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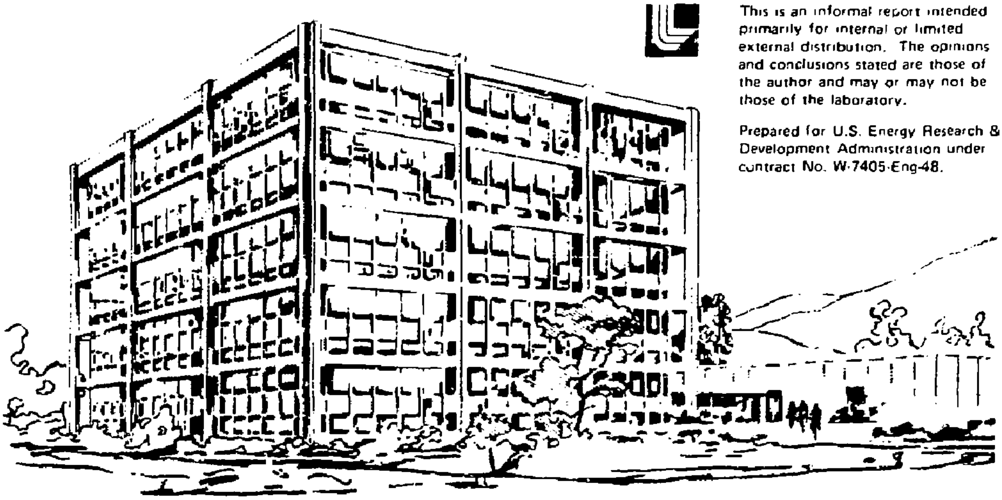

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EVIDENCE FOR NEUTRAL BEAM INJECTED OXYGEN IMPURITIES IN 2XIIB

R. Paul Drake and H. Warren Moos*

Lawrence Livermore Laboratory
Livermore, CA 94550

ABSTRACT

A series of experiments indicates that the principal source of impurities in the 2XIIB mirror confinement plasma experiment at Lawrence Livermore Laboratory is oxygen in the neutral beams. The dependence of O II 539 Å emissions on neutral beam current, spatial scans of oxygen emissions, impurity injection experiments, spectral scans of the O VI 1032 Å line, and other experiments all support this conclusion.

*R. Paul Drake - student guest from Johns Hopkins University
H. Warren Moos - participating guest from Johns Hopkins University

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INTRODUCTION

Impurities are of concern in high energy plasmas because they can radiate substantial energy [1,2] and otherwise adversely affect plasma confinement and heating. Impurities due to neutral beams are particularly damaging since they may be implanted deep within the plasma and confined for long times, even in open-ended systems. Consequently, the impurity content of neutral beams used to heat major fusion research experiments must be low.

The 2XIIB mirror confinement device at Lawrence Livermore Laboratory creates high beta plasmas by firing 20 kV Lawrence Berkeley Laboratory (LBL) type netural beams [3] across the magnetic field into a target plasma injected along field lines by deuterium plasma guns; this results in a rapid plasma buildup to high density and large mean ion energy [4]. Typical plasmas, during the experiments reported here, had T_e = 80 eV, $W_\perp$ = 12 keV, radius = 11 cm, line density = 7×10^{14} cm^{-2} and neutral beam current = 400 amps (equivalent proton current).

In a previous set of experiments it has been shown by using extreme ultraviolet (EUV) spectrophotometric techniques that the principal impurity in 2XIIB is oxygen with a concentration of a few percent [5]. All ionization states up through O VI (the limit of the spectrophotometric equipment) emitted strongly, indicating large amounts of oxygen in the plasma. This letter describes experiments which indicate that the primary source of this oxygen is the neutral beams which produce and maintain the plasma.

EXPERIMENTAL RESULTS

The 0.4 m EUV monochromator used in these experiments covers the spectral range from 300 Å to 1700 Å [6] with a photometric sensitivity calibrated against National Bureau of Standards reference diodes. The line of sight on the monochromator is approximately in the 2XIIB midplane, roughly perpendicular to the mirror axis and the neutral beams. The field of view can be varied in size and although usually at the center can be scanned across the plasma midplane on a shot to shot basis.

The O II emissions showed a strong dependence on beam current. The peak signal from the O II 539 Å multiplet was measured on February 24 and June 6, 1978 as the neutral beam current was systematically varied from 150 equivalent amps to 500 amps on a shot to shot basis. Figure 1 shows the O II signal as a function of beam current from June 6. (This data has been corrected for a significant background signal which was carefully measured during the June 6 run.) The best power law fit to the O II data in Fig. 1 is that O II increases as beam current to the 1.6 power. The line density is roughly proportional to beam current. The C III 977 Å data, obtained June 9, shows that impurity emissions do not in general behave like the O II emissions.

