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ELECTRIC FIELD MEASUREMENTS FROM SATELLITES-TO- FORBIDDEN LINE RATIOS IN AN OMEGA-UPGRADE LASER-PRODUCED PLASMA

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Hans R. Griem, Raymond C. Elton and Benjamin L. Welch

University of Maryland
College Park, MD 20742-3511

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Second Semi-Annual Report

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During this reporting period we conducted experiments both on the Omega Upgrade 60 beam laser at the University of Rochester Laboratory for Laser Energetics (LLE) and on the Trident laser at Los Alamos National Laboratory (LANL).

LLE Omega-Upgrade Experiments:

The LLE/Omega experiments were carried out September 23-27, 1996. The purpose of these Phase II experiments was to expand on our earlier two- to four-beam experiments on Omega Upgrade, where we used plane targets of Mg and NaF (some with CH coatings). The primary goal for both series was to develop the diagnostic capability to observe plasma satellite spectral lines, from which the laser electric field in the plasma could be determined at various times in the event. In the present experiments, we used all 60 beams and spherical targets. Also, in this second series we added time resolution to our flat-field grazing incidence extreme ultraviolet (xuv) spectrograph, using an LLE streak camera. In these experiments we complimented our xuv spectroscopy with time resolved harder x-ray spectroscopy in the 1-2 keV range (using an LLE/LLNL crystal spectrograph with streak camera detection), and with time-resolved pinhole x-ray images using a gated microchannel plate detector.

From the data obtained using our flat-field grazing-incidence spectrograph, we have been able to identify extreme ultraviolet (xuv) spectral lines from H- and He-like C, Mg, Na and F, and Li-like Mg and F, in the spectral range covered. Not surprising, the carbon lines were strongest early in the pulse and the heavier elements later as the temperature rose and the plasma collapsed radially and the shells burned through. No neon lines from the gas filling of the hollow spherical targets were observed at the relatively low density present ($\sim 10^{19}/cm^3$ at 1 atm fill pressure). Future experiments with this instrumentation will be directed towards greater sensitivity and spectral resolution.

In the spectra from the time-resolved x-ray crystal spectrograph we have identified 5 Mg, 2 Al, 3 Na and even 2 Cl (impurity) H- and He-like resonance lines (see, e.g., Fig 1). The chlorine lines are observed later in the discharge which is to be expected, since the ionization potential of the He-like ion is 3.7 keV; this implies that temperatures ~1 keV are achieved. The resonance lines from H- and He-like magnesium appear and burn through during the heating cycle. There appears to be significant opacity broadening on these lines from the initially 1-μm thick layer. This interpretation, rather than source broadening, is supported by the time-resolved x-ray pinhole photographs. Aluminum lines from similar species in a deeper and thinner (300 Å) layer begin later, and tend to be narrower due to less opacity broadening. Also, an electron collisionally excited innershell transition line in Li-like magnesium, a satellite to the 1s-3p line of the He-like species, occurs on some shots at peak compression when the density and temperature are at a maximum and multi-keV electrons may be present.

Our conclusions so far from these LLE experiments include evidence that satellites to strong spectral lines are of potential use in measuring fundamental parameters in plasmas produced by high power lasers. In the xuv spectral region, satellites to n=2 to n=3 transitions in the He-like Mg XI spectrum are associated with laser intensities comparable to the input irradiance to the target. Similar results are obtained in the same plasma from Li-like Mg X transitions. We also are analyzing data in the x-ray spectral region on innershell satellites to n=1 to n=3 He-like resonance lines in both Al XII and Mg XI. An apparent density sensitivity in the line intensity involving a collisionally excited 1s2s3p upper level identifies this as a convenient electron density indicator. In fact, our modeling shows that that the density dependence is essentially the same in a recombining plasma as well as in a nearly steady-state plasma, indicating that the diagnostic application is valid in a variety of transient plasmas. The intensity appears to scale upwards rapidly with Z and hence becomes increasingly useful at higher (compressed) densities in inertial confinement fusion plasmas.

