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Far ultraviolet emission spectrum of xenon induced by electron impact at 100 eV

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Abstract

The FUV emission spectrum of xenon, which contains five emission lines at 117.04, 119.2, 125.1, 129.56 and 146.96 nm over the wavelength range 110–160 nm, produced by electron impact at 100 eV is presented. The measurements were obtained under near-optically-thin conditions at a spectral resolution of 1.0 nm FWHM. In addition, the absolute emission cross sections at 100 eV electron impact energy were obtained for these emission lines. Most prominent features of the FUV spectrum are the Xe I lines at 146.9 and 119.2 nm with the emission cross sections of 58.5×10^{-18} cm^2 and 45.0×10^{-18} cm^2, respectively, with an uncertainty of 27%.

1. Introduction

The present investigation on Xe is a part of a continuation of our previous work [1–3] of electron–rare gas atoms (He, Ne, Ar, Xe) collision processes. The absolute values of inelastic cross sections for the xenon are of interest in understanding the basic physics of collisional excitation processes and in technological applications such as laser and plasma physics [4], Tokamak fusion research [5] and electroluminescence intensity calculations in Xe [6].

Electron-impact-induced emission cross section measurements for Xe are scarce. Only few quantitative experimental results of the electron impact emission cross sections of specific electronic states in xenon are available. Feltsan and Zapesochnyi [7] reported the absolute optical excitation cross sections for 34 lines of Xe I and showed excitation functions for 32 of these from threshold to 100 eV electron impact energy. Mukhitdinova and Yakhontova [8] showed the excitation function of the 146.96 nm line up to 100 eV electron impact energy in relative terms. Later, Pavlov and Yakhontova [9] reported the electron-impact-induced photoemission cross sections for the Xe I resonance lines. They measured the absolute emission cross sections for the 146.96 nm and 129.56 nm lines at an electron impact energy of 150 eV. Comprehensive reviews of previous experimental measurements of electron-impact-induced emission cross sections and optical excitation functions for xenon in the ultraviolet (UV) spectral region have been published most recently by van der Burgt et al. [10] and by Heddle and Gallagher [11].

Direct electron-impact-excitation cross sections for Xe, however, are pretty well established. Filipovic et al. [6] measured electron-impact excitation of xenon at incident energies between 15 and 80 eV. Ester and Kessler [12] reported inelastic electron scattering cross cross sections for Xe in the 15–100

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eV impact-energy region. Khakoo et al. [13] reported relative electron-impact differential cross section measurements (DCS's) and theoretical calculations for Xe. Most recently, extensive DCS measurements and theoretical calculations for electron-impact excitation for the 1st to 20th lowest levels of Xe were reported in two companion papers at 10, 15, 20 and 30 eV impact energies by Khakoo and co-workers [14,15].

A laboratory study of far ultraviolet (FUV) emissions resulting from electron impact on xenon at 100 eV over the wavelength range from 110–160 nm has been completed and, in this Letter, the electron-impact-induced absolute emission cross sections corresponding to five Xe I spectral features are reported.

2. Experimental procedure and results

The experimental apparatus, calibraton procedure, and cross-section measurement technique have been described in our recent publications [1,16]. The medium-resolution 1.0-m spectrometer system was used in the present measurements. It consists of an electron-impact collision chamber in tandem with a UV spectrometer. The FUV emission spectrum of Xe was measured, under near-optically-thin conditions, by crossing a magnetically collimated beam of electrons with a beam of research grade Xe gas (99.995% purity as stated by the manufacturer) formed by a capillary array. Emitted photons, corresponding to radiative decay of collisionally excited states of Xe were detected at 90° by the UV spectrometer equipped with a photomultiplier detector. The resulting emission spectrum for Xe, measured at 100 eV incident electron beam energy, was calibrated for wavelength sensitivity from 110 to 160 nm according to the procedures described by Ajello et al. [17]. The relative cross sections, for each Xe feature, were obtained by integrating the signal intensity over the wavelength interval for the feature of interest. In order to put these relative cross sections on an absolute scale, as accurately as possible, a three-step procedure was employed:

(a) Pressure correction. Since the Xe I resonance lines were found to be extremely sensitive to the

