of the intensity before and immediately after the switch off. The line intensity is integrated along the line of sight intersecting the skin of the plasma (cf. fig. 4); i.e. the annular zone in which the energy is coupled in. It is to be expected that the contribution to the line intensity of the plasma part on the line of sight but outside the skin region can be neglected.
The solid curve in fig. 3 is the best fitting one with a slope determined by independent T_e measurements [6]. We find a value of $\gamma = 1.37$. A plot for the region just above the load coil gives the value $\gamma = 1.25$. This is in accordance with the fact that the more electrons are heated (and heavy particles cooled) the higher γ should be. In principle it must be possible to deduce T_e from the slope of the curve for highly excited states. However this can only be done if spatially resolved measurements are used; an aim for the direct future. Figure 3 shows that the lower excited Ar levels (4p) are not on the curve. This is related to the fact that the densities of these levels deviate from the Saha value $n^s(4p)$. These deviations from Saha, their relation to the ionization and recombination processes and the recombination coefficient as obtained from the recombination period "2" (cf fig. 1) are discussed in [1].

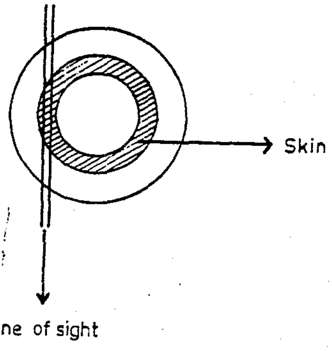

Fig 4

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