Short Communication

Emission Coefficients in Helium†

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Abstract

We have presented measurements of emission coefficients for two levels of helium at high *E*/*N* values. Measurements were performed in a drift tube which consists of a pair of plane electrodes, with a diameter of 79 mm at a distance of 14.7 mm, placed inside a close fitting quartz tube. The cathode was made of stainless steel and the anode of graphite so that backscattering of electrons from the anode is minimized. The self-sustained Townsend discharge between 1 10^{-19}Vm^2 and 3.3 10^{-18}Vm^2 was maintained by running low current discharges at pressures between 5 10^2 Pa and 1 10^2 Pa, respectively. The absolute emission coefficients were determined from the measurements of the optical signal at the anode.

Key words: helium, spatial profiles, ionization and emission coefficients

Introduction

The studies of spatial profiles of excitation reveal non-hydrodynamic behavior close to the electrodes and at high *E*/*N*, effects of reflection and heavy particle excitation. Understanding the kinetics of excited helium is of practical importance for modeling processes in gas discharge devices that include plasma displays, new sources of light, metal lasers, and sources for spectral analysis, circuit breakers and plasma applications in microelectronics. In particular excitation coefficients may be used to improve uniqueness of the cross sections obtained for higher mean energies and may be even used directly for diagnostics of non-equilibrium discharges.[1,2]

In this paper we present measurements of spatial distributions of emission in helium, for two transitions. The data may be further normalized, based on absolute callibration, current and known geometrical factors to become absolute emission coefficient at the anode and used to fit the cross sections. We used drift tube technique for measuring the absolute emission intensities in low-current self-sustained Townsend type discharges. The data were obtained between moderate *E*/*N* values, where electrons are in equilibrium, and very high *E*/*N* values where electrons may not be in equilibrium with the local field. In particular at higher *E*/*N* effects of heavy particle excitation may be observed. In case of helium, due to its low mass, effects of fast neutrals may be expected even at relatively lower *E*/*N*.

Experimental set-up

A standard parallel plate drift tube is used in the measurements of excitation coefficients and the setup has been described in our previous references.[3–6] The anode is made of graphite to reduce backscattering of electrons, and the cathode is made of highly polished stainless steel. The schematic diagram of the apparatus is given in Figure 1. A closely fitting quartz tube is used to prevent the long path breakdown at low pressures to the left of Paschen minimum. The gap between the electrodes and the glass however is large enough to allow efficient pumping. System was evacuated to pressures of the order of $<4\ 10^{-4}$ Pa and filled with gas that was replaced every 15–20 minutes. The spectrum was used to test for the presence of impurities, especially nitrogen. We have maintained the procedure described above even though we have never observed lines or other effects due to pollution from air molecules. The gap between electrodes is 1.47 cm and the diameter is approximately 8 cm. The field in the system may be regarded as uniform since the maximum current was limited to 2 μA.[7–9]

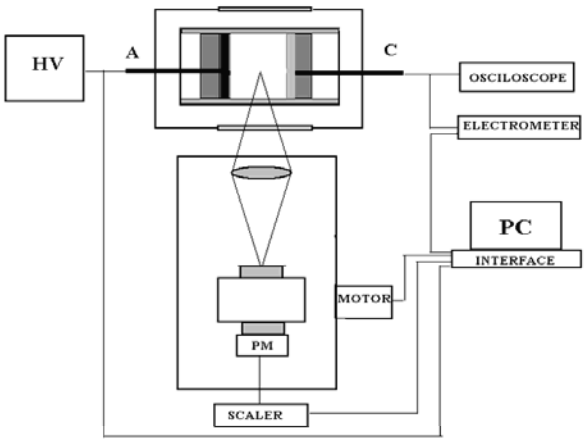

Figure 1. Schematic of the experimental set-up.

The optical emission was detected by a system consisting of a collimator, set of lenses, spectrometer, photomultiplier operating in a single photon counting regime and a pulse counting and shaping electronics. The system was callibrated by using a standard tungsten ribbon lamp. The monochromator and the optical system were mounted on a movable platform controlled by a computer and thus the spatial profiles were scanned. The spatial profiles of emission were recorded and extrapolated to the anode to obtain the absolute excitation coefficients.

The measured signal count S_a close to the anode, from a state j with population N^j is equal to:

$$N_j = \frac{S_a}{Q(\lambda) f(\Delta\lambda) A_{ji} G S \Delta x} \qquad (1)$$

where $Q(\lambda)$ is the a quantum efficiency (ratio of the number of the actual number of counted photons and the actual number reaching the photomultiplier); $f(\Delta\lambda)$ is the correction for the overlap between the line and the transmition of the monochromator and intention is to integrate the whole line; $G = \Omega/4\pi$ is the geometric factor described by the effective solid angle; Δx is the width of the entrance slit of the monochromator and S is the area of the anode.

