ABOUT THE «ENLIGHTENMENT» OF NONIDEAL HYDROGEN-OXYGEN PLASMA AT A ELECTRONS' CONCENTRATION $N_E \le 3{\cdot}10^{19}$ cm^{-3}

O.A. Fedorovich

Institute for Nuclear Research NASU, Kiev, Ukraine

E-mail: oafedorovich@kinr.kiev.ua

The results of experimental determination of the emissivity of the hydrogen-oxygen plasma pulsed discharge in water and their comparison with calculations. It is shown that when concentrations nonideal plasma $N_e > 3{\cdot}10^{18}$ cm^{-3}, is observed "enlightenment" of plasma. The reduction of a emitting ability ε can be more order in the $N_e=3{\cdot}10^{19}$ cm^{-3} and increases with increasing electron concentration.

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INTRODUCTION

Emissivity ε nonideal hydrogen plasma has been determined experimentally up to electron densities $N_e< 10^{19}$ cm^{-3} [1, 2]. At higher N_e, the information about the experimental studies of ε in literature is absent. In pulsed discharges in water (PDW) were obtained $N_e \le 5{\cdot}10^{20}$ cm^{-3} [3].·Get the experimental distribution of the emissive of the non-ideal hydrogen-oxygen plasma until $N_e = 3{\cdot}10^{19}$ cm^{-3} at a temperature of 17.3 K· we were able to (γ = 0.3).

MAIN PARTS

For the experimental determination of ε requires the measurement of the intensity distribution I of the emission spectrum, the channel diameter d, the optical thickness τ, the inhomogeneity of the channel. For the calculation of ε is necessary to know the value of N_e and temperature. All these data were obtained in this work experimentally, and the inhomogeneity parameter M calculated according to [4]. With decrease in optical thickness τ of the RWI plasma channel, the spectrum of the radiation of the channel remains continuous. But on his background is possible to select the lines of the hydrogen: first H_α, later H_β and still later H_γ. On the distribution of intensity in the wings of reabsorbed H_α line, broadened in the plasma microfield, we can obtain the distribution of τ in the far wings. If change in wavelength does not change the τ absolute value, then it is taken as τ continuum, since occurs a smooth transition of the lines wing into continuum [5]. Inhomogeneity parameter M was calculated based on the excitation energy of the upper level of the last visible line, and formed for continuum value from [4]:

$$M=\sqrt{\frac{E_g-h\upsilon}{E_g}}=0.84...0.93, \quad (1)$$

$$\text{at} \quad \frac{kT_m}{E_g-h\upsilon}<<1\,(0.19...0.3),$$

where E_g – excitation energy level, from which it can be assumed that the levels form a quasicontinuous sequence. For area of the spectrum of 350.0...700 nm, the parameter M = 0.84...0.93 for the continuum of the hydrogen plasma in the last observed lines H_α, H_β, H_γ. The condition of applicability of formulas for calculating the parameter M is performed [4].

Averaged along the observation ray emissivity, according to [4], is:

$$\varepsilon=\frac{I_\upsilon\cdot\tau_\upsilon}{Y\cdot d}, \quad (2)$$

where: I_υ - the spectral distribution of radiation intensity, Y - a parameter that takes into account the influence of the optical thickness of the plasma on the I: it is determined from the plot of Y = f (τ, p) [4], and at each time has its own value, d - diameter of the plasma channel . The parameter M is taken into account by introducing into the formula (2) amendments to the value of I_v. It was assumed that τ, resulting in a distant wing of the Nα slightly varies in the range of the Balmer series. When τ > 0.5, dependence Y (τ) starts to deviate strongly from the straight and a little with increasing τ. Therefore, significant errors in the determination of ε under this assumption will not. The error in determining ε will be tens of percent. In Fig. 1 shows the experimental values of the emissivity of the non-ideal hydrogen-oxygen plasma at $3{\cdot}10^{19} \ge N_e> 3.5{\cdot}10^{17}$ cm^{-3}. For $N_e>3{\cdot}10^{19}$ cm^{-3} it does not to determine N_e and measure the τ. The optical thickness in the lines large (τ >> 1). Therefore, for the calculation of ε in the lines, values I do not have to divide by the channel diameter (d ≈ 2 cm). This should be done for the continuous spectrum, as there τ < 1.

Take into account the dependence of the parameter Y from τ, the calculation of ε was based on the formula 2. Averaging I is conducted over diameter of the channel, τ in a given moment of time is small and there is no significant effect of the parietal cold regions on the intensity of radiation [8]. Influence of heterogeneity itself is taken into account at determining ε from I. The same way taken into account influence of the optical thickness on I. The diameter of the channel was measured by the method of illumination from an external source of radiation [3]. The calculation of ε spectral distributions was performed on the four formulas. The first calculation is performed for hydrogen plasma on the Unsold-Kramers equation for the total free-free and free-bound radiation. Oxygen supplementation should be given only in the emissivity as a linear section [4].

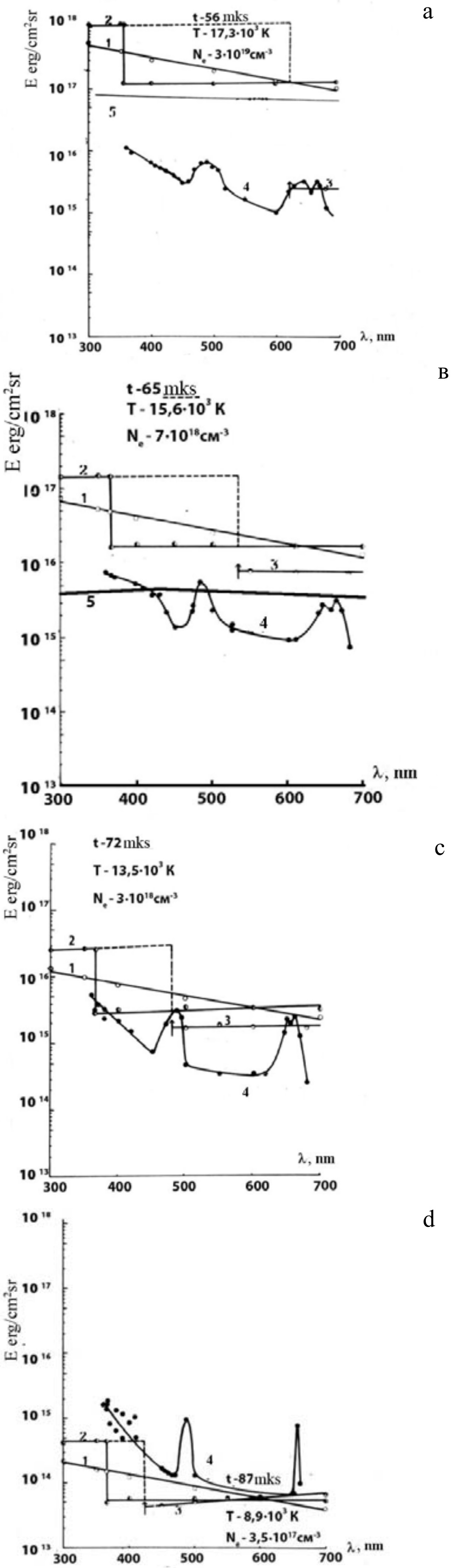

Fig. 1. The emissivity of hydrogen-oxygen plasma. The calculation by the formulas: 1 – Unsold-Kramers [5]; 2 – Biberman-Norman [8]; 3 – Norman [9]; 4 – experimental; 5 – Kramers [5]. (a – 56 mks, b – 65 mks, c – 72 mks, d – 87 mks)

The value of the Gaunt- factor is chosen equal to unity [4]:

$$\varepsilon_\upsilon = \varepsilon_\upsilon^{ff} + \varepsilon_\upsilon^{bf} = C_4 N_e N_i \frac{Z^2}{T_e^{1/2}}, \quad (3)$$

where $C_4 = 5.44\times10^{-39}$ units GHS.

The electron density was determined from the broadening of the H_α and the temperature of the radiation intensity at the maximum line reabsorbed H_α [4]. The result of calculations using this formula in Fig. 1 shows as number 1. Has also calculated by the formula ε Biberman-Norman [6]:

$$\varepsilon_\upsilon = C_4 \frac{N_e N_i Z^2}{T_e^{1/2}} \xi \quad (4)$$

Biberman-Norman factor ξ was taken for hydrogen in [4], and the results of calculation by this formula are marked as number 2 in Fig. 1. According to the formula Biberman-Norman, calculation was carried out in two approximations: 1) a violation of the principle of spectroscopic stability (solid curve), 2) non-infringement of the principle of spectroscopic stability in the gap (dashed curve).

The third calculation performed by the Norman formula [7] for ε for strongly coupled plasma (taken the total recombination and bremsstrahlung):

$$\varepsilon_\upsilon = 6.36\cdot10^{-54} N_e N_i (kT)^{-1/2} Z^2 \exp\left(\frac{\Delta I}{kT} + \frac{h\upsilon_o}{kT} - \frac{h\upsilon}{kT}\right) \xi' \text{ [J × s -1 × sm3sr-1 (c-1) -1]}, \quad (5)$$

where ΔI - reduction of the ionization potential, ξ '– an effective, ξ – a factor which led rank is determined by the formula [7]:

$$\xi' = \xi(\upsilon)\exp\left(-\frac{h\upsilon_0}{kT}\right)\cdot\left[\exp\frac{h\upsilon_0}{kT} - \exp\frac{\Delta E}{kT} + 1\right], \quad (6)$$

where ΔE – the gap, which is equal to [7]. where $\frac{\Delta E}{kT} = C_\gamma$, $C_\gamma = 3.5$ for hydrogen. Moreover, the calculations on the latest formula one should distinguish parts of the spectrum with $\upsilon > \upsilon_g$ and $\upsilon < \upsilon_g$, where υ_g - the frequency limits of the series. Moreover, it is considered that, in a region with $\upsilon > \upsilon_g$ - the calculation can be carried out for ξ '= ξ, and if $\upsilon > \upsilon_g$, then: $\frac{h\upsilon_0}{kT} = \frac{h\upsilon}{kT}$.

To calculate ε for reducible formulas can only be part of the spectrum towards lower frequencies than specified by Ingliss-Teller shift the boundaries of the series. Calculate the distribution of ε in the "gap" in this equation is impossible. The calculation results are indicated by number 3. The experimental values of ε marked as number 4. Performed the calculation of ε and the Kramers formula for the free-free transitions:

$$\varepsilon_\upsilon^{ff} = C_4 Z^2 \frac{n_e n_r}{T_e^{1/2}} \exp\left(-\frac{h\upsilon}{kT_e}\right) \quad (7)$$

(Curve indicated by the number 5). When N_e=3.5 10^{17} cm^{-3} (see Fig. 1,d) estimated the total value of ε for the continuous spectrum is somewhat less experimental. This is consistent with the data of other authors. For N_e the opposite effect is observed: the· increase up to $3\cdot10^{18}$ cm^{-3} values of ε, calculated for all three formulas, the above experimental data (see Fig. 1,c). In a series of theoretical values of the boundary ε practically coincide with experimental ones. In the "gap" in the longer wavelengths the experimental values of ε is several times smaller than calculated. Closest to the experiment is calculated using the formula by Norman [9]. With, the calculated values is an·further increase of N_e (for N_e =7·10^{18} cm^{-3}) ·order of magnitude higher than the experimental (Fig. 1,c), and for N_e=3·10^{19} cm^{-3} calculated values of the more experimental more than two orders of magnitude (see Fig. 1,a). The best agreement with experiment in magnitude ε gives a formula Norman [7]. The smallest discrepancy between theory and experiment is in the limits of the Balmer series. There is a difference (10...50) time between ε. Accounting for non-violation of the principle of spectroscopic stability, leads to a difference between theory and experiment in the "gap" in the three orders of magnitude, especially in the area of 600 nm. Even in the border area a series of calculated values of ε higher in comparison with the experiment. This confirms the presence of nonideal hydrogen-oxygen plasma effect "enlightenment" with $N_e > 10^{18}$ cm^{-3}, predicted theoretically in [7, etc]. The effect of "enlightenment" of hydrogen-oxygen plasma increases with increasing N_e. In the longer wavelength than that determined by Ingliss-Teller shift of the ionization threshold, ε NP well described by the formulas given in [7]. When N_e=(3...7)·10^{18} cm^{-3} value experimentally determined emittance agrees well· with the calculated values obtained by the Kramers formula for the free-free transitions [4]. At N_e – (N_e> 7·10^{18} cm^{-3}), experimentally observed values of less than higher values above $N_e \leq 10^{17}$ cm^{-3} calculated by this formula, while The disappearance of the excited energy levels is an exception mechanism of the photoionization absorption of these states and leads to a decrease of the absorption coefficient [7].

CONCLUSIONS

In the hydrogen-oxygen NP observed the effect of "enlightenment" with $N_e > 3 \cdot 10^{18}$ cm^{-3}. The experimentally determined values of the spectral distribution of ε is much smaller than the given formula for an ideal plasma. N_e to determine the emissivity of a nonideal plasma is impossible, as the data obtained an order of magnitude or more may be overstated (at $N_e > 10^{18}$ cm^{-3}).

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О «ПРОСВЕТЛЕНИИ» НЕИДЕАЛЬНОЙ ВОДОРОДНО-КИСЛОРОДНОЙ ПЛАЗМЫ ПРИ КОНЦЕНТРАЦИЯХ ЭЛЕКТРОНОВ $N_e \leq 3 \cdot 10^{19}$ см$^{-3}$

О.А. Федорович

Приведены результаты экспериментального определения излучательной способности водородно-кислородной плазмы импульсных разрядов в воде и их сравнение с расчетными. Показано, что при $N_e > 3 \cdot 10^{18}$ см$^{-3}$ наблюдается «просветление» водородно-кислородной неидеальной плазмы. Различие может составлять больше порядка при $N_e = 3 \cdot 10^{19}$ см$^{-3}$ и увеличивается с возрастанием концентрации электронов.

ПРО «ПРОСВІТЛЕННЯ» НЕІДЕАЛЬНОЇ ВОДНЕВО-КИСