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POPULATION DENSITY MEASUREMENTS OF SOME EXCITED LEVELS IN NEON RING DISCHARGE PLASMA*

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The results of 40 MHz inductively coupled Ne plasma investigation are presented and discussed. The hook method was employed to determine the lowest lying excited Ne I levels population densities.

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1. Introduction

The hook method, done by Rozhdestvensky in 1912 [1], proved to be the most convenient and accurate technique for anomalous dispersion measurements in the vicinity of an optical resonance.

The method has been developed by numerous investigators especially from Rozhdestvensky's school and is continually utilized for two basic topics, namely, the oscillator strength and the population density determinations. Primarily the measurements were done for atomic species closed in absorption cells or discharge tubes. In the last twenty years many investigations were done adopting the hook method to new experimental techniques and problems, e.g., for determination of oscillator strengths and transition probabilities at molecular species [2, 3], or investigation the excitation processes in metallic vapours heated by shock waves [4–6]. As new examples of the hook method application, the spatially resolved measurements in hypersonic gas flow [7] and the time resolved studies of the pulsed discharge [8] should be mentioned.

These numerous applications based on the advantages of dispersion measurement, which are the insensitivity to optical thickness and the weak sensitivity to the shape of a line profile. These have been taken into account at the choice of a method for the RF (radio–frequency) discharge plasma studies. The ring discharge plasma created in a gas medium placed in the RF field of an inductive coil was examined by the hook method. The results of population density measurements are presented and discussed below.

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2. *Principle of the method*

The Rozhdestvensky hook method combines both interferometer and spectrometer techniques. The main part of the experimental set-up is a two-beam interferometer which contains a tube with gas or vapour to be examined in one arm, while in the other identical compensating tube and plane-parallel plate producing an additional path difference between interfering light beams are placed. The interferometer produces a set of fringes at each wavelength present in a light source. The interference pattern is focused on the slit of a spectrometer which analyses it at individual wavelengths. Near the absorption line the interference fringes bend rapidly on both sides of the line creating hooks.

For a single line the distance between the hooks, according to Rozhdestvensky, is expressed by

$$\Delta^2 = \frac{e^2\lambda_{ij}^3}{mc^2K} N_i f_{ij} l \left(1 - \frac{N_j g_i}{N_i g_j}\right), \tag{1}$$

where Δ is the hook separation in terms of wavelengths; N_i, N_j — the population densities of the lower and upper levels of the transition at λ_{ij}, respectively; K — the constant of the apparatus; g_i, g_j — the statistical weights of the i-th and j-th level, respectively; f_{ij} — the oscillator strength of the transition; l — the length of the absorbing medium; e, m, c — the physical constants.

If the negative dispersion term, $N_j g_i/N_i g_j$, is small with respect to unity, from Eq. (1) one can obtain

$$N_i f_{ij} l = \frac{mc^2}{e^2} K\lambda_{ij}^3 \Delta^2. \tag{2}$$

This expression is useful for the direct determination of either f_{ij} values, if a measurement is made with a gas of known density, or N_i values, for a transition of known oscillator strength.

3. *Experimental procedure*

The experimental arrangement used for the population density measurements is illustrated in Fig. 1. The high-pressure xenon arc lamp XHP-450 served as a continuous light source. As it follows from Fig. 1, the Mach–Zehnder interferometer, usually employed for a hook method, was replaced by a compensated Michelson's interferometer which is simpler to adjustment. Its sensitivity to changes in the refractive index is twice that of Mach–Zehnder interferometer. There was no need to set the additional plate in the compensating arm of the interferometer. The necessary path difference between interfering light beams was produced by moving one of the totally reflecting mirrors in the direction perpendicular to the optical axis. The interferometer was mounted on an iron table supported by damping rubber–aluminium blocks. The discharge excited by radio-frequency power was observed in a quartz tube shown in Fig. 2. The length and diameter of the active part of the cell were 300 and 6 mm, respectively. A coupling loop, parallel to the discharge

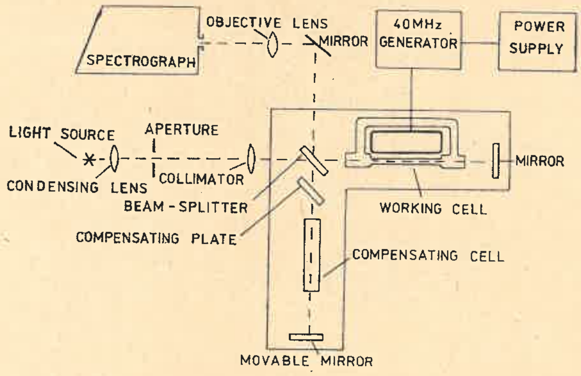


Fig. 1. Schematic view of the experimental set-up

tube was connected with 40 MHz generator. As a result of changing the input power of the generator from 50 to 1300 W the relative power absorbed by the discharge changed from 1 to 10. The discharge tube was degassed and evacuated by a diffusion pump to 2×10^{-6} Tr before an introduction of neon.

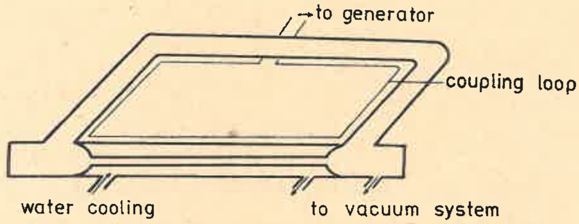
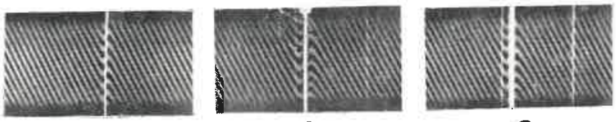


Fig. 2. The construction of the discharge tube

The hooks near the lines 6402 Å, 6334 Å, 6266 Å and 6506 Å were photographed with a grating spectrograph. The reciprocal dispersion in the 5-th order of a grating (650 groves/mm) was about 5.5 Å for these wavelengths. The lower order spectra were eliminated by placing a glass filter in front of the spectrograph slit.

4. *Results and discussion*

The population densities of levels belonging to $2p^5 3s$ configuration were measured for pressure range of 0.16–1.3 Tr and different output powers of the radio-frequency generator. The energy level diagram of Ne with transitions utilized for the measurement is shown in Fig. 3. In the group of the lowest lying excited levels, the s_5 and s_3 are metastable but from the s_4 and s_2 the ultraviolet transitions to ground level are possible. The population densities calculated from the separation of the hooks formed near the tube axis varied from 0.4–1.6 Å depending on a transition and discharge conditions. Examples of the hook spectra are shown in Fig. 4.



a b c

Fig. 4. The hook spectra for the line $\lambda = 6402$ Å at different powers, P, of the generator; a) $P = 2.2$, b) $P = 5.3$, c) $P = 10$

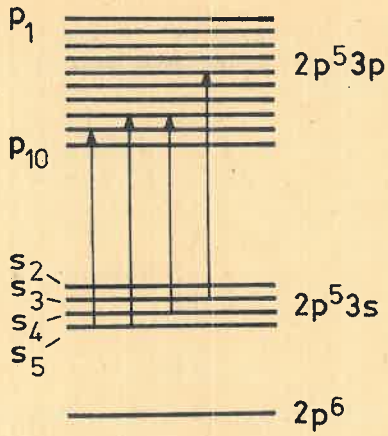


Fig. 3. Partial energy level diagram of Ne I

The population densities of s_5, s_4 and s_3 levels show nearly the same dependence on pressure and RF power (Fig. 5). The ratio of the population densities of these levels are constant to within 20%. The mean value of the ratio

$$N_5 : N_4 : N_3 = 4.91 : 3.09 : 1,$$

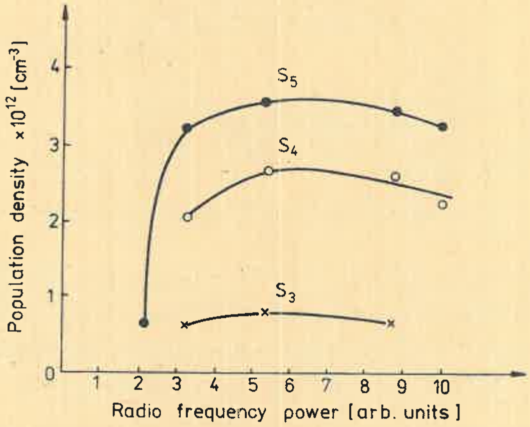


Fig. 5. Population density versus RF power for some levels of the $2p^53s$ configuration. Neon pressure $p = 0.4$ Tr

which is very close to the ratio of their statistical weights:

$$g_5 : g_4 : g_3 = 5 : 3 : 1,$$

suggests a strong collisional coupling between the levels.

The hooks about the $\lambda = 5852$ Å line were masked by a strong emission line so the hook distance determinations and as follows, the population density of the s_2 level calculation were impossible. However, the estimated population of this level seems to be closer rather to the population of the level, s_3, than s_4, despite their equal statistical weights of $g_2 = g_4 = 3$. The strong ultraviolet transition to the ground level which depopulates s_2, the higher lying level of the $2p^5 3s$ configuration, is probably the reason for this discrepancy.

Fig. 6 presents the population density of the s_5 level versus the absorbed RF power for different Ne pressures. The saturation and even the maximum (for the higher pressure) can be seen in the shape of the curves. According to previous calculations [10], at high

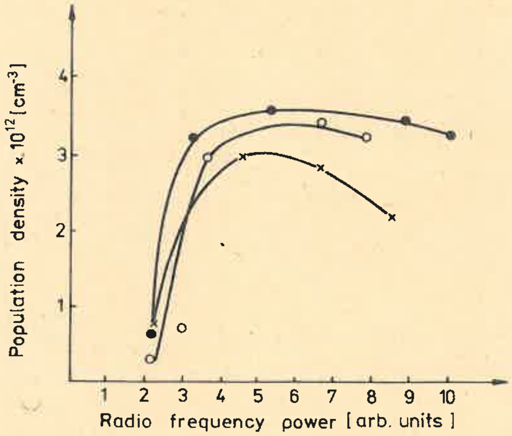


Fig. 6. Population density of the s_5 level versus RF power for different pressures of Ne; a) —○— 0.16 Tr, b) —●— 0.4 Tr, c) —×— 1.28 Tr

concentrations of electrons, the increase in the E/p ratio (E is the electric field, p — gas pressure) is followed by a rapid decrease in a number of fast electrons. The change in electron concentration distribution induces a change in the population of the levels for which the collisions with fast electrons are the dominant populating mechanism. On the basis of the above considerations, the shapes of the curves in Fig. 6 can be explained as a result of changes in a number of electrons with an energy of approximately 16 eV necessary for excitation the levels of $2p^5 3s$ configuration.

In the determination of the population density the negative dispersion term, $N_j g_i / N_i g_j$, was neglected as insignificant in respect to unity. When providing $N_j/N_i \leqslant 10^{-2}$, according to paper [11], the introduced error is estimated to be of a few per cent.

TABLE I

Line (Å)	Transition	Oscillator strength [9] f_{ij}
6506	$s_4 \rightarrow p_8$	0.232
6402	$s_5 \rightarrow p_9$	0.373
6334	$s_5 \rightarrow p_8$	0.0818
6266	$s_3 \rightarrow p_5$	0.394

The oscillator strengths utilized in the calculations are from Wiese [9] and shown in Table I.

Under the conditions of the present experiment the hook separation changes from 0.4 to 1.6 Å. Stark and Doppler broadenings are about 0.04 and 0.02, respectively. Using Eq. (1), which neglects the influence of the broadening mechanisms on the calculated population densities is therefore well justified.

Because the hook constants were of the order of 8000, they could be determined in the conventional way [12] with an accuracy of 1.5%.

The experimental error is largely connected with the measurement of hook distances and this accuracy depends on the sharpness of the spectrogram. The Carl-Zeiss comparator was utilized for this measurement. The inaccuracy introduced by this procedure causes and error of 0.1—0.4×10^{12} cm^{-3} in the calculated population density.

The uncertainty in Figs. 5, 6 is estimated to be about 15% for the s_5 level at its maximum density region to 35% for the s_3 level at its minimum density region. The relatively large experimental error in the minimum density region is due to the small separations of hooks.

In order to obtain a greater precision of the measurement, the development of the experimental set-up, especially the application of the spectrograph of higher resolution is planned.

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