At the same time, we may write the equation covering the simple kinetics of the excited state:

$$\frac{dN^j}{dt} = 0 = k_e^j N n - A_j N^j + k_q N N^j \qquad (2)$$

where k^j_e is the rate coefficient for excitation of gas atoms with density N by electrons with density n. The losses are due to radiative deexcitation (A_j) and collisional deexcitation (quenching-k_q) in collisions with the parent gas atoms. Combining (1) and (2) we obtain:

$$\frac{k_e^j N n}{A_j + k_q N} = \frac{S_a}{Q(\lambda) A_{ji} G S \Delta x} \qquad (3)$$

Since the relationship between rate coefficients describing temporal development and the coefficients describing spatial development in the steady state Townsend experiment is given by $k_e^j = w\frac{\varepsilon}{N}$, where ε/N is Townsend's excitation coefficient (only *excitation coefficient* in the further text) giving number of excitations per unit length covered by electrons, we obtain:

$$\frac{w\frac{\varepsilon}{N} N n}{A_j + k_q N} = \frac{S_a}{Q(\lambda) A_{ji} G S \Delta x} \,. \qquad (4)$$

We choose to observe a very narrow region close to the anode where all the current is carried by electrons and thus we may normalize the measured excitation coefficient to the electron density by using $wnS = \frac{i}{e}$, where i is the current of the discharge integrated over the entire area of the anode. Having this in mind, we arrive at:

$$\frac{\varepsilon}{N} = \frac{S_a}{i} \frac{e}{Q(\lambda) G \Delta x N} \frac{A_j}{A_{ji}} \left[1 + \frac{N}{A_j} k_q \right] \qquad (5)$$

which is the formula used in our analysis of the experimentally measured photon counts (S_a) and separately determined calibration and geometric factors. In the normalization of the emission signal the photon counts were normalized by the current and by the geometric factor, the slit width and the calibration. Transition probabilities for the lines that were studied were taken from.[10]

The errors of the final excitation coefficients are due to uncertainty in the measurements of: the slit width, solid angle, absolute callibration, pressure, voltage and current measurements and photon counts. The overall uncertainty varies with the intensity of the line as there is a strong statistical component of the uncertainty of the photon count. The overall uncertainty depending on E/N and on the line is between 25% and 35%.

Results and discussion

In Figure 2 we show the spatial distribution of 504.774 nm He emission obtained at two different E/N.[11] The positions of the electrodes are shown by the vertical dashed lines. The spatial scans of lines show (see Figure 2) an exponential increase of the measured intensity as we scan from the cathode to the anode. Near the cathode (marked by a peak of scattered light) there

is a region of small intensity of emission, which is higher than the background noise. In Figure 3 we show the spatial distribution of 388.865 nm He emission obtained at two different *E*/*N*.

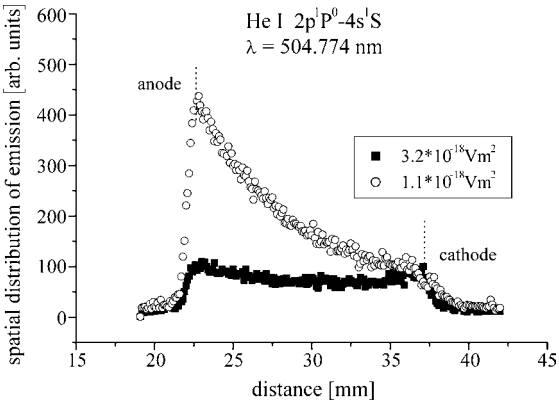

Figure 2. Spatial distribution of He I (λ=504.774 nm) at two different *E*/*N*.

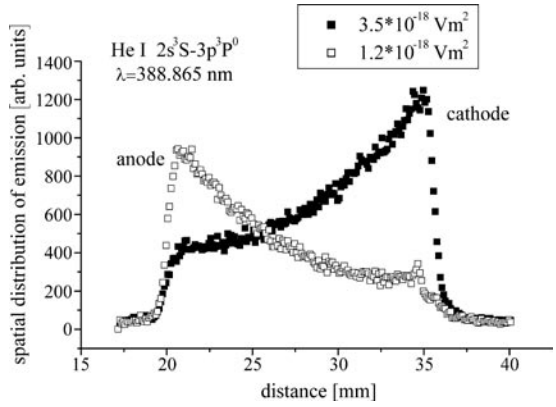

Figure 3. Spatial distribution of He I (λ=388.865 nm) at two different *E*/*N*.

We have measured spatial profiles for several transitions of helium. These profiles may be normalized to the excitation coefficients and be used to obtain the cross-section data with the aid of some numerical techniques.[12] In particular, such data may be used to identify heavy particle excitation[13] that is recognized by its growth towards the cathode.

From the slope of the curves of the spatial distribution of emission we determined the ionization coefficients. In Figure 4 we show comparison between experimental data from our measurements and Dutton[14] for the ionization coefficients of helium. At high *E*/*N* our data are somewhat lower than the accurate ionization data which may be expected since there could be non-negligible contribution of fast neutrals to the profile of emission which cannot be separated easily. At highest *E*/*N* where fast neutral contribution becomes clearly distinguishable the agreement improves. Our measured ionization coefficients at lower *E*/*N* somewhat higher than the other data, possibly due to Penning ionization. Nevertheless our results for ionization coefficients agree in general with the available accurate data.

