RELATIVE INTENSITIES OF LINES IN F I- B I-LIKE Ti, Cr, Fe, Ni, and Ge: A COMPARISON OF THEORY AND EXPERIMENT

B.C. Stratton and H.W. Moos
Department of Physics and Astronomy
Johns Hopkins University
Baltimore, Maryland

U. Feldman and J.F. Seely
E.O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, D.C.

S. Suckewer
Plasma Physics Laboratory
Princeton University
Princeton, N.J.

M. Finkenthal
Racah Institute of Physics
Hebrew University
Jerusalem, Israel

INTRODUCTION

Allowed $2s^2 2p^k - 2s2p^{k+1}$ transitions in the F I- B I-like ions of elements with $Z \geq 20$ are often observed in spectra of high-temperature ($T_e \geq 10^7$ K) laboratory and astrophysical plasmas. Calculations of level populations in these ions are important in the interpretation of measured intensities of these lines for plasma diagnostics. Impurity ion densities and radiated power losses in tokamak plasmas, and the emission measure of astrophysical sources, can be derived from spectroscopic measurements using level population calculations. Certain line-intensity ratios can be used to measure the electron density in astrophysical plasmas; this technique may also be useful in some low-density laboratory plasmas. It is therefore important to experimentally check the level populations in high-Z ions using spectra from a well-diagnosed laboratory plasma, such as that of a tokamak. This has been previously done only for some transitions in Fe XVIII - Fe XXII (Suckewer and Hinnov 1979).

In the present work, measured relative intensities of many allowed $2s^2 2p^k - 2s2p^{k+1}$ transitions (60-200 Å) in the F I- B I-like ions of Ti, Cr, Fe, Ni, and Ge are compared with values from level population calculations (Bhatia, Feldman, and Doschek 1980; Feldman *et al*. 1980; Feldman, Seely, and Bhatia 1984). Spectra of all the elements were obtained from Princeton Large Torus (PLT) tokamak plasmas with line average electron densities ($\bar{n}_e$) near 2.5×10^{13} cm^{-3}; for Ti and Cr, spectra were also obtained at $\bar{n}_e \cong 5 \times 10^{12}$ cm^{-3}. Comparison of PLT iron spectra at $\bar{n}_e = 5 \times 10^{12}$ cm^{-3} and $\bar{n}_e = 3.5 \times 10^{13}$ cm^{-3} demonstrates that certain line-intensity ratios can be reliably used for density diagnostics. These spectra strongly resemble published spectra of high-temperature regions of solar flares.

https://doi.org/10.1017/S025292110008564X Published online by Cambridge University Press

The measurements were made with a grazing incidence time-resolving spectrograph (Hodge, Stratton, and Moos 1984) which covers the 15-360-Å region with 0.7-Å resolution. The spectrograph was absolutely calibrated from 60 to 360 Å using synchrotron radiation from the National Bureau of Standards SURF II facility. The measured relative intensities are therefore reliable. This was confirmed by comparison of 12 measured and calculated branching ratios: 10 of the measured ratios agreed with the calculations within 30%. Thus, the accuracy of the measurements is taken to be 30%. Small amounts of the impurity elements were introduced into the current plateau periods of ohmically-heated deuterium plasmas using the laser-blowoff technique.

RELATIVE INTENSITIES OF Ti, Cr, Fe, Ni, and Ge LINES

The peak brightness of each line was measured and converted to a relative intensity by taking its ratio with the brightness of a line due to a transition observed in all five elements. Of the 58 lines observed at $\bar{n}_e \cong 2.5 \times 10^{13}$ cm^{-3}, the measured relative intensities of 47 agree with the predicted values within 30%. In most cases, the exceptions can be reasonably attributed to problems with the measurements, such as blended lines. Thus, it appears that the level population calculations at this density can be used with some confidence for plasma diagnostics. In the C I-like ions, there is evidence that proton collisional excitation and de-excitation between the levels of the ground configuration should be included in the calculations: the $2s^22p^2\ {}^3P_2 - 2s2p^3\ {}^3D_3/2s^22p^2\ {}^3P_0 - 2s2p^3\ {}^3D_1$ intensity ratios calculated including proton collisions are in better agreement with the measurements in Fe XXI, Ni XXIII, and Ge XXVII than the values calculated not including proton collisions.

