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Precision Measurements of the Wavelengths of Emission Lines of Mg-like and Na-like Kr in Alcator C Plasmas

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Abstract

The wavelengths of lines from Na- and Mg-like Kr ions were precisely determined by puffing Kr gas into Alcator C tokamak plasmas and observing with a time-resolving spectrograph equipped with a multi-element spectral detector.

Recently the possibility of laser action in UV and X-ray regions has been discussed widely [1]. Kr is considered one of the promising elements, and it is important to measure the energy levels of its highly ionized states precisely.

A powerful method for the study of emission spectra of highly ionized, medium- and high-Z ions is to introduce them into high temperature, magnetically confined plasmas and observe the resulting emission with a time-resolving spectrograph.

Kr was introduced into Alcator C tokamak [2] discharges by gas puffing, and Kr ionization states up through Ne-like are obtained with ease. In these discharges the toroidal magnetic field was 8T, the plasma current was 290 kA, and the line average electron density was 2.3×10^{14} cm^{-3}. The radius of the plasma column was 12.5 cm. Central electron and ion temperatures were 1200 eV and 900 eV respectively. Identification of Kr emission lines is made by comparing the spectra of discharges with large and small amounts of seed Kr.

The VUV emissions from these plasmas were monitored by a 2.2 m. grazing incidence spectrometer with a spectrally resolving detector on the Rowland circle. The detector observes about 30–40 Å of the spectrum with approximately 0.2 Å resolution and can be scanned from $\sim$ 28 Å to 570 Å in first order. It is composed of a micro-channel plate with a CsI photo-cathode, backed by a phosphor screen which is coupled by a fibre-optic bundle to a 1024 pixel, photodiode array. The array can be read out every 2,4,8,16,32,64, or 128 msecs.

In Fig. 1 is shown a composite spectrum from 5 discharges into which only trace amounts of Kr were puffed. The most prominent features are from intrinsic oxygen in the plasma. The following lines are used for wavelength calibration: OVI (150.089 Å,150.124 Å), OVI (172.935 Å, 173.082 Å), OVI (183.937 Å, 184.117 Å), OV (192.751 Å, 192.799 Å, 192.906 Å), OV (215.040 Å, 215.103 Å, 215.245 Å), and OV (220.352 Å) [3]. Shown in Fig. 2 is the same region of the spectrum when significantly more Kr is puffed into the discharge. (Z_{eff}-1 due to Kr is ~ 0.1 for these discharges.) In this spectrum the Kr lines dominate. The emission line at 158.23 ±0.05 Å is identified as the $3s^2\ {}^1S_0 - 3s3p\ \ {}^1P_1^\circ$ transition in Mg-like Kr. This line has also been identified by Stewart, et. al. [4], who give the wavelength as 158.15 ± 0.03 Å. The line at 179.03 ± 0.03 Å is from Na-like Kr ($3s\ \ {}^2S_{\frac{1}{2}} - 3p\ \ {}^2P_{\frac{3}{2}}^\circ$), given in [4] as 178.98±0.03 Å. This compares favorably to the prediction of 178.97 Å by Edlen [5]. The other member of the Na-like doublet ($3s\ \ {}^2S_{\frac{1}{2}} - 3p\ \ {}^2P_{\frac{1}{2}}^\circ$), is observed at 220.05 ± 0.01 Å, given in [4] as 220.07 ± 0.05 Å, and predicted by ref. [5] to be 220.03 Å. The results are summarized in Table 1.

Table 1

Transition Array	Multiplet	Wavelength (Å) this work	Wavelength (Å) ref. [4]
Kr XXV			
$3s^2 - 3s3p$	${}^1S_0 - {}^1P_1^\circ$	158.23 ± 0.05	158.15 ± 0.03
Kr XXVI			
$3s - 3p$	${}^2S_{\frac{1}{2}} - {}^2P_{\frac{3}{2}}^\circ$	179.03 ± 0.03	178.98 ± 0.03
$3s - 3p$	${}^2S_{\frac{1}{2}} - {}^2P_{\frac{1}{2}}^\circ$	220.05 ± 0.01	220.07 ± 0.05

Thus the $3s3p\ \ {}^1P_1^\circ$, the $3p\ {}^2P_{\frac{3}{2}}^\circ$ and the $3p\ {}^2P_{\frac{3}{2}}^\circ$ levels are found to be 632190 cm^{-1}, 558570 cm^{-1} and 454440 cm^{-1} above the ground states respectively. Fig. 3 confirms the Mg-like and Na-like identifications by showing the regularity in the level energy of the Kr levels when plotted with the energies of ions from Sc through Mo. These data up to Mn are derived from [6], while those for Fe through Ni are from [7]. The values from Na-like of Cu through Br are derived from the data of Kononov, et al. [8]. The data for Zr and Mo are from Hinnov [9] and Shirai, et al. [10] respectively.