This strong dependence of oxygen signal on beam current is expected if the beams are the source of oxygen. The O II emissions are approximately proportional to the rate at which oxygen is injected and trapped in the plasma. This is because both ionization and excitation rates are proportional to n_e. Thus, the average number of photons emitted by each O II ion before it changes ionization state is independent of electron density; it depends only weakly on T_e. The rate at which neutral beam oxygen atoms are trapped by the plasma depends on the product of the oxygen current (probably a fixed percentage of the beam current) and the attenuation of that current by the plasma, which increases when the plasma line density does. This leads to a greater than linear dependence of oxygen trapping and hence of O II emissions on beam current.

The spatial distribution of O II emissions did not show a well defined shell structure. Background subtracted O II 539 Å spatial data is presented in Fig. 2, along with line density data from the same run. The spatial data is limited by the availability of shots with constant machine parameters. This data does not allow a precise determination of the O II density profile by Abel inversion. However, the inversions of curves drawn through the data may be used to place limits on the O II shell structure. This procedure showed that the O II density at r = 0 cm is 50% ± 30% of the peak O II density which occurs near r = 8 cm. Several spatial scans all gave similar results. This is consistent with dominant beam injection of oxygen, but not with oxygen trapping from low energy radial sources. The mean free path of a 100 eV oxygen neutral in the 2XIIB plasma is 0.5 cm, so low energy oxygen atoms should form an O II shell at the plasma boundary. In consequence, for impurities injected with low energies, only the higher ionization states (~O V) should exist near the plasma center.

Low energy oxygen sources were simulated by injecting neon impurities in two ways. When neon gas was injected radially by a pulse valve 55 cm from the plasma, the Ne III 490 Å brightness was one-third that of Ne IV 544 Å. In contrast, observed O IV 554 Å brightnesses are ten times those of O III 703 Å. The excitation rate coefficients are similar for these two elements. In addition, the plasma is destroyed if enough neon gas is introduced to obtain a Ne IV brightness comparable to that of O IV. These facts imply that low energy radial oxygen sources are normally unimportant. In the second experiment, a gas arc plasma gun was used to inject ions along field lines. The background corrected Ne II 460 Å signal peaked before 3.5 ms, then decreased to near zero by 5 ms. In contrast, O II signals from similar plasmas reached a broad plateau during the high density phase of the discharge, lasting from 4 to 8 ms in this case. The sharp decrease in Ne II emission showed the attenuation of singly ionized axial impurity fluxes as the plasma density increased. The quite different O II time behavior indicated that axial oxygen fluxes from the plasma guns were not significant.

Additional evidence eliminating the axial plasma guns as the dominant oxygen source comes from the relative intensity of carbon and oxygen emissions. In plasmas created by these guns, C III 977 Å emissions were 1.6 times brighter than O III 703 Å emissions. On the other hand, in beam fueled plasmas, the O III light is 5.4 times brighter than the C III light, implying one or more additional oxygen sources must be present when the beams are used.

Doppler broadening measurements of the O VI 1032 Å and 1038 Å lines (see Fig. 3) show the high transverse velocity of the oxygen ions. The expected 2:1 brightness ratio is observed with a full width at half maximum (FWHM) of 3.5 Å. Allowing for the 1 Å FWHM spectrometer slit width, the half maximum Doppler shift corresponds to a directed velocity of about 3.6×10^7 cm sec^{-1}, or 11 keV of energy. This could result from beam injection of high energy oxygen, but is unlikely to result from slow collisional heating [7]; the lifetime of low energy impurities is too short.

Further evidence that the oxygen is injected by the neutral beams comes from the charge exchange analyzer [8], which is able to resolve the energy components of the neutral beam when the beams are fired into low pressure neutral gas. A one-tenth energy deuterium component is observed at such times which is consistent with the breakup of D_2O from the neutral beam [9]. Similar results have been obtained at LBL and Princeton Plasma Physics Laboratory [10, 11].

DISCUSSION

In summary, there is a significant concentration of oxygen in the 2XIIB neutral beams. If the oxygen current is 10 amps (out of 500), as estimated in reference [5], the concentration of oxygen in the beams is 2%. Using these beams without improvement will lead to power losses due to line radiation, ionization and charge exchange which will decrease the efficiency of neutral beam heating. In 2XIIB, the oxygen power loss is small compared to the deposited beam power [5]. In future devices, with longer confinement times and a lower deposited power density, this may not be true.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1 Data obtained during neutral beam current scans. Background subtracted O II 539 Å signal and C III 977 Å signal are shown as a function of beam current.

Figure 2 O II 539 Å spatial data indicating the presence of O II at the center of 2XIIB. Other scans have shown the profile to be symmetric.

Figure 3 A shot to shot spectral scan of the O VI 1032 Å and 1038 Å lines showing Doppler broadening.

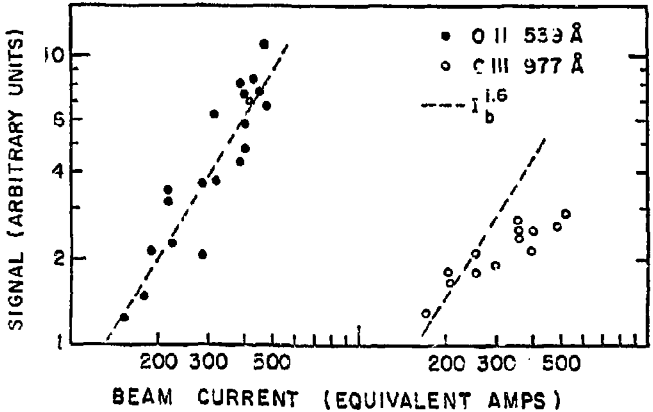
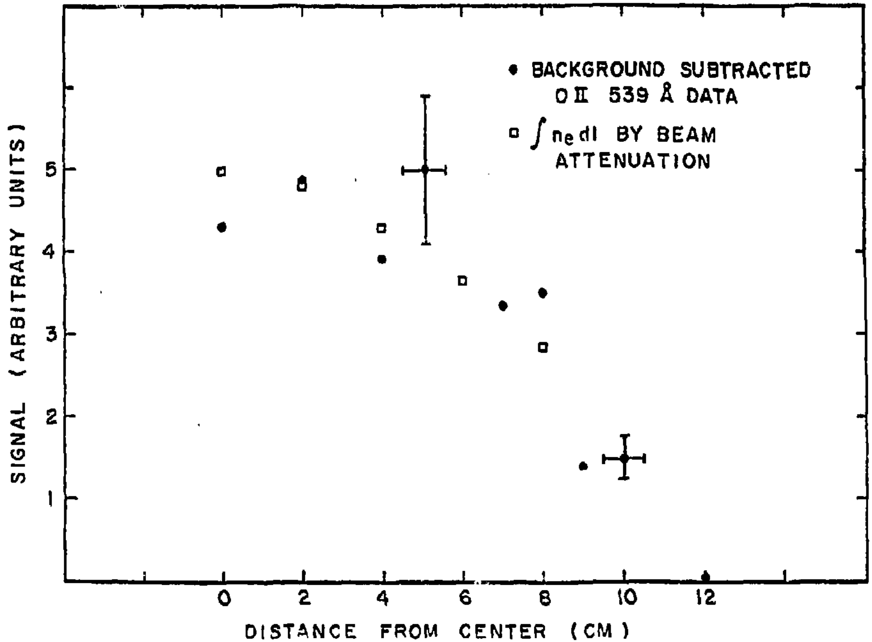

O II 539 Å
C III 977 Å
$I_b^{1.6}$
SIGNAL (ARBITRARY UNITS)
10
5
4
2
1
200 300 500
200 300 500
BEAM CURRENT (EQUIVALENT AMPS)

Fig. 1



• BACKGROUND SUBTRACTED O II 539 Å DATA
□ ∫ ne dl BY BEAM ATTENUATION
SIGNAL (ARBITRARY UNITS)
1
2
3
4
5
0
2
4
6
8
10
12
DISTANCE FROM CENTER (CM)

Fig. 2

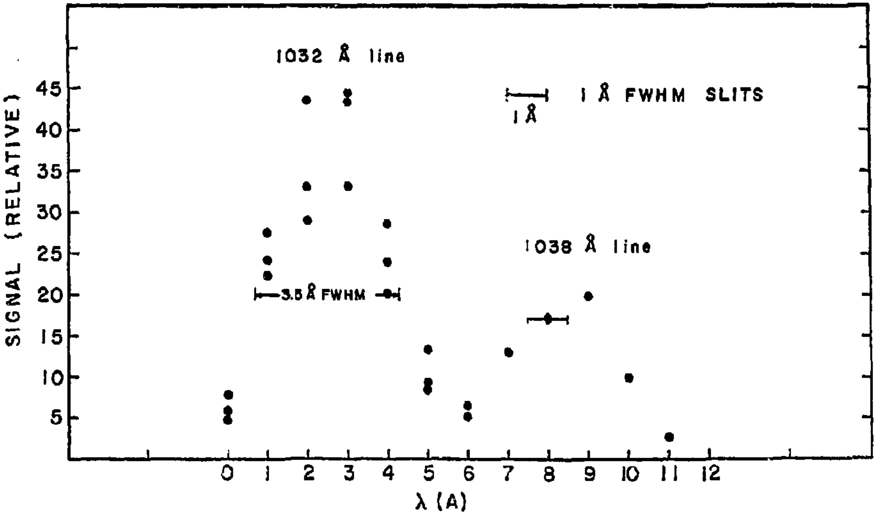

1032 Å line
1 Å FWHM SLITS
1 Å
1038 Å line
3.5 Å FWHM
SIGNAL (RELATIVE)
45
40
35
30
25
20
15
10
5
0 1 2 3 4 5 6 7 8 9 10 11 12
λ (A)

Fig. 3