THE RELEVANCY OF MAGNETICALLY CONFINED PLASMAS - TOKAMAK AND MIRROR - FOR ATOMIC SPECTROSCOPY AND ASTROPHYSICAL PLASMA DIAGNOSTICS.

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This talk presented the magnetic confinement experiments from a different angle, i.e. as laboratory sources which allow the study of various problems in such fields as atomic physics and astrophysics.

Tokamak and magnetic mirror plasmas have properties which make them particularly suitable for basic atomic physics experiments; they are stable over long intervals of time and have wide ranges of electrom densities and temperatures. Also, models on which electron density and temperature diagnostics are based in astrophysical research can be checked since these quantities are accurately measured by independent non-spectroscopic methods.

In a tokamak, the plasma is confined in a torus by a magnetic configuration obtained from the superposition of an external toroidal field and the poloidal field created by the plasma current (the current is induced in the plasma which acts as a secondary of a transformer, H. Furth, 1981). Once the current reached its maximum value, a steady state phase of the discharge is established, while for hundreds of milliseconds to several seconds the major plasma parameters at given radial positions in the plasma are practically constant. The radial profiles (across the minor radius of the torus, which varies in present day experiments from ten to a hundred cm.) of the electron density and temperature are peaked on the axis and their overall shape is fairly represented by a gaussian. The range of the central electron densities in tokamak experiments is from several times 10^{12} to 10^{14} cm^{-3} and peak electron temperatures of 1 to 2 keV are obtained in ohmically heated discharges. When additional heating (such as neutral beam injection or electron/ion cyclotron resonance heating) has been used, central ion temperatures as high as 8 keV and electron temperatures of the order of 4-5 keV have been attained (Eubank et al. 1979).The major plasma parameters are measured by various methods: microwave interferometry, electron cyclotron emission, Thomson scattering, energetic neutral particle spectra analysis, probes, etc. (Furth H, 1981). Most of these diagnostics when carefully built and calibrated can provide measurements with errors of the order of 10-20% (which represents a great improvement over the rather rough estimates in the complex and short lived high density plasmas, laser, spark, exploding wires, etc).

The tandem mirror machine is an open ended device, in which the plasma is confined in a central cell by magnetic and thermal barriers set up in the two end plugs. The densities here are 10^{11}-10^{12} cm^{-3} and the electron temperatures(without auxilliary heating) vary from several tens to 200 eV (Simonen et al. 1983).

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The results presented here have been obtained from the PLT tokamak at Princeton Plasma Physics Laboratory and TMX U tandem mirror at Lawrence Livermore Laboratory.

(1) SPECTROSCOPY OF HIGHLY IONIZED ATOMS

The spectrum of a high Z element, having a complete n=3 shell, will be very complex when 3-3 transitions are emitted simultaneously by many ions having very close ionization potentials. For example, Mo XVI, IP 100eV) to MoXXIV (IP 500eV) will emit thousands of lines originating from $3p^6 3d^k - 3p^5 3d^{k+1}$ transition in the 60-90 Å range. It is therefore very difficult to assign the lines to given ions unless some method is found to separate between various ionization states. In laser or spark produced plasmas, by varying the power deposition on the target or the energy content of the discharge one can separate a few states of ionization. But the difficulty still exists, since even three or four ions, such as for instance MoXVII to MoXX will emitt an enormous number of lines. It is practically impossible to follow the time histories of these lines simultaneously in the short lived plasmas (tens to hundreds of nanoseconds). On the contrary, in the tokamak spectra the identification and classification of the strong lines is possible because various ionization states recorded simultaneously are separated according to their time and space evolution. This simultaneous recording of the time resolved - wide spectral range was made possible by the use of image intensifier detectors mounted on high resolution grazing incidence spectrometers (Schwob at al. 1983, Hodge at al. 1984). In addition to the identification of the lines according to their individual time histories (Stratton et al. 1983) these instruments can scan radially the tokamak plasma, thus relating the emission to a given electron temperature. Zirconium, molybdenum and silver have been injected in the PLT tokamak by a laser blow off technique (Marmar et al.1975) and strong lines originating from 3-3 transitions belonging to ions isoelectronic to KI, ArI, ClI and SiI have been identified. The identifications, based on both extrapolations/interpolations along the isoelectronic sequences and ab initio relativistic energy level computations, are presented and discussed in two papers (Finkenthal et al. 1984a, Schwob et al. 1984).