Finally, Edlen [5] has determined a scaling relation for the energy of the $3p\ {}^2P_{\frac{1}{2}}^\circ$

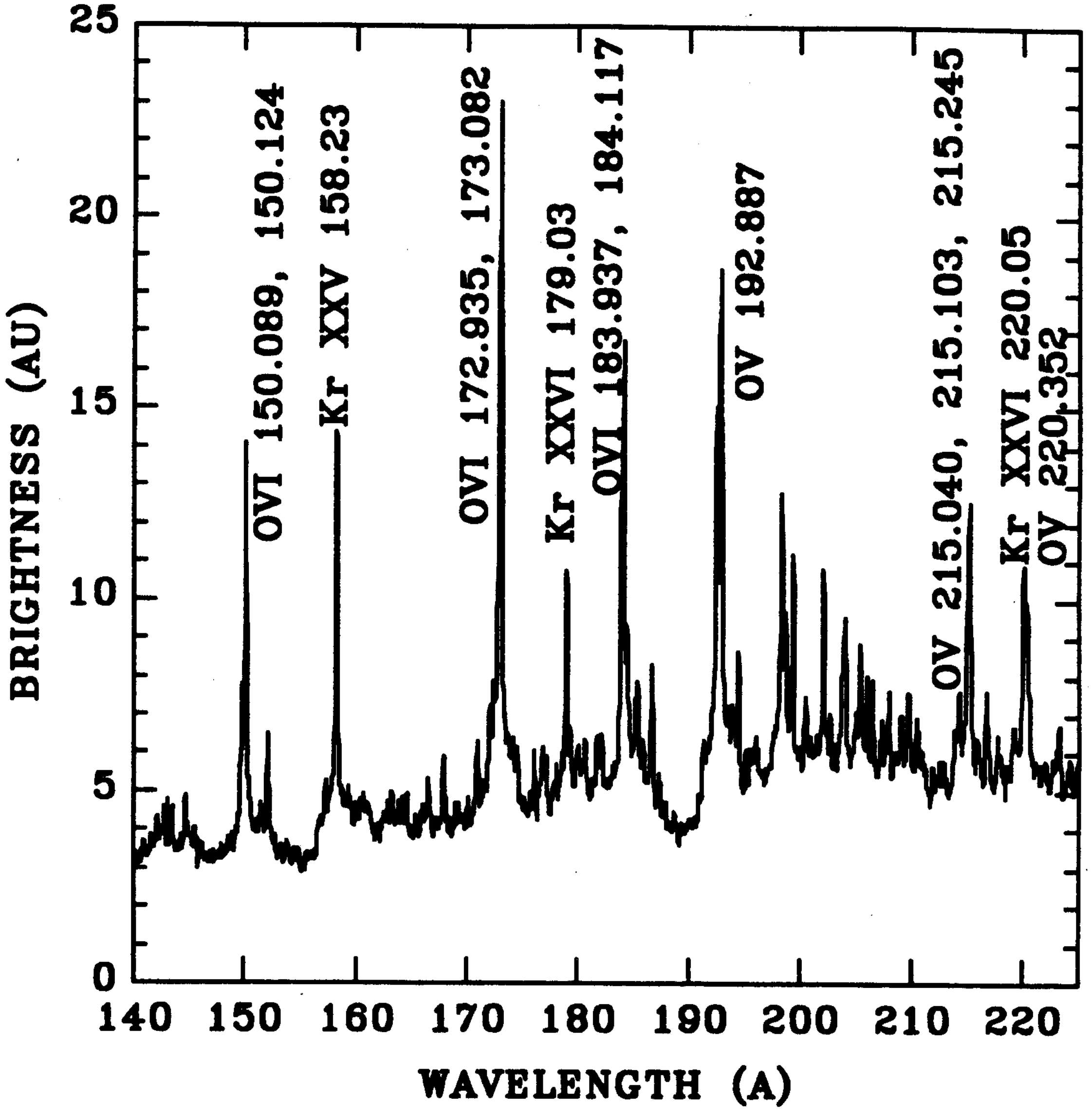

Figure 1. Composite spectrum from 5 similar discharges when only trace amounts of Kr were present.

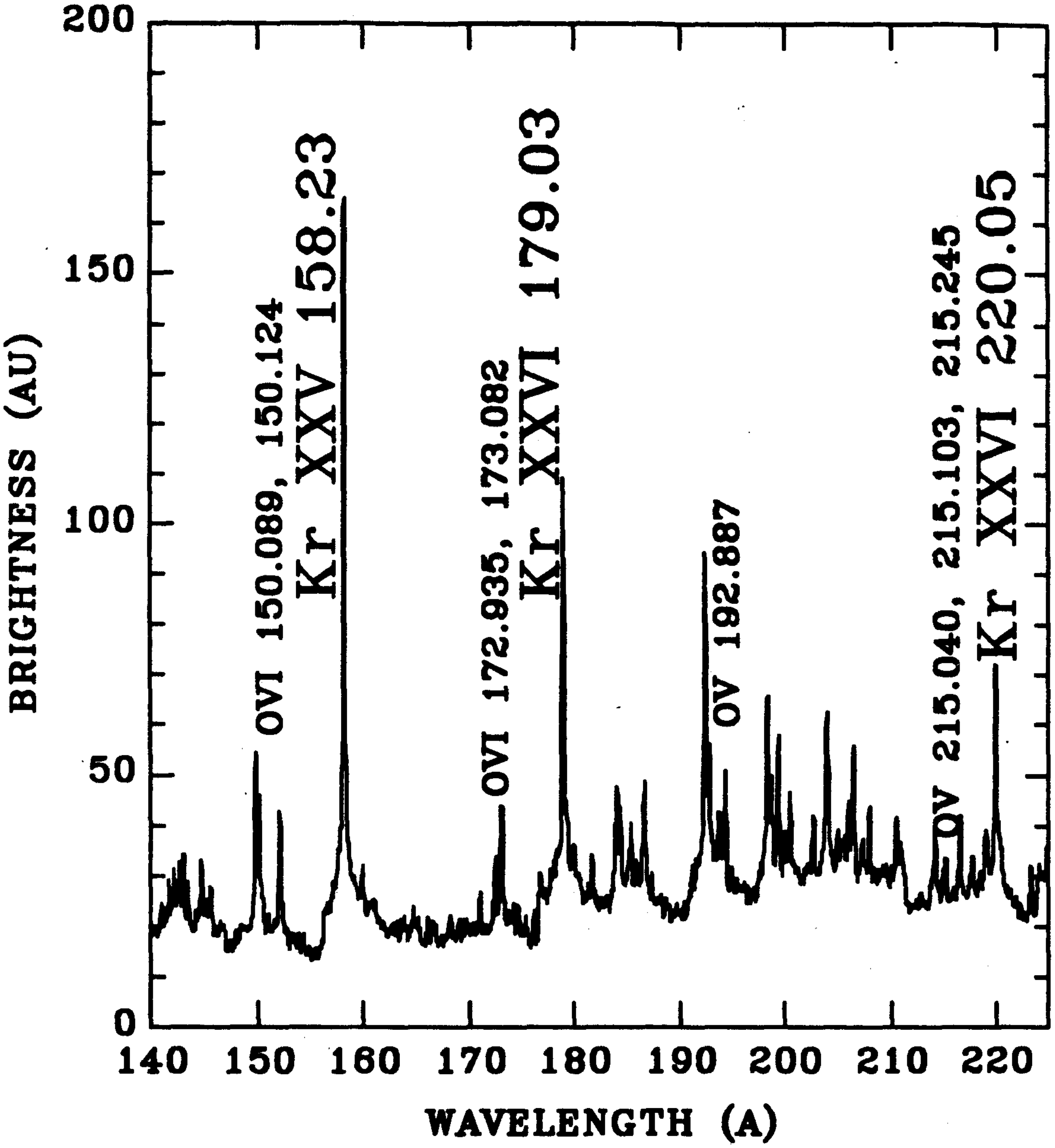

Figure 2. Composite Kr spectrum when enough Kr was puffed into the discharge so that Z_{eff}-1 due to Kr was ~ 0.1.