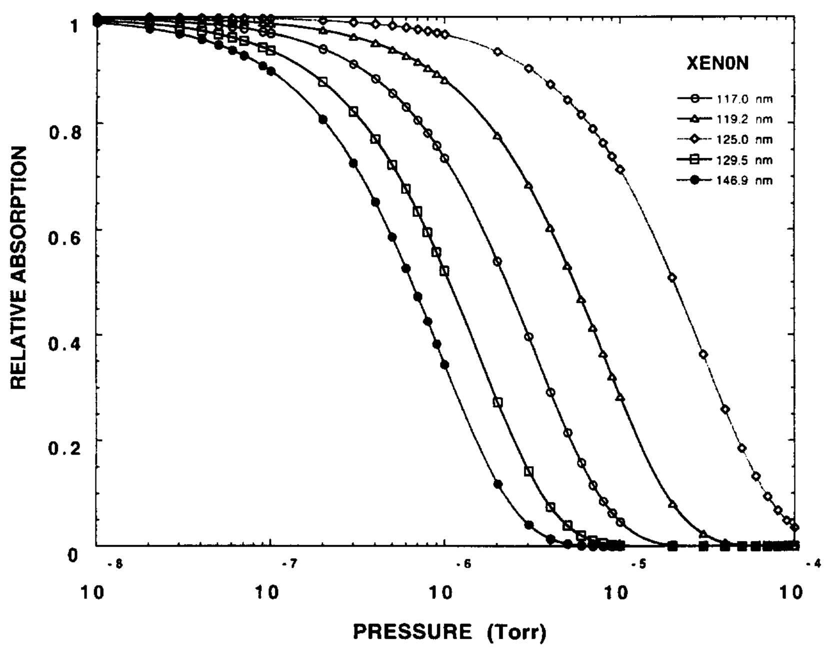

Fig. 1. The calculated relative absorption (I/I_0) of the Xe I lines at 117.0, 119.2, 125.0, 129.5 and 146.9 nm as a function of Xe gas pressure. The ratio (I/I_0) is approximately constant for all lines up to about 2×10^{-8} Torr and starts decreasing, indicating the onset of self-absorption of individual Xe I lines.

background gas pressure, one should carefully determine what gas pressure was to be used in the measurements to avoid effects of self-absorption.

A theoretical model has been employed to predict the variation of the intensity ratios with pressure for the Xe resonance lines. The attenuation or relative absorption (I/I_0) experienced by radiation passing through a slab of absorbing gas is given by Beer's law:

$$I/I_0 = \exp(-\tau_0), \tag{1}$$

where τ_0 is the optical depth at line center and is given by

$$\tau_0 = \sigma_{\text{abs}} n l, \tag{2}$$

where σ_{abs} is the absorption cross section over the Doppler width $(\Delta\nu_D)$ at line center, n is the number density of the absorbing gas, and l is the path length (16.83 cm) from the collision volume to the spectrometer entrance slit. The absorption cross sections for the Xe features, at line center, are obtained using the optical oscillator strengths f [18] for the Xe resonance transitions and the Doppler width. It is given by

$$\sigma_{\text{abs}} = \left(\frac{\pi e^2}{mc}\right) f/\sqrt{\pi}\,\Delta\nu_D, \tag{3}$$

where e and m are the charge and mass of an electron, respectively. The theoretical plot of I/I_0 against pressure, shown in Fig. 1, gives the amount of self absorption for the Xe lines at 117.04, 119.2, 125.1, 129.56 and 146.96 nm. Based on the predictions of the model for each Xe line, a background gas pressure about 4×10^{-8} Torr was used to minimize self absorption effects and still maintain a good signal-to-noise ratio. The relative cross sections for Xe lines were later corrected for a small amount of pressure effect (a few %) as suggested by the model.

(b) Polarization correction. The relative cross section measurements were made at an angle of 90° between electron beam axis and optic axis. The XeI resonance lines are polarized as much as 30% at 25 eV and the polarization sharply decreases to 5% at 100 eV as reported by Uhrig et al. [19]. The polarization correction for the present cross section measurements (at 100 eV) was found to be negligible (less than 2%) based on the following formula [10]:

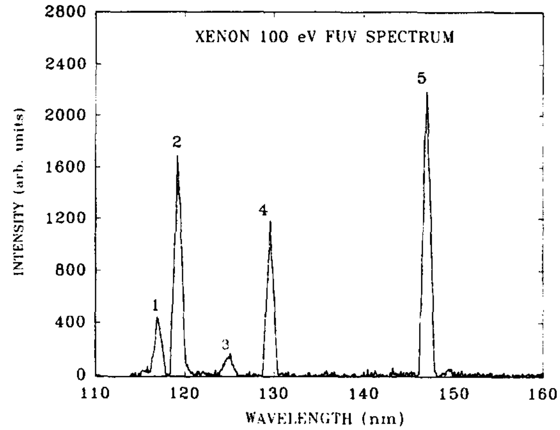

Fig. 2. Calibrated, electron-impact-induced emission spectrum of Xe at 100 eV. The spectrum was obtained in the crossed-beam mode at 4×10^{-8} Torr background gas pressure. Emission cross sections for the identified features (numbered) are listed in Table 1.

$$\sigma_{ij}(E_0) = \frac{C[1 - P(E_0)/3]}{1 - P(E_0)\cos^2\theta} I(\theta), \tag{4}$$

where $\sigma_{ij}(E_0)$ is the photoemission cross section at an electron impact energy (E_0), $P(E_0)$ is the polarization, $I(\theta)$ is the intensity of the emitted radiation at some angle, θ (where $\theta = 90°$ in our experimental set up) and C is a constant related to the electron beam current, number density of the target gas and the path length of the electron beam through the target.

