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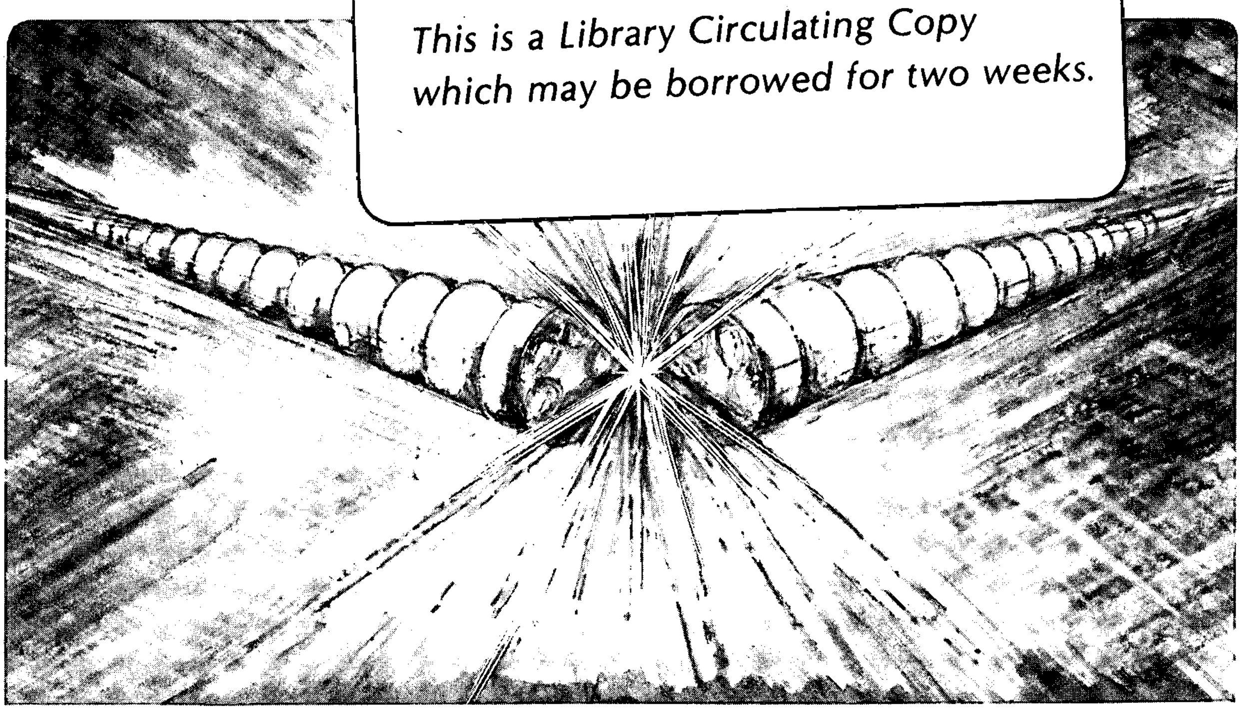

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HIGH RESOLUTION KRYPTON $M_{4,5}$ X-RAY EMISSION SPECTRA

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ABSTRACT

High resolution $M_{4,5}$ (3d → 4p) x-ray emission spectra from a krypton plasma were measured using a recently developed grazing-incidence reflection-grating monochromator/spectrometer with very high flux rates at extreme ultraviolet and soft x-ray wave lengths. The nominal resolving power of the instrument, E/ΔE, is about 300 in this energy range (~80 eV).

Three dipole-allowed 3d → 4p emission lines were observed at 80.98 eV, 80.35 eV and 79.73 eV. A broad peak at about 82.3 eV, is tentatively assigned to transitions resulting from Kr^{2+}, and effects of excitation energy on $M_{4,5}$ x-ray emission were observed.

