SUPRA THERMAL ELECTRON TAILS EFFECTS ON X-RAY LINE EMISSION IN A TOKAMAK PLASMA

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INTRODUCTION

The soft X-ray lines emitted by highly ionized impurities are one of the most prominent spectral features of today's tokamaks. In fact the hydrogen isotope plasmas produced in these devices attain temperature values ranging from about one to several keV. A great deal of information about the plasma conditions can be drawn, in particular, from the highly resolved spectra of medium-Z ions which are very rich in satellites excited via dielectronic recombination and innner shell excitation (Dubau and Volontè 1980, Bitter et al. 1979).

The intensity ratio between a dielectronically excited satellite and the resonance line of the parent ion is an example of a diagnostic tool useful for the electron temperature measurement of a thermal plasma. This ratio, in effect, is sensibly dependent upon that temperature because electrons of different energies are involved in the excitation of the two lines, the resonance one being excited by the electrons whose energy is greater than the threshold Eo and the satellite by those who resonate with its excitation energy Es that is usually lower than Eo by a few keV.

On the other hand the values of these ratios in plasmas where the electron distribution function deviates from a Maxwellian are expected to be sensibly different from thermal ones (Gabriel and Phillips 1979).

In this presentation the experimentally observed effects on these ratios in situations where supra-thermal electron tails are present are briefly described. It is also shown how quantitative information about the electrons in the tail can be deduced using this method.

THE EXPERIMENT

Our experiments have been performed on the Frascati Tokamak FT, a high toroidal magnetic field device. Such devices are characterized by a higher current density as compared to other tokamaks and their plasmas are therefore more easily affected by supra-thermal phenomena. The discharges studied are characterized by temperature profiles that are peaked at the plasma centre reaching peak values between 0.7 and 2 keV. The electron density profiles are peaked at the centre too and their peak values range from 0.5 to $5 \cdot 10^{14}$ cm^{-3}. In these discharges the soft X-ray line spectra of He-like Cr and Fe have been recorded. Their emission is estimated to come from a limited region about the plasma centre.

In a purely maxwellian framework a theoretical value $R_{th} = I_s / I_w$ can be worked out for the ratio between the

https://doi.org/10.1017/S0252921100085274 Published online by Cambridge University Press

intensity I_S of a dielectronically excited satellite and the intensity I_W of the resonance line of the ions considered, starting from well established expressions for the two intensities (Dubau and Volontè 1980, Bely-Dubau et al. 1982). This ratio in the low density limit is only dependent on the electron temperature, and has been extensively checked in different tokamak experiments (Bitter et al. 1981, Apicella et al. 1983).

A good agreement of the experimental ratio R_{exp} and the theoretically expected value has been observed in our experiments at electron densities higher than $2.5 \cdot 10^{14}$ cm^{-3}. This has been found for Cr XXIII, using the d_{13} line as the dielectronic satellite, and for Fe XXV, using the close group of satellites A, B, d_{13}. But for densities decreasing below the mentioned value an increasingly important deviation of R_{exp} from R_{th} has been observed (figs. 1 and 2 referring respectively to Cr and Fe). This has been interpreted as due to the presence of a supra-thermal electron tail enhancing the excitation of the resonance line with respect to a maxwellian situation (Apicella et al. 1983).

INTERPRETATION OF RESULTS

To get quantitative information about the electrons in the tail from these observations a model expression should be assumed in principle for the tail distribution function, in order to evaluate the relative contribution of these electrons to the excitation rate coefficient of the resonance line $Q_W = \int f(E)\sigma_W v \, dE$. But in this case a favourable coincidence permits to get rid of this assumption.

To understand this it is useful to look at the fig. 3. The crosses there indicate the $\sigma_W v$ product versus the energy of the incident electron as deduced by recently published values of the excitation cross section σ_W for the Fe XXV resonance line (Mann 1984). These values are well fitted asymptotically by the dashed line, that has been computed by using the non relativistic Bethe expression for σ_W

$$\sigma_W = 4\pi a_0^2 \frac{E_H}{E_0} \frac{E_H}{E} f \cdot \left[\ln \frac{4E}{E_H} (K a_0)^2 \left(\frac{E_H}{E_0}\right)^2 \right].$$

Here the values $f = 0.744$ and $K = 11.7/a_0$ have been used for the oscillator strength and the cutoff wavenumber respectively, a_0 is the Bohr radius and $E_H = 13.6$ eV is the Rydberg constant.