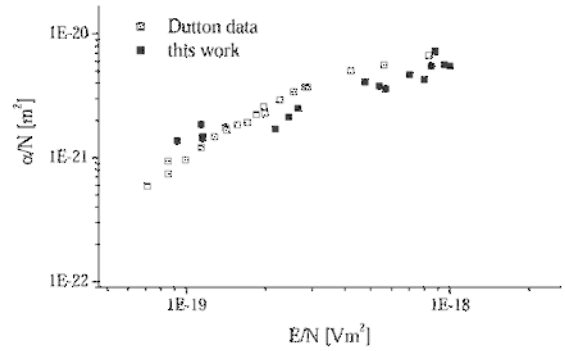

Figure 4. Comparison between experimental and Dutton data for ionization coefficients in helium.

The spatial distribution of emission is extrapolated and normalized to give the excitation coefficients at the anode. As the data for quenching are not available, we have not taken that process into account and thus our results are effectively emission coefficients, which may be normalized if the quenching data become available. However, experience with helium indicates that for most of the pressure range quenching should be negligible. Emission coefficients were obtained for 15 lines in helium but in this paper we have room to show results for only two lines. In Figure 5 the emission coefficients for He I (λ=504.774 nm) transition are shown as a function of *E*/*N*. As *E*/*N* values increases the number of electrons which have sufficient energy to excite the state increases rapidly. With further increase of *E*/*N*, the average electron energy approaches the energy of the maximum of the cross-section and the value of the excitation coefficients levels off. For even higher *E*/*N*, a decrease of the excitation coefficients is observable, which is in agreement whit the shape of the cross-sections. In Figure 6 the emission coefficients for He I (λ=388.865 nm) transition are shown as a function of *E*/*N*.

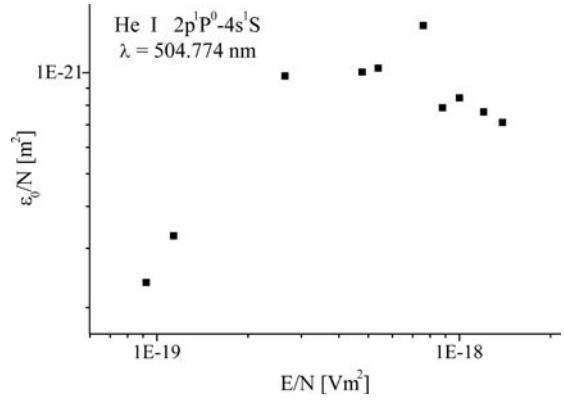

Figure 5. Emission coefficients for He I (λ=504.774 nm).

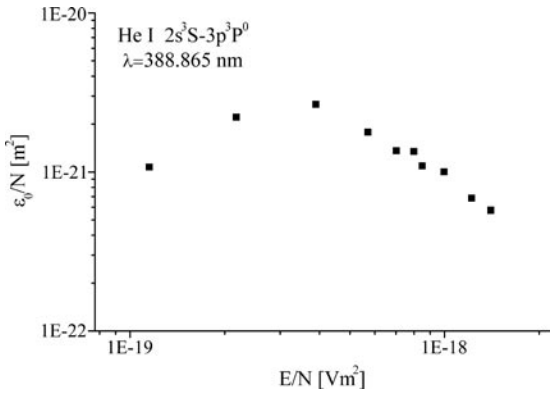

Figure 6. Emission coefficients for He I (λ=388.865 nm).

Conclusions

We have presented measurements of emission coefficients in helium at high *E*/*N* values. The spatial profiles of emission provide us with a lot of information on heavy particle excitation, on non-hydrodynamic behaviour of the discharge and on the reflection of electrons from the anode. This information can be used in plasma modelling. The absolutely calibrated spatial profiles of emission may be used to separate the effects of electron and heavy particle excitation at high *E*/*N* values and obtain the cross-sections for fast neutral excitation.

Acknowledgements

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Povzetek

Predstavljeni so rezultati meritev emisijskih koeficientov za dva energijska nivoja helija pri visokih razmerjih *E*/*N*. Meritve so bile opravljene v potovalni komori, ki jo sestavlja par planarnih elektrod s premerom 79 mm, oddaljenih 14,7 mm, znotraj kvarčne cevi. Katoda je izdelana iz nerjavnega jekla and anoda iz grafita, tako da je povratno sipanje elektronov minimizirano. Samodejno Townsendovo razelektritev med 10^{-19} Vm^2 in $3{,}3\times10^{-18}$ Vm^2 smo vzdrževali z nizkotokovno razelektritvijo pri nizkem tlaku 500 Pa oziroma 100 Pa. Absolutne emisijske koeficiente smo določili z meritvijo optičnega odziva na anodi.