In this report, high resolution $M_{4,5}$ x-ray emission spectra from a krypton plasma produced in the discharge region of a Penning-type sputtering source [1,2] are presented. The discharge was excited by application of a high potential difference (1-2 kV) and magnetic field (~ 1.2 kgauss) between two aluminum cathodes and a grounded anode. In the evacuated region between these cathodes, the krypton gas was leaked in continuously to an equilibrium pressure. At some distance (200 mm) from the discharge region, a thermocouple gauge measured a gas pressure of ~15 mtorr. The diffuse discharge, extending over ~5 mm in diameter, was placed behind the entrance slit of the monochromator. A recently-developed reflection grating spectrometer/monochromator, which provides extremely high throughput in the extreme ultraviolet (UV) and soft x-ray (SXR) spectral regions [3] was used. Based upon measurements of the grating efficiency at the wavelengths reported here, the net throughput of the instrument is estimated to be 2 x 10^{-5} steradians. This includes the efficiency of a channel electron multiplier overcoated with MgF_2 to enhance the photon detection efficiency, which was positioned to intercept the radiation passing through the exit slit of the monochromator. Sufficiently high count rates were provided to allow high resolution measurements of the spectral lines of krypton, i.e., at a nominal resolving power ($E/\Delta E$) of approximately 300-500.

Presented in Figure 1 is a wide scan of krypton plasma (along with aluminum) over the 100-200 Å spectral region. This stepped-scan spectrum was obtained in about 30 mins. The prominent Al(IV) and Al(III) spectroscopic lines were observed. An accurate energy (or wavelength) calibration of the spectrum presented in Fig. 1 was obtained using Al(IV) ($2p^6 \rightarrow 2p^5 3s$) lines at 77.45 eV and 76.68 eV [1,4]. The spectral features in Fig. 1 agree with the low resolution electron excited krypton $M_{4,5}$ x-ray emission spectra [5] from a supersonic jet of krypton gas.

A detailed study of the 148-158 Å spectral region was performed with higher resolution and better statistics, as shown in Figs. 2 and 3. The energies (wavelengths) of the prominent features in Figs. 2 and 3 are listed in Table 1. The detailed spectrum presented in Fig. 2 was obtained maintaining the source voltage at about 1.5 kV, which is below the binding energy of krypton-L electrons. The prominent features A, B and C are identified as dipole-allowed $3d \rightarrow 4p$ emission lines. These assignments were confirmed by the observed 1:2:3 intensity ratio of peaks in the order of decreasing photon energy as predicted by a simple one-electron model and the energy differences as derived from the measured spin-orbit splitting of 3d levels [6] and 4p levels [7] in krypton. The broad peak D is tentatively assigned to transitions resulting from Kr^{2+} (3d 4s) which can be produced in the plasma either from initial single ionizations followed by Coster-Kronig decay, or from direct double ionization. Previous work by Deslattes et al. [1] has shown that Penning sources produce multiple ionized species.

The Kr-$M_{4,5}$ x-ray spectrum, presented in Fig. 3, was obtained with potential difference in the Penning source maintained at 2.2 kV, which is sufficient to ionize L electrons in krypton (L_I

electronic binding energy is 1.9 keV). Comparing spectra presented in Fig. 2 with those in Fig. 3 (lower) obtained with the same instrumental resolution (about 300), the feature A' is more prominent when the potential difference in the source is 2.2 kV. To resolve the feature A', the resolving power ($E/\Delta E$) of the instrument was improved to about 500 by closing the entrance and exit slits. The spectrum thus obtained is presented in Fig. 3 (upper). The feature A' is assigned as resulting from multiple ionization in krypton, which would be enhanced by Coster-Kronig decay of the L_I hole state. Similar features were observed in $L_{2,3}$ ($2p \rightarrow 3s$) x-ray emission spectra of argon [8].

In summary, high resolution Kr-$M_{4,5}$ x-ray emission spectra from a krypton plasma were measured. Accurate calibration of the prominent spectral features was obtained using Al(IV) lines at 77.45 and 76.66 eV. The intensity of the three dipole-allowed $3d \rightarrow 4p$ emission lines agrees well with calculated intensities from a simple one-electron model. The multiple ionization features in Kr-$M_{4,5}$ x-ray emission spectra were observed.

A significant improvement in sensitivity could be made possible by simultaneously recording the spectrum upon a position-sensitive detector rather than the step-scanning mode utilized in this work. A recently developed high resolution spectrometer [9] would yield up to a factor of 100 increase in resolution. This instrument employs an aberration-corrected reflection grating, which permits use of the detector at normal incidence to the radiation, enabling position-sensitive detection which would yield a factor of 200 increase in sensitivity over the spectral range shown in Fig. 1. Combining such an instrument with the high flux and tunability available from proposed 1-2 GeV storage rings, these satellite features can be disentangled and applied to provide insight into understanding the fundamental behavior of atoms.