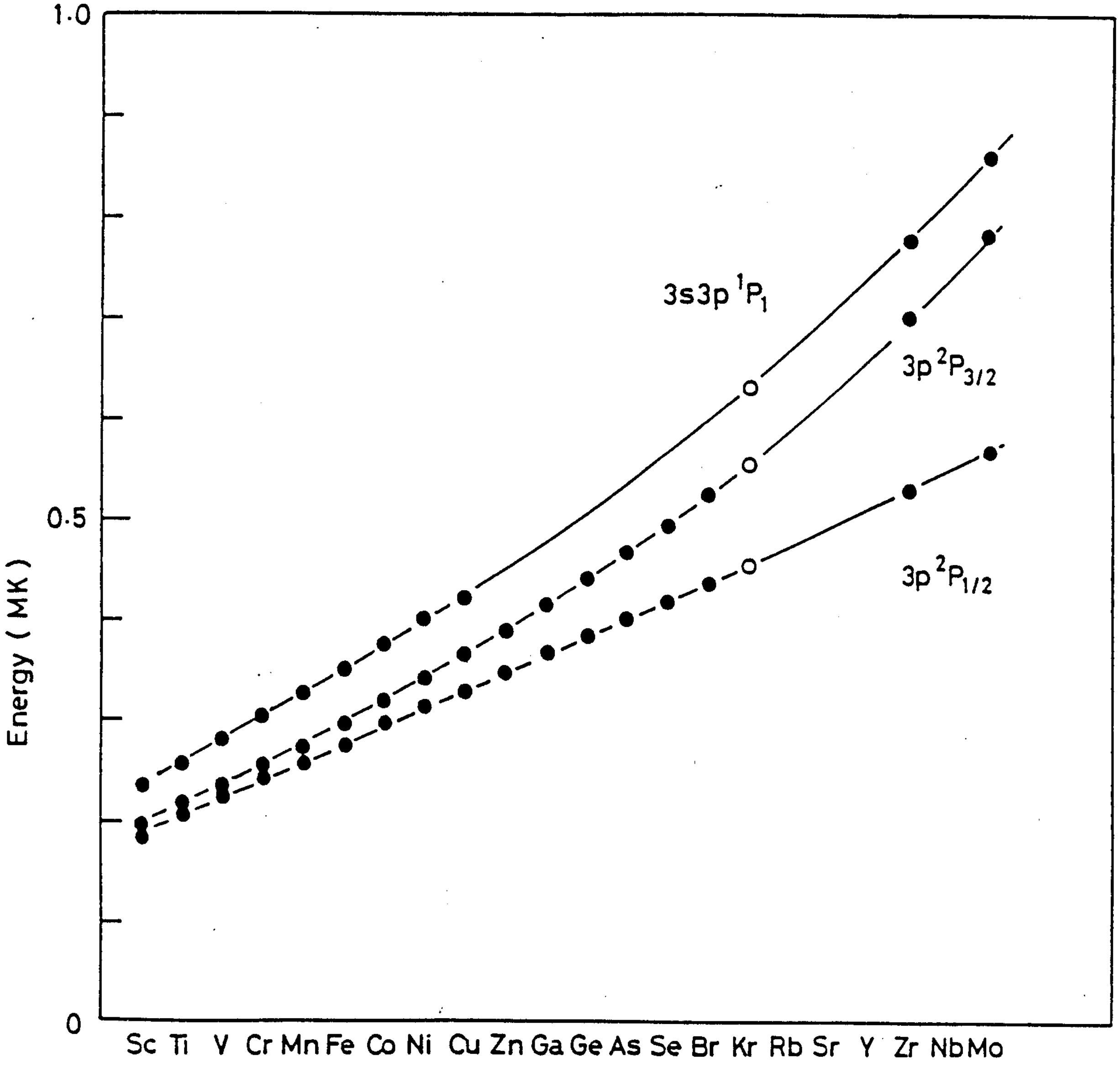

Figure 3. Regularities in the energy above the ground state for the $3s3p\ ^1P_1^o$ level of the Mg-like ion and the $3p\ ^2P^o_{\frac{3}{2},\frac{1}{2}}$ levels of the Na-like ion.

level above the ground state, which includes the effects of the Lamb shift of the 3s ground state. It is

$$\Delta E(cm^{-1}) = 16481.6(Z-10) + 10163 - 27800(Z-8.7)^{-1} + 0.700(Z-6)^{3} - L(3s),$$

where Z is the nuclear charge and $L(3s)$ is the Lamb shift. The measured wavelength implies a Lamb shift of the 3s ground state of 2120±20 cm^{-1}, where the uncertainty reflects only the uncertainty in the wavelength and does not include errors in the scaling relation.

In conclusion, the wavelengths of the $3p\ {}^2P^{o}_{\frac{3}{2},\frac{1}{2}} \rightarrow 3s\ {}^2S_{\frac{1}{2}}$ transitions in Na-like Kr and the $3s3p\ {}^1P^{o}_{1} \rightarrow 3s^2\ {}^1S_0$ transition in Mg-like Kr have been determined by puffing Kr into Alcator C discharges and observing the emissions with a time-resolving spectrograph.

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