LANL Trident Experiments:

In support of our main LLE/Omega program, we were fortunte to obtain over 50 shots (a record-tying 13 on July 11 alone) on the LANL/Trident laser facility with full power on both beams over 5 days beginning 8 July 1996 and ending 12 July, 1996. We operated at 1 ns pulse width. Our targets were 1 mm x 1 mm square magnesium foils of 3 μm thickness. Many were coated with 1 μm of CH on both sides as a tamper. Most were illuminated from both sides.

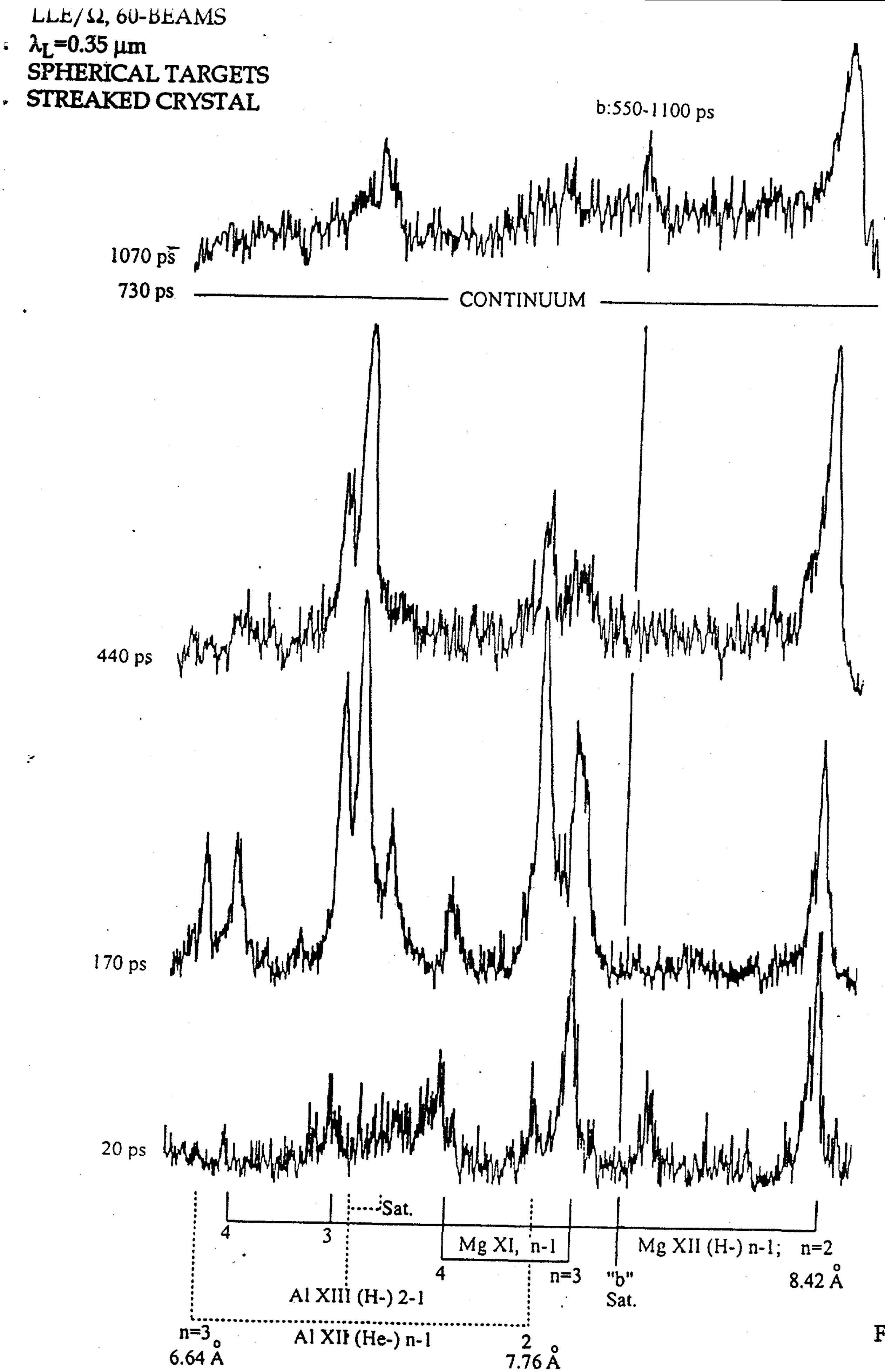
Our primary diagnostic for this campaign was a Gated Imaging Spectrometer (GIS) consisting of a KAP crystal followed by a 4-frame Gated X-ray Imager and a CCD camera readout. This gave a beautiful K-region x-ray spectrum of the hydrogenic and helium-like ions of magnesium, along with an abruptly rising continuum at n=5-7 in both species. We varied the gating time to obtain the temporal history of this region. We backed up this data with snapshots of the plasma using both coated and uncoated targets, using a gated 16-frame imager.