Acknowledgments

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Table 1. The component wavelengths (energies) and assignments of major components in krypton plasma

Peak	Wavelength (Å)/Energy (eV)	Assignment
A	155.5±0.1/79.73	$Kr(3d_{5/2}\rightarrow 4p_{3/2})$
A'	155.0±0.1/79.99	
B	154.3±0.1/80.35	$Kr(3d_{3/2}\rightarrow 4p_{1/2})$
C	153.1±0.1/80.98	$Kr(3d_{3/2}\rightarrow 4p_{3/2})$
D	150.6±0.2/82.31	$Kr^{2+}(3d\ 4s)$
	138.7±0.2/89.39	$Kr(3d^8 4p^6\rightarrow 3d^9 4p^5)$

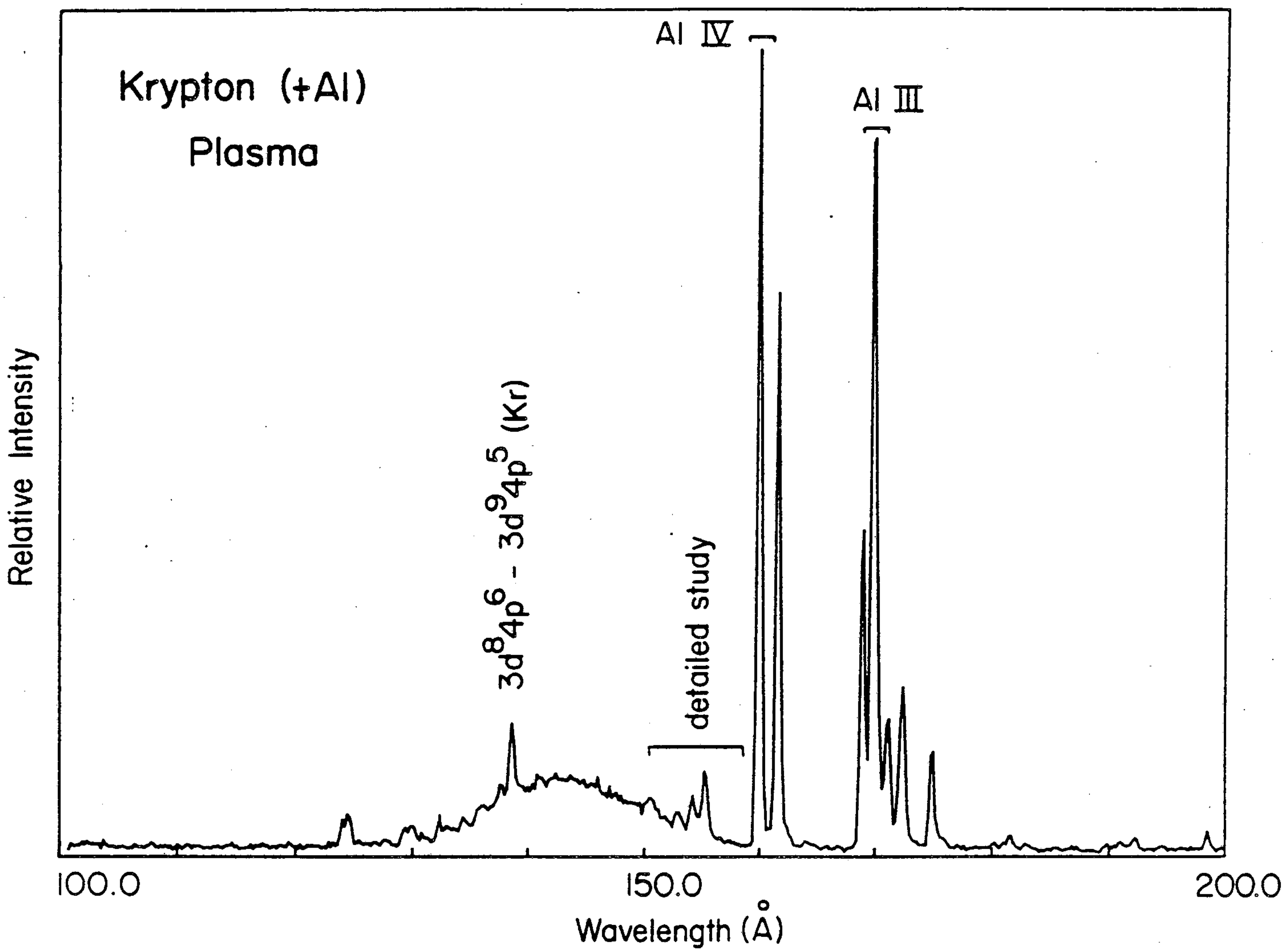

Fig. 1. Wide scan spectrum of krypton (+ aluminum) over the 100-200 Å spectral region from a Penning discharge tube. Prominent Al(IV) lines provided an accurate wavelength calibration.