For Ti and Cr at $\bar{n}_e \cong 5 \times 10^{12}$ cm^{-3}, agreement between the measured and calculated relative intensities is not as good: the measured relative intensities of 16 out of 33 of the observed lines agree with the calculated values within 30%. Again, many of the exceptions can be traced to problems with the measurements. The remaining discrepancies are probably due to the fact that the low-density calculations do not include proton collisions. Calculations which include proton collisions are being performed and will be used to test this hypothesis.

COMPARISON OF TOKAMAK AND SOLAR-FLARE IRON SPECTRA

Fig. 1 shows PLT iron spectra in the 90-140 A region at $\bar{n}_e$ = 5×10^{12} cm^{-3} and $\bar{n}_e = 3.5 \times 10^{13}$ cm^{-3} and a solar-flare spectrum of the same region obtained in 1969 by the Goddard Space Flight Center grating spectrometer on the OSO 5 satellite (Flare E in Kastner, Neupert, and Swartz 1974). The similarity between the tokamak and flare spectra is clear, especially in the low-density case, indicating that the density and temperature of the flare and low-density tokamak plasmas are approximately the same. (These tokamak spectra are discussed in detail in Stratton, Moos, and Finkenthal 1984).

In order to check the reliability of line-intensity ratios in Fe XIX - Fe XXII for density diagnostics, measured values of seven density-dependent ratios were compared at both densities with values from level population calculations (Feldman *et al.* 1980; Bhatia and Mason 1980; Mason *et al.* 1979; Mason and Storey 1980). The ratios are Fe XIX 108.35 Å/119.98 Å, Fe XIX 108.35 Å/91.02 Å, Fe XX 121.83 Å/110.64 Å, Fe XXI 121.21 Å/128.73 Å, Fe XXI 102.22 Å/128.73 Å, Fe XXII 114.41 Å/117.17 Å, and Fe XXII 114.41 Å/135.78 Å. With the exception of the Fe XXII 114.41 Å/135.78 Å ratio at the low density, the measured and calculated values agree within 30%. Thus, these ratios can be reliably used to measure the density in solar flares, other astrophysical plasmas, and laboratory plasmas.

REFERENCES

Bhatia, A.K., Feldman, U., and Doschek, G.A. 1980, *J. Appl. Phys.*, *51*, 1464.

Bhatia, A.K., and Mason, H.E. 1980, *Astr. Ap.*, *83*, 380.

Feldman, U., Doschek, G.S., Cheng, C.C., and Bhatia, A.K. 1980, *J. Appl. Phys.*, *51*, 190.

Feldman U., Seely, J.F., and Bhatia, A.K. 1984, *Atomic Data and Nuclear Data Tables*, in press.

Hodge, W.L., Stratton, B.C., and Moos, H.W. 1984, *Rev. Sci. Instr.*, *55*, 16.

Kastner, S.O., Neupert, W.M., and Swartz, M. 1974, *Ap. J.*, *191*, 261.

Mason, H.E., Doschek, G.A., Feldman, U., and Bhatia, A.K. 1979, *Astr. Ap.*, *73*, 74.

Mason, H.E., and Storey, P.J. 1980, *M.N.R.A.S.*, *191*, 631.

Stratton, B.C., Moos, H.W., and Finkenthal, M. 1984, *Ap. J. (Letters)*, *279*, L31.

Suckewer, S., and Hinnov, E. 1979, *Phys. Rev. A.*, *20*, 578.