The object of these Phase-I experiments was to extend the interesting Phase-0 results of May 1995 on aluminum (reported at the November 1995 APS/DPP meeting) to magnesium. For one thing, we wanted to observe the hydrogenic series free of overlapping lines, not in the range of the spectrograph for aluminum but perfect for magnesium. We were completely successful and obtained data with both coated and uncoated targets as a function of time during the pulse and for focal spot sizes of 125 and 500 μm. We also varied the direction of view from 30° to 60° to 90° relative to the incoming laser axis.

We were particularly interested in a Li-like satellite to the He-like ion n=3 to n=1 resonance transition that is observable only above a critical electron density (approximately 10^{22} cm^{-3} for Al) at which collisional population of the upper level from nearby levels becomes competitive with autoionization from these source levels. On this series of shots we did indeed observe this feature in Mg as sought and obtained the intensity as a function of time and hence decaying electron density (Fig. 2 here). This should provide a further density signature at a lower value. We also have been able to obtain from this data the electron density from the merging of the lines into the continuum (Inglis-Teller effect) and the electron temperature from line ratios, as was done on prevous aluminum shots (shown in Fig. 3).

Summary of both experiments:

We presented our combined results from these sets of experiments at LLE and LANL at the 1996 Conference on Radiative Properties of Hot Dense Matter held in Santa Barbara, CA, and the LLE results at the APS Division of Plasma Physics Conference held in Denver, CO in November 1996 [Bull. Am. Phys. Soc. **41**, 1594 (1996]. We are presently preparing a manuscript for the proceedings of the former conference, which are to appear in the Journal of Quantitative Spectroscopy and Radiative Transfer in 1997.



LLE/Ω, 60-BEAMS
λL=0.35 μm
SPHERICAL TARGETS
STREAKED CRYSTAL
b:550-1100 ps
1070 ps
730 ps
CONTINUUM
440 ps
170 ps
20 ps
Sat.
4
3
Mg XI, n-1
Mg XII (H-) n-1; n=2
4
n=3
"b"
Sat.
8.42 Å
Al XIII (H-) 2-1
n=3
6.64 Å
Al XII (He-) n-1
2
7.76 Å