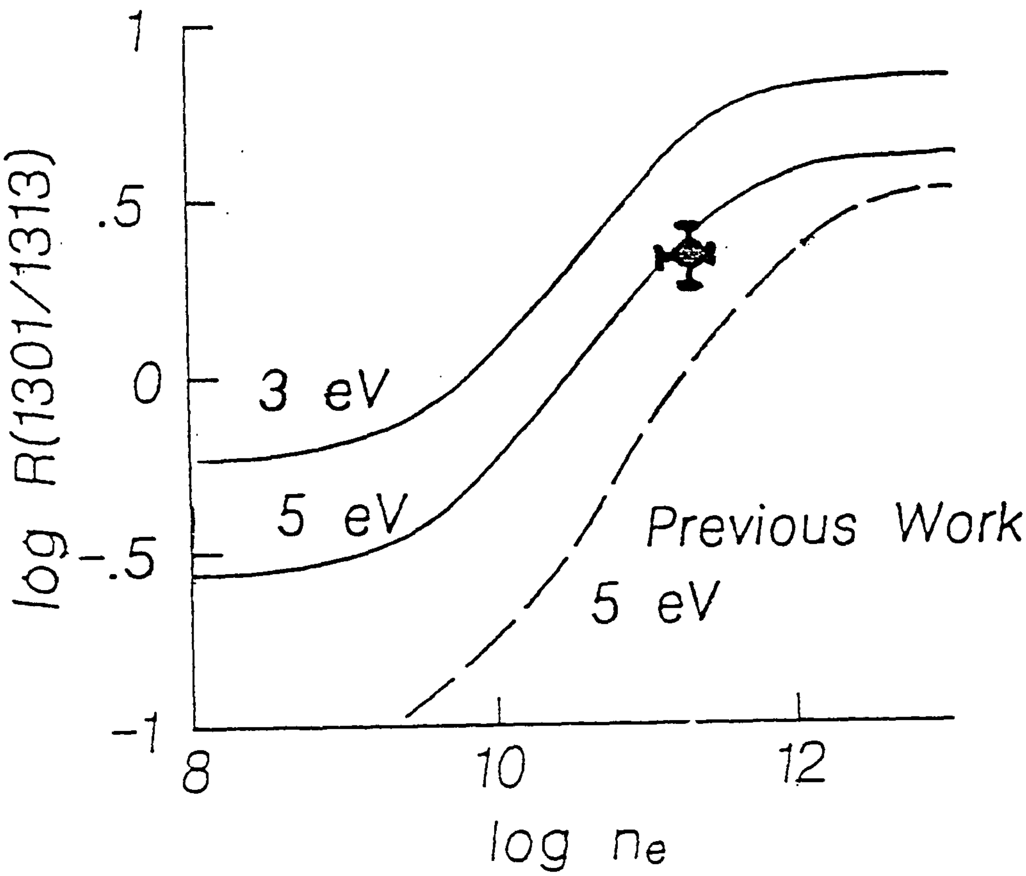
(2) ATOMIC PHYSICS

(a) COMPARISON OF DIFFERENT COLLISION STRENGTH COMPUTATIONS WITH EXPERIMENTAL DATA.

Two sets of computations of line intensity ratios in the case of the SiIII ion, lead to very different results insofar as their electron density dependence is concerned (Nicolas et al.1979, Dufton et al. 1984).

The levels considered and the assumptions concerning level populating mechanisms were similar in the two works. The computed transition probabilities were also very close. The difference between the two, was in the way the electron impact collision strength have been computed: the first work used the distorted wave technique while in the second, the R-matrix technique was used and the effect of the resonances has been included.

The comparison between the two, in the case of our particular line ratio and the experimental result obtained from the TMX U silicon spectrum is presented in figure 1.



As one can see in figure 1, the difference between the two theoretical computations would lead to a difference of an order of magnitude in the infered electron density both for solar corona and flare. The experimental values of several line ratios,(discussed in detail in T.Yu et al. 1984), indicate that the effect of resonances is very important and must be taken into account in the collision strength computations.

(b) THE EFFECT OF INNER-SHELL IONIZATION PROCESSES ON THE LINE INTENSITY OF MgI - LIKE IONS IN TOKAMAK PLASMAS.

A persistent departure from the predicted 'resonance - intercombination' line ratios within the MgI like sequence (from Sc X to Mo XXXI has been observed in tokamak spectra (Finkenthal et al. 1982 a, Finkenthal et al. 1982 b). A model including 47 energy levels has been considered for the Se XXIII ion and a large discrepancy still subsisted between theory and experiment as seen in table 1.

Transition	λ (A)	Brightness (photons/cm^2-sec-sr)	Relarive Intensity meas.	calc.
$3s^2\ ^1S_0 - 3s3p\ ^1P_1$	175.92	2.2(15)	100	100
$3s^2\ ^1S_0 - 3s3p\ ^3P_1$	265.7	3.4(14)	15	6.5
$3s3p\ ^3P_2 - 3s3d\ ^3D_3$	154.04	1.3(14)	6	2.2
$3s3p\ ^1P_1 - 3s3d\ ^1D_2$	158.86	1.6(14)	7	5.7

Table 1.

The ionization from the AlI like ion (ground state $3s^23p$) by an inner shell ionization process has been included in the level population model.(One of the 3s electrons is eliminated,bringing thus the newly produced MgI like ions, directly into the excited 3s3p state). When the relative concentration of AlI/MgI like ions is close to two,the experimental results come in good agreement with those predicted by theory. A detailed discussion of this topic is currently under publication (Finkenthal et al 1984 b).

