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

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Résumé

En utilisant le nouveau frôlant-incidence, réflexion-raseur $M_{4,5}$ (3d → 4p) monochromator/spectrometer, on a mesuré les spectres bien-resolus des rayons X du Plasma de krypton, avec les cours très grands du flux et aux ondes ultra-violets extremes et des rayons X doux. Le pouvoir nominal de la resolution de l'instrument, E/ΔE, est à peu près 300 dans ce regime d'énergie.

On a observé, à 80.98, 80.35 et 79.73 eV, les trois (3d → 4p) lignes spectrales que le dipole permet. On a assigné, provisoirement, un pic large, à peu près 82.3 eV, aux transitions qui resultent du Kr^{2+}. On a observé les effets sur des rayons X ($M_{4,5}$) de l'énergie d'excitation.

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 wavelengths. 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 2×10^{-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

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high count rates were provided to allow high resolution measurements of the spectral lines of krypton, i.e., at a nominal resolving power (E/ΔE) 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.

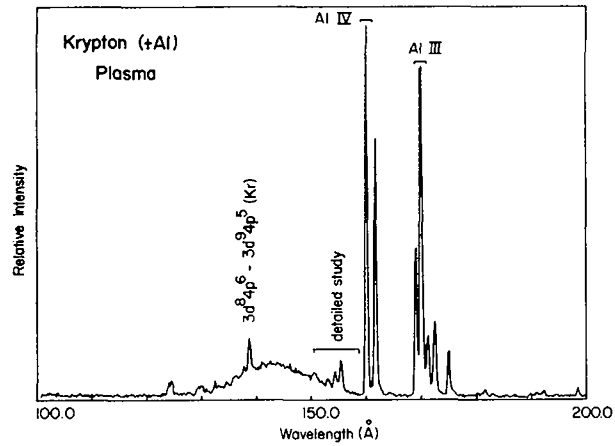

Fig. 1. Wide scan spectrum of krypton (+ aluminum) over the 100-200 Å spectral region from a Penning discharge tube. Prominent Al(IV) lines provided an accurate wavelength calibration.

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 → 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

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	$Kr(3d^8 4p^6 \rightarrow 3d^9 4p^5)$

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/ΔE) 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 → 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→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]

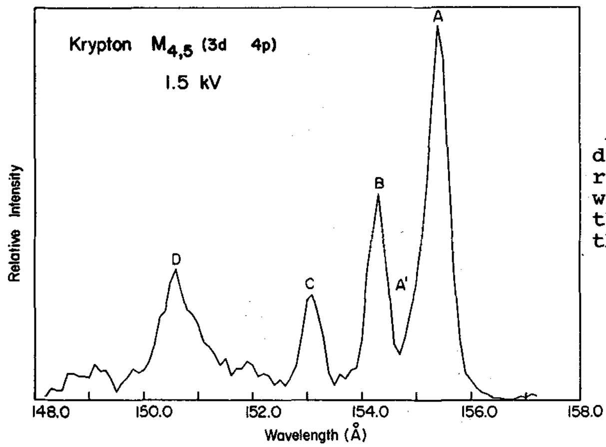

Fig. 2
A moderate resolution (~300) detailed study (background removed) of the krypton plasma with a potential difference in the source below the ionization threshold of all L electrons.

would yield up to a factor of 100 higher 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.

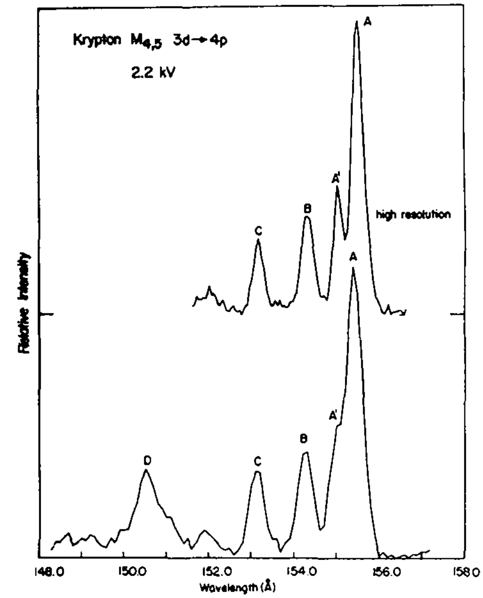

Fig. 3
Detailed study (background removed) of krypton plasma with a potential difference in the source above the ionization threshold of all L electrons. Lower figure obtained with resolution (~300) and upper figure with higher resolution (~500).

Acknowledgments

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