Figure 1

LANL/TRIDENT, TWO-BEAMS
λ_L=0.53 μm
PLANAR TARGETS
CRYSTAL/GATED MCP

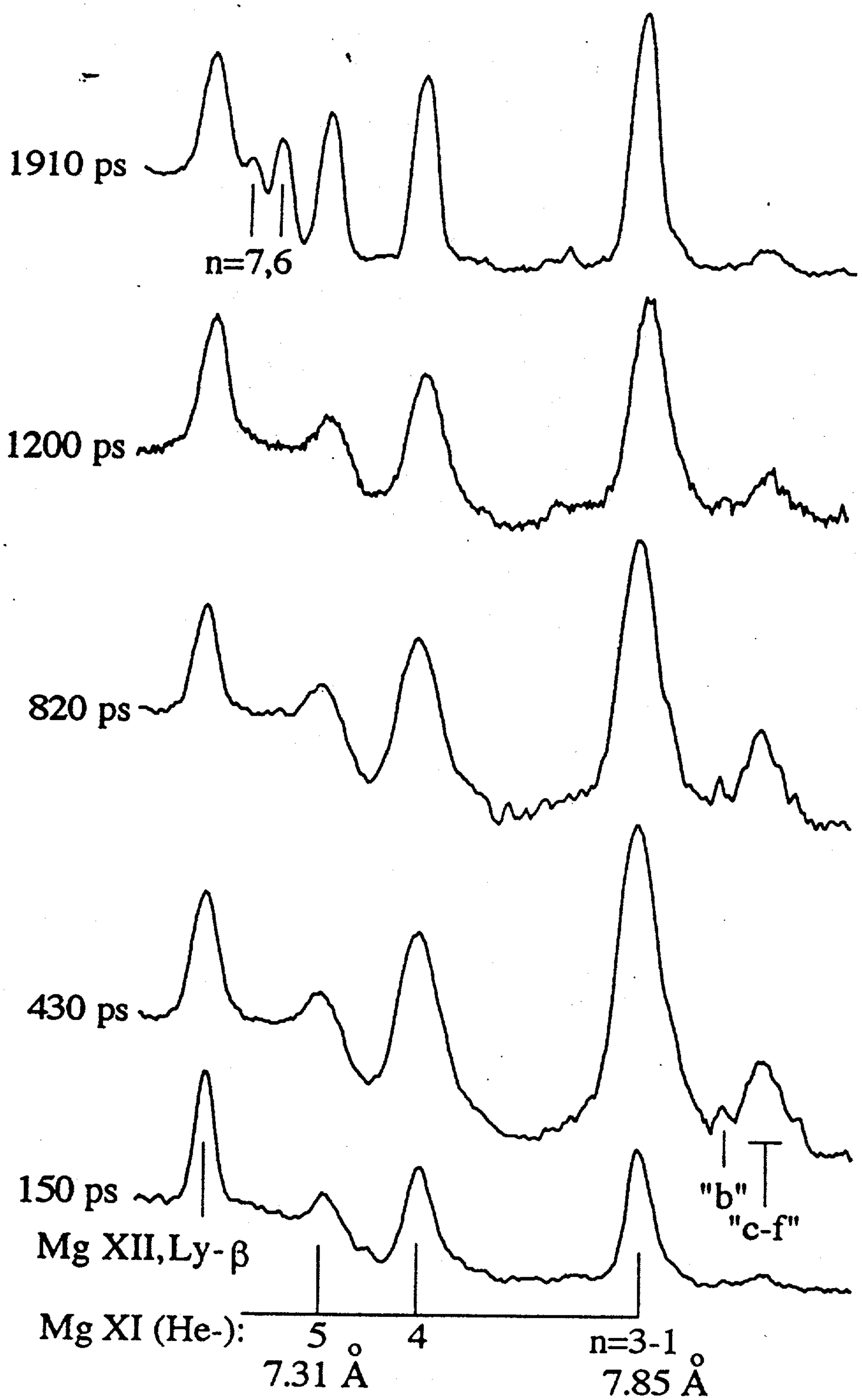


Figure 2

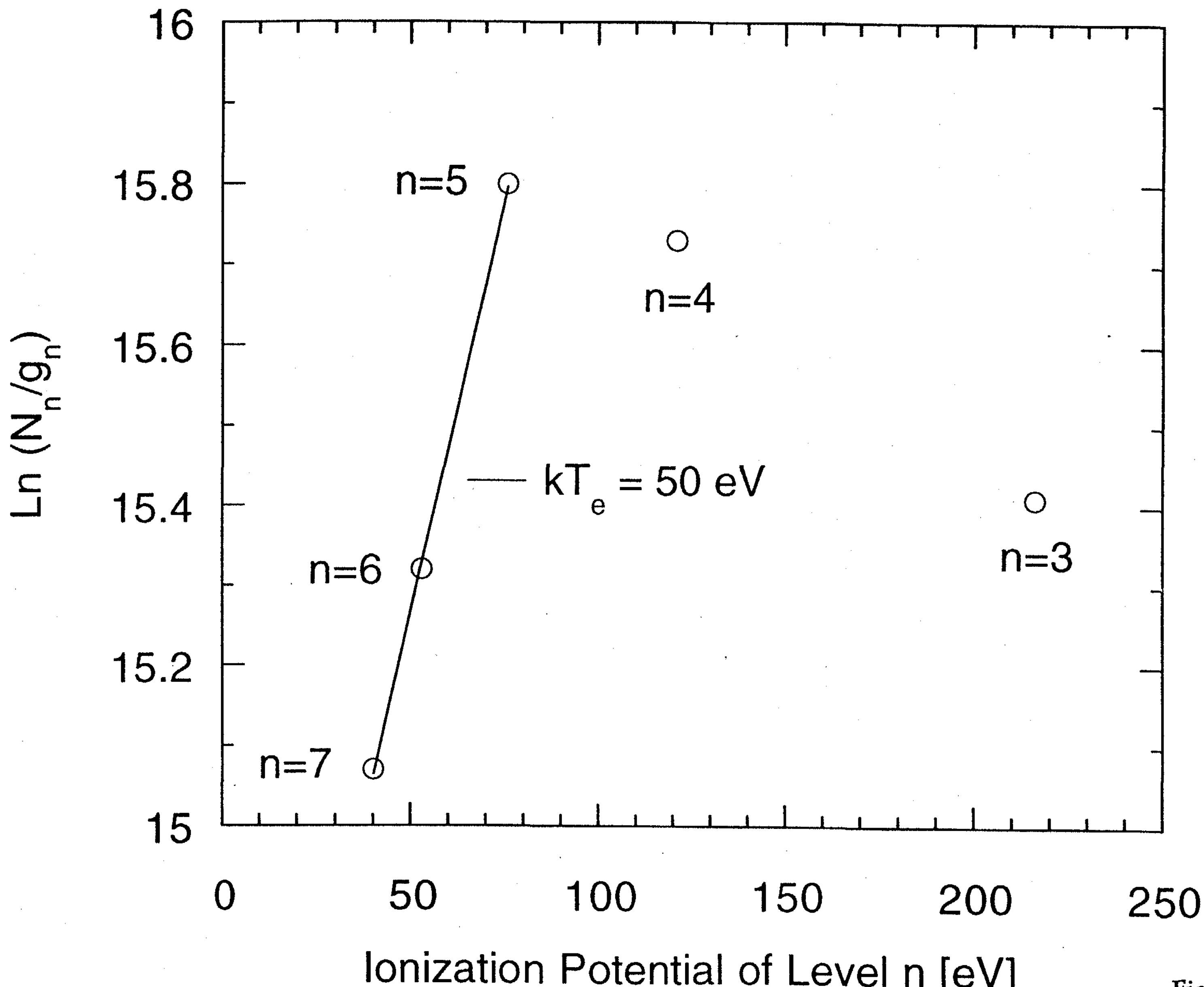

Ln (N_n/g_n)
16
15.8
15.6
15.4
15.2
15
0
50
100
150
200
250
Ionization Potential of Level n [eV]
n=5
n=4
n=6
n=7
n=3
kT_e = 50 eV

Figure 3