(c) Normalization. The final stage of the three-step procedure (normalization) was performed to determine the absolute value of the emission cross section corresponding to each measured Xe feature. This was achieved by admitting a research grade gas mixture (purchased from a commercial source) containing 10% Xe and 90% N_2 into the scattering chamber and measuring the fluorescence signal from the gas mixture $(Xe + N_2)$ and then by comparing the integrated signal intensity for the Xe I spectral feature (feature no. 2 in Fig. 2) at 119.2 nm to that of the N I $g\,^4S_o - ^4P$ (at 119.95 nm) fluorescence signal at 100 eV electron impact energy. The well-estab-

lished absolute cross section of the N I 119.95 nm spectral feature of N_2 ($38.0 \pm 8.4 \times 10^{-19}$) [20], at 100 eV impact energy, was then used to put the relative intensity of the Xe I (at 119.2 nm) spectral feature on an absolute scale. Static gas ($Xe + N_2$) mode was utilized to maintain the 1-to-9 number density ratio (Xe to N_2, respectively) in the target region during the measurements. There are two reasons for having this ratio: 1) to keep the partial gas pressure of Xe at a low level such that we can maintain near-optically-thin condition for the strong and pressure sensitive self-absorbing Xe 119.2 nm resonance line and 2) to obtain, at the same time, good signal-to-noise ratios both for the Xe spectral line at 119.2 nm and much weaker N I 119.95 nm normalization feature. The Xe I line at 119.2 nm, which is about 0.8 nm away from the N I 119.95 nm spectral feature, was chosen because the spectral response of our detector as a function of wavelength was found to be the same within 1.0 nm. The absolute cross section for the Xe I (119.2 nm) spectral feature was then used to put the other four Xe features (nos. 1, 3, 4 and 5 in Fig. 2) on an absolute scale using the 100 eV calibrated FUV spectrum of Xe. It should be pointed out here that both pure Xe and the ($Xe + N_2$) gas mixture pressures were measured by an ion gauge and the ion gauge readings were corrected for the relative sensitivity of ion gauge response data for Xe (N_2 pressure was not corrected) published by Bartmess and Georgiadis [21]. The corrected value for gas pressure of Xe in the collision chamber was calculated to be approximately 4×10^{-8} Torr for the (N_2 + Xe) gas mixture.

Fig. 2 shows the Xe laboratory emission spectrum in the FUV spectral region at 100 eV electron-impact energy in the wavelentgth range of 110–160 nm. The spectrum was obtained at a gas temperature of 298 K, under near-optically-thin conditions, at a spectral resolution of 1.0 nm FWHM, and calibrated for wavelength. As stated earlier, the background pressure for the Xe emission spectral measurement was 4×10^{-8} Torr. The emission spectrum of Xe consists of five spectral features in the 110–160 nm wavelength region. Table 1 lists the candidate identifications and the measured absolute emission cross sections corresponding to Xe I transitions at 100 eV electron-impact energy. The identifications for Xe I features were taken from Moore [22]. Unfortunately,

Table 1
Absolute emission cross sections of Xe at 100 eV

Feature	Species	Integrated λ (nm)	Observed peak λ (nm)	Emission cross cross section ($\times 10^{-18} cm^2$)
1	Xe I	115.9–116.9	117.0	11.4
2	Xe I	118.3–120.9	119.2	45.0
3	Xe I	123.9–125.9	125.1	4.69
4	Xe I	128.8–130.5	129.6	29.1
5	Xe I	146.0–148.0	147.0	58.5

there is no experimental data available for electron-impact-induced emission cross sections of Xe at 100 eV to which the present results can directly be compared. As mentioned above, the cross sections reported here were corrected for the amount of self absorption given for the individual Xe lines (Fig. 1). The correction was found to be the largest for the Xe 146.9 nm line (5%). The 146.96 nm (feature no. 5) spectral line also represents the strongest feature in the 100 eV emission spectrum with an absolute cross section of 58.5×10^{-18} cm^2. It contains transitions from the unresolved excited levels of $6s[3/2]_1 + 6s[3/2]_2$ to the ground state $5p^6\ {}^1S_0$ of Xe.

The uncertainties in the absolute cross sections in this work were estimated as follows: (1) uncertainty of 15% in the relative calibration, (2) uncertainty of 22% in the N_2 (119.95 nm) emission cross section [20] and (3) signal statistics uncertainy of 3% in signal statistics. Thus the overall error (square root of the sum of the squares of the contributing errors) in the present cross section measurements is estimated to be about 27%.

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