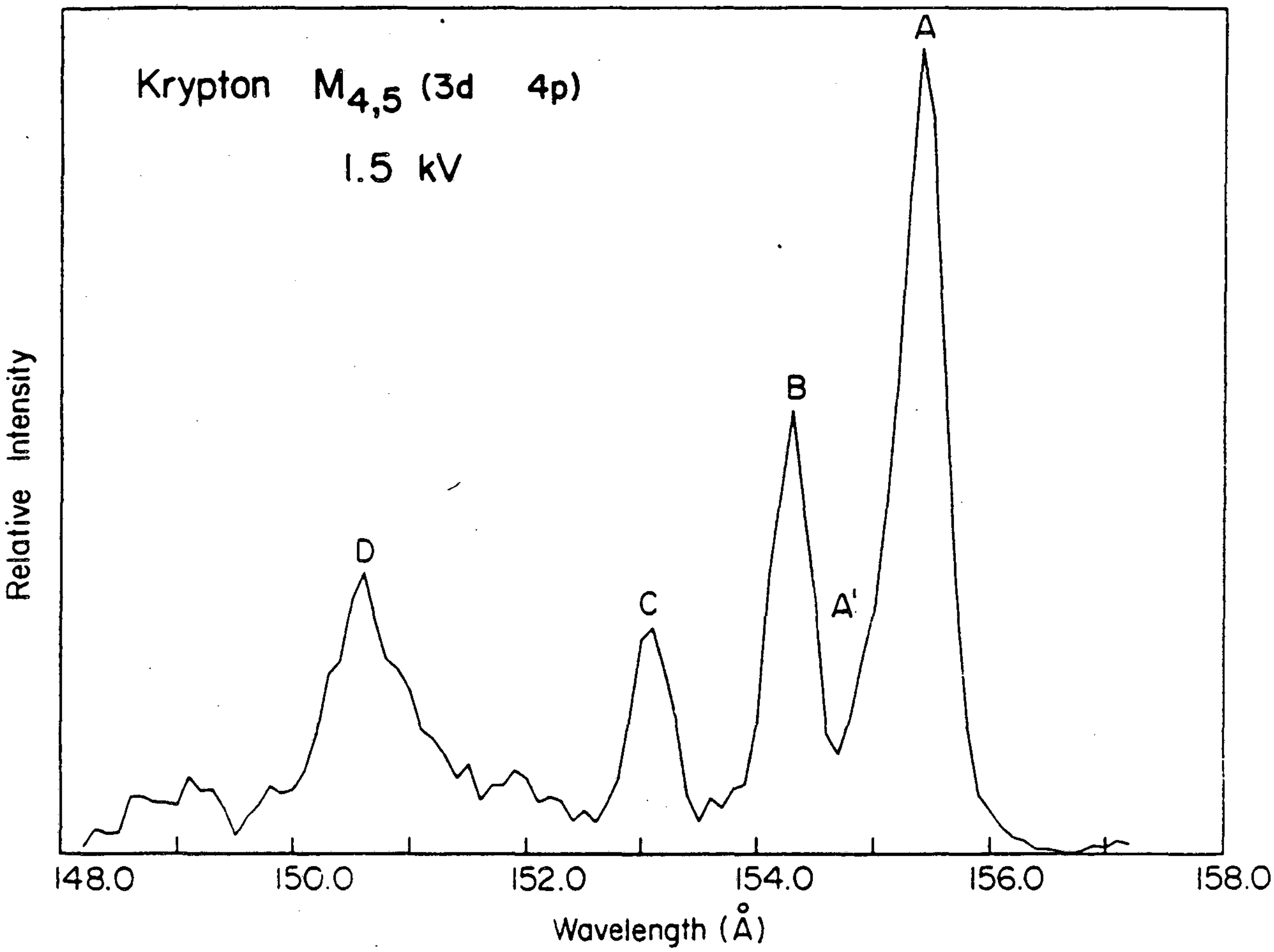

Fig. 2. A moderate resolution (~300) detailed study (background removed) of the krypton plasma with a potential difference in the source below the ionization threshold of all L electrons.

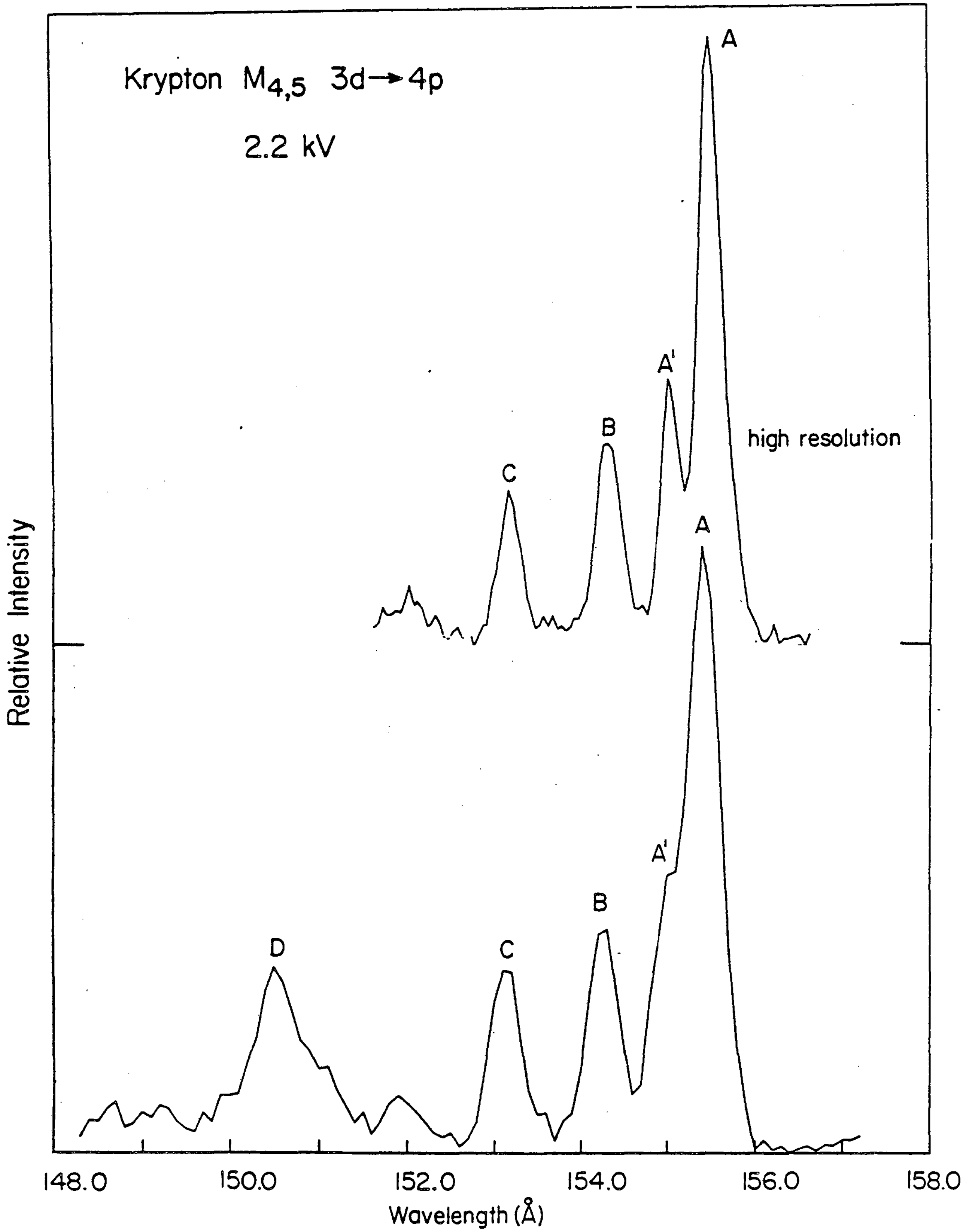

Fig. 3. Detailed study (background removed) of krypton plasma with a potential difference in the source <u>above</u> the ionization threshold of all L electrons. Lower figure obtained with moderate resolution (~300) and upper figure with higher resolution (~500).

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