But at the energies we are speaking of, this description is no more correct because, as the electron energy E approaches the relativistic domain, a new effect starts playing an increasingly important role: this is the interaction with the ion through exchange of virtual photons (Fano 1963). In this case the relativistic expression has to be used for the cross section:

$$\sigma_W = \frac{8\pi a_0^2}{m v^2} \frac{E_H^2}{E_0} f \cdot \left[\ln \left\{ \frac{\beta^2}{1-\beta^2} (K a_0)^2 \left(\frac{E_H}{E_0}\right)^2 \frac{2mc^2}{E_0} \right\} - \beta^2 \right]. \quad \left(\beta = \frac{v}{c}\right)$$

The $\sigma_W v$ product so deduced is represented in the figure by the continuous line. It has to be considered as a fairly good approximation for energies greater than about 15 keV. Moreover up to energies of the order of the MeV and higher it has the pleasant feature not to depart more than a small percentage from its median value $\langle\sigma v\rangle$.

This occurrence permits us to interpret the increment in the resonance line intensity as simply proportional to the number of electrons in the tail through a coefficient that is independent of their distribution function, provided that the tail develops for energies sensibly greater than the threshold Eo=6.7 keV. Thus we are led to a simple expression for the density n_s of electrons that are in excess of the maxwellian number over the threshold energy:

$$n_s/n_e = \left(Q_s(T_e)/\langle\sigma v\rangle \right) \cdot \left(1/R_{exp} - 1/R_{th}(T_e) \right),$$

where n_e is the electron density and $Q_s(T_e)$ is the dielectronic satellite excitation rate coefficient.

SOME RESULTS

To show an example of application of this kind of analysis we present fig. 4. There the quantity n_s/n_e for a set of ohmic discharges is plotted versus the Dreicer parameter $\mathcal{E}/\mathcal{E}_c$, that is the ratio between the toroidal electric field in the plasma and the critical field $\mathcal{E}_c$. This is the field whose force would not be compensated by the collision frictional resistance for electrons whose energy is greater than kT_e. The boxes in the figure refer to discharges done at toroidal magnetic field of 8 Tesla and the dots at 4 Tesla. A clear dependence of the supra-thermal population on the Dreicer parameter can be seen. But an even more remarkable dependence upon the magnetic field appears from these data. This cannot actually be understood in terms of the collisional theories of runaway electrons generation in static electric fields. Probably more complicated effects involving the presence of waves in the plasma should be included in the picture in order to get a better insight in these phenomena.

REFERENCES

Apicella, M.L., Bartiromo, R., Bombarda, F. and Giannella, R. 1983 Phys. Lett., 98 A, 174.
Bely-Dubau, F., Dubau, J., Faucher, P., and Gabriel, A.H. 1982 Mon. Not. R. Astron. Soc., 198, 239.
Bitter, M., von Goeler, S., Horton, R., Goldman, H., Hill, K.W., Sauthoff, N.R., and Stodiek, W. 1979 Phys. Rev. Lett., 42, 304.
Bitter, M., von Goeler, S., Hill, K.W., Horton, R., Johnson, D., Roney, W., Sauthoff, N.R., Silver, E. and Stodiek, W. 1981 Phys. Rev. Lett., 47, 921.
Dubau, J., and Volontè, S. 1980, Rep. Prog. Phys., 43, 199.
Fano, U. 1963, Ann. Rev. Nucl. Sci., 13, 1.
Gabriel, A.H., and Phillips, K.J.S. 1979 Mon. Not. R. Astron. Soc., 189, 319.
Mann, J.B. 1984 Atom. Data and Nucl. Data Tables, 29, 407.

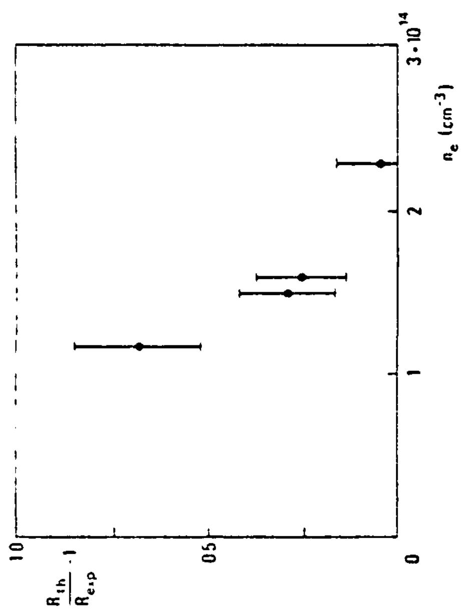

Figure 1

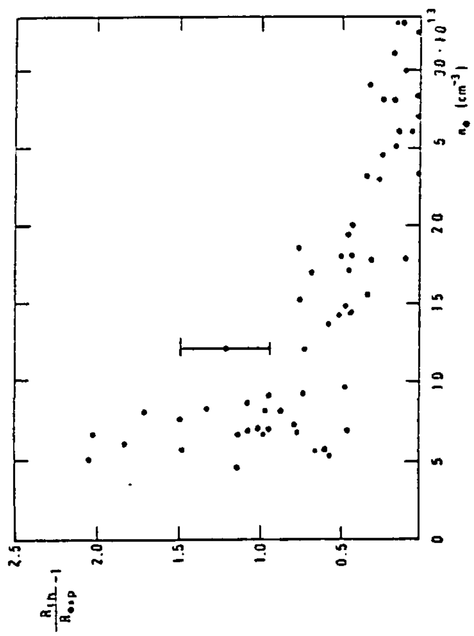

Figure 2

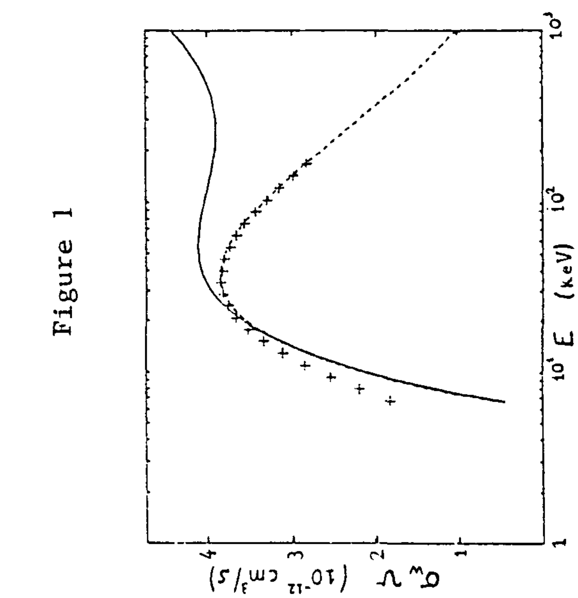

Figure 3

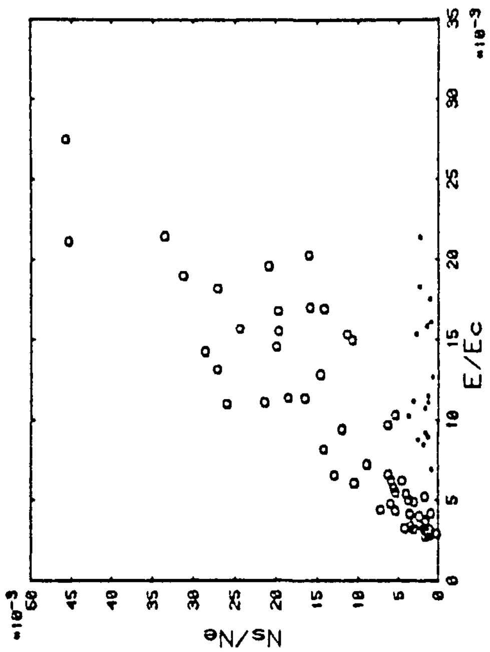

Figure 4

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