OCTOBER 1980

PPPL-1712

UC-20f

TRACER ELEMENT INJECTION INTO PDX
TOKAMAK FOR SPECTRAL LINE
IDENTIFICATION AND LOCALIZED
DOPPLER TEMPERATURE MEASUREMENT

BY

S. SUCKEWER, J. CECCHI, S. COHEN,
R. FONCK, AND E. HINNOV

MASTER

**PLASMA PHYSICS
LABORATORY**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

**PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY**

This work was supported by the U.S. Department of Energy
Contract No. DE-AC02-76-CHO 3073. Reproduction, translation,
publication, use and disposal, in whole or in part,
by or for the United States government is permitted.

Tracer Element Injection into PDX Tokamak for Spectral Line Identification
and Localized Doppler Temperature Measurement

S. Suckewer, J. Cecchi, S. Cohen, R. Fonck and E. Hinnov
Princeton Plasma Physics Laboratory, Princeton University
Princeton, New Jersey 08544 USA

ABSTRACT

Magnetic dipole lines in ScXIII - XVII and resonance
lines of ScXVIII - XIX were observed and identified.
Advantages of ion thermometry by means of tracer element
injection are described.

The spectrum lines of various ionization states of elements such as Fe,
Ti and Cr have been extensively used in tokamak discharges [1] for radially
localized measurements of ion temperatures, impurity concentrations, transport
rates, plasma rotations, etc. In the Poloidal Divertor Experiment (PDX), with
the divertor in operation, discharges often do not contain adequate amounts of
titanium or other sufficiently heavy elements for such spectroscopic
diagnostics in the core of the plasma. However, the technique of laser blow-
off of metallic films allows the injection of appropriate amounts of a
suitable element into the discharge, with the advantages that the element may
be chosen to fit optimally the expected electron temperature profile, and the
time of injection is adjustable. The known appearance time and the subsequent
distinctive time behavior of light of the different ionization states also
greatly facilitates positive identification of any previously unobserved lines
of the injected element. In this paper we describe the identification

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

74

of several forbidden (magnetic dipole) lines as well as some resonance lines of highly ionized scandium, and the application of some of these lines for near-central ion temperature measurement on a (diverted) PDX discharge [2].

The discharge under consideration was D-shaped by the divertor coils, with an average plasma minor radius $\bar{a} \approx 40$ cm, toroidal field $B_T \approx 20$ kG and plasma (ohmic heating) current $I_p \approx 300$ kA. The central electron temperature and density during the quasi-steady phase were $T_e \approx 1$ keV, $N_e \approx 3 \times 10^{13} \text{ cm}^{-3}$, respectively. Scandium (with L-shell ionization potentials about 0.75 - 1.3 keV) was injected into the discharge in the equatorial plane from a film deposited on a glass plate. Irradiation of the metal film-glass interface by a high-power laser beam results in the generation of a highly directional burst of 1-20 eV neutral atoms [3,4]. The amount of scandium, $\sim 10^{17}$ atoms per shot, was insufficient to cause appreciable changes in the plasma (with a volume $\sim 4 \times 10^6 \text{ cm}^3$). The resulting scandium line intensities were measured either with an argon-filled 1m Ebert-Fastie monochromator with sufficiently high resolution for Doppler profile determination [5], or, in the vacuum u.v. region, with a 1m grazing incidence spectrometer, both instruments being calibrated for absolute intensity measurements.

Figure 1 shows the transitions and wavelengths (in air for $\lambda > 2000\text{\AA}$) of the various scandium ions observed in the PDX discharges, together with some of the intercombination lines (in parentheses) that have not yet been observed. In all these cases, the wavelengths were quite accurately predictable from interpolations along isoelectronic sequences by the method of Edlén [6] with adjustments from our previous measurements [7] in titanium, chromium, iron and nickel where appropriate. In case of the magnetic dipole lines, the results were as follows, with the predicted wavelengths available before the measurement given in parentheses:

	<u>OBSERVED</u>	<u>PREDICTED</u>	<u>TRANSITION ENERGY</u>
ScXIII	2637.2 $\pm$ 0.2Å	(2637.2Å)	37908 $\pm$ 3 cm ⁻¹
ScXIV	3206.1 $\pm$ 0.3Å	(3207.0Å)	31179 $\pm$ 3 cm ⁻¹
ScXVI	4530.3 $\pm$ 0.4Å	(4530.6Å)	22067 $\pm$ 2 cm ⁻¹
	4354.3 $\pm$ 0.4Å	(4353 Å)	22959 $\pm$ 2 cm ⁻¹
ScXVII	2190.5 $\pm$ 0.2Å	(2190.6Å)	45637 $\pm$ 4 cm ⁻¹

In ScXVIII the $^3P_{2+1}$ line was not observed, possibly because it was too weak under the experimental conditions. However, there are some recent indications that the wavelength may be somewhat longer, perhaps around 2909Å.

In the case of the intercombination lines there are no direct observations in neighboring elements (except for the $2s2p \ ^3P_1+2s^2 \ ^1S_0$ transitions) and the uncertainties may be several Angstroms. On the other hand, the allowed resonance lines of the beryllium [8] and particularly the lithium [9] sequences are predictable more accurately than our present measurement uncertainties. (A recent compilation of energy levels and evaluation of previous experiments is given in [10].) We find the ScXVIII line at $180.7 \pm 0.1\text{Å}$ in good agreement with previous observation by Fawcett and Hayes [11]. The ScXIX lines are at $279.8 \pm 0.2\text{Å}$ and near 326Å (with uncertainty not well determined but probably $< \pm 0.3\text{Å}$).