ACKNOWLEDGEMENTS

The authors would like to thank the PLT group, headed by J. Hosea, for supporting these measurements; S. Cohen, J. Timberlake, and T. Bennett for providing the impurity injection; and A.K. Bhatia of the Goddard Space Flight Center for useful discussions. This work was supported by Department of Energy Contract No. DE-AS02-76ET53006.

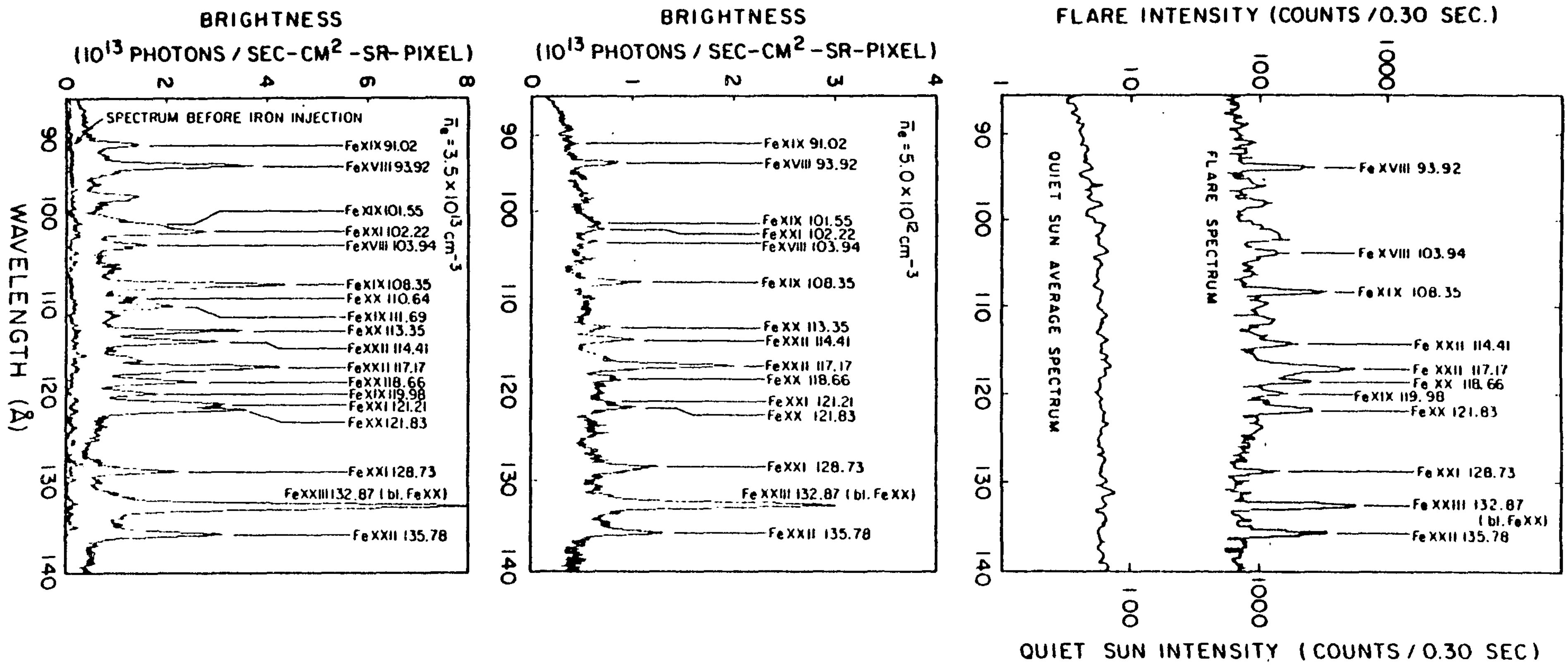

Fig. 1. Solar flare and quiet sun average spectra (upper). Tokamak spectra at $\bar{n}_e = 5 \times 10^{12}$ cm^{-3} (middle) and $\bar{n}_e = 3.5 \times 10^{13}$ cm^{-3} (lower). (From Stratton, Moos, and Finkenthal 1984).