3. ASTROPHYSICS

Iron has been injected into the PLT tokamak (by the above mentioned technique) at two different central electron densities, $5 \times 10^{12}\ cm^{-3}$ and $3.5 \times 10^{13}\ cm^{-3}$. The spectra obtained have been compared in the 90-140 Å region with a solar flare spectrum. Figure 2 shows the comparison of the three spectra. The first striking thing is the similarity of the low density tokamak and flare spectra. This would already indicate that both electron density and temperature conditions of the two emitting plasmas are fairly close. The next step was to analyze in detail the line brightness within different ionization states and compare their experimental density dependence with this predicted by the theoretical models (the spectrometer which recorded the tokamak spectra has been calibrated at the SURF facility at NBS). The results for Fe XVIII to Fe XXII ions have been presented elsewhere (Stratton et al. 1984 a) and first results of an extension of this work for other elements, from titanium to selenium is presented at this conference (Stratton et al. 1984 b). As a general conclusion one should remark the good agreement between theory and experiment in these cases, which indicates that the basic assumptions made in the models, concerning populating mechanisms, transition probabilities and collisional excitation rates, are correct. This kind of 'laboratory simulations' of astrophysical plasmas is extremelly valuable for astrophysical plasma diagnostics and will be further pursued in future experiments.

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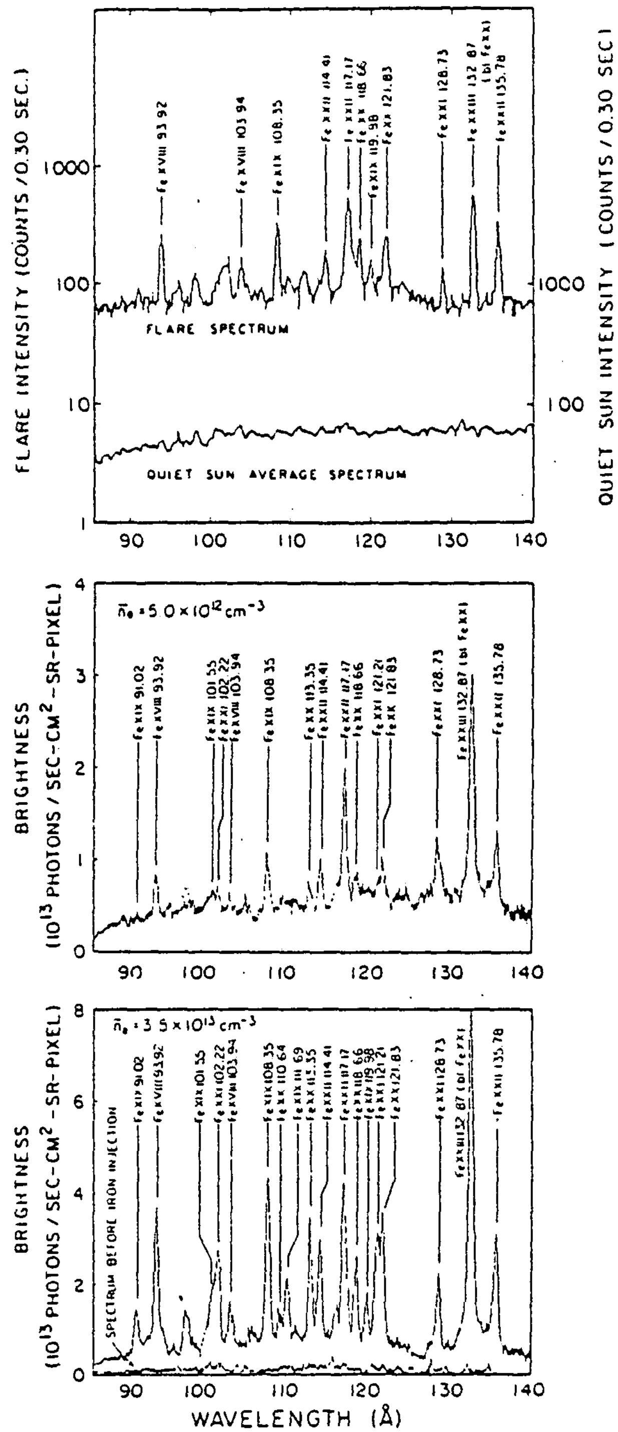

UPPER: SOLAR FLARE AND QUIET SUN AVERAGE SPECTRA (FLARE E IN S.O. KASTNER, W.M. NEUPERT, AND M. SWARTZ 1979, AP. J., 191, 261).

MIDDLE AND LOWER: PLT TOKAMAK IRON SPECTRA AT $\bar{N}_E = 5 \times 10^{12}$ CM^{-3} AND $\bar{N}_E = 3.5 \times 10^{13}$ CM^{-3} (B.C. STRATTON, H.W. MOOS, AND M. FINKENTHAL 1984, AP. J. (LETTERS), 279, L31)

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