Identification of previously unknown lines is much simpler with injection of a known element than with intrinsic impurities in the plasma, especially if such element (e.g., Sc) is not present in the discharge before injection. Figure 2 shows some typical samples of the intensity behavior of the ScXVII 2190Å and ScXIII 2637Å lines following an injection at about 585 msec.

measured with the 1-m spectrometer in the 5th and 4th order, respectively. The 100Hz modulation is caused by a vibrating LiF plate in front of the exit slit, providing a repeated spectral scan of the line profile. The time dependence of the line intensity is thus given by the envelope of the modulated part of the signal. There is also an increase of the (unmodulated) background radiation, which is probably caused by a many-line pseudocontinuum mostly from lower ionization states of the injected scandium.

The distinctive time behavior of the different lines is caused primarily by the different ionization potentials and hence ionization times of the ions (while the quantitative details are determined by plasma conditions). Thus the state of ionization of the injected element to which an unknown (e.g., forbidden or intercombination) line pertains is unequivocally determined by comparison with the relatively well-known electric dipole resonance lines. The line shape is also helpful in wavelength measurements by allowing relatively easy discrimination from any neighboring lines intrinsic to the plasma.

The principal reason for the prominent early peaks in the time behavior of the observed lines is that, in a plasma with electron temperature larger than the ionization potentials involved, the ionization time for each successive charge state is about twice as long as the preceding one, resulting in a transient pile-up of populations. In the observed signal, both time and space variations (along the line of sight) of the emissivity are involved. However, it is known experimentally that most of the radiation of a given line is emitted from radial locations where the electron temperature is roughly comparable to the ionization potential of the ion (1.3 keV for ScXVII and 0.75 keV for ScXIII). Thus the ScXVII emission occurs near the center of the discharge, and ScXIII roughly half-way out. At the prevailing plasma

conditions, the deuterium-scandium thermal equilibration times are $\sim 10^{-5}$ sec, i.e., all plasma ions have the same local temperature.

The ion temperatures shown in Fig. 2 were determined from the measured spectral profiles by means of a computerized program that performs a polynomial fit of the profile, averages over two or more successive scans where appropriate, subtracts the (usually small) instrumental profile, and computes the Doppler temperature. In case of the relatively slowly-varying ScXVII line, three successive spectral scans were averaged for each temperature point shown, whereas in the case of ScXIII, each temperature point corresponds to a single profile. As a consequence, the uncertainties of the latter measurements are fairly large, about 30-40%, compared to about 10-20% for the ScXVII temperature. Zeeman effect also requires a noticeable ($\sim 15\%$) correction in the ScXIII temperature measurement, but is practically negligible in the smaller wavelength, higher temperature ScXVII case.

Extending the method to other ionization states and perhaps to different elements injected at different times, it is clearly possible to determine the entire evolution of the ion temperature in space and time. Furthermore, it is at least in principle possible to construct a sufficiently sophisticated spectrometer that could do the measurement in a single discharge.

Acknowledgments

We would like to thank K. Bol, M. Bell, R. Hawryluk, R. Jacobsen, K. McGuire, D. Meade and M. Okabayashi for their help in the experiment. We are also grateful to J. McEnerney for adapting for PDX the computer program for T_i measurements.

This work is supported by the United States Department of Energy Contract
No. DE-AC02-76-CHO-3073.

References

- [1] E. Hinnov, R. Fonck and S. Suckewer, Princeton University, Plasma Physics Laboratory Report PPL-1669, 1980.
- [2] D. Meade, et al., Proc. of 8th International Conference on Plasma Physics and Controlled Nuclear Fusion, Brussels, 1-10 July 1980.
- [3] S. Cohen, J. Cecchi and E. Marmar, Phys. Rev. Lett. 35 (1975) 1507.
- [4] E. Marmar, J. Cecchi and S. Cohen, Rev. Sci. Instrum. 46 (1975) 1149.
- [5] S. Suckewer and E. Hinnov, Nuc. Fusion 17 (1977) 945.
- [6] B. Edlén, Solar Physics 24 (1972) 356, Optica Pura y Aplicada 10 (1977) 123, and private communications, 1979, 1980.
- [7] E. Hinnov and S. Suckewer, Physics Letters 1980, to be published.
- [8] B. Edlén, Physica Scripta 20 (1979) 129.
- [9] B. Edlén, Physica Scripta 19 (1979) 225.
- [10] J. Sugar and C. Corliss, J. Phys. Chem. Ref. Data 9 (1980) 473.
- [11] B. C. Fawcett and R. W. Hayes, Mon. Not. R. Astron. Soc. 170 (1975) 185.

(PPPI-806404)

Fig. 1. Energy levels and wavelengths of scandium forbidden transitions in $2s^2 2p^x$ configurations and allowed $2p-2s$ transitions of ScXVII and ScXIX. Wavelengths in boxes are those observed in the PDX tokamak.

(PPPL-806366)

Fig. 2. Time behavior of the intensity of ScXVII and ScXIII lines following scandium injection (at about 585 msec). The rapid modulation is caused by spectral scan by means of a vibrating LiF plate. Ion temperatures are deduced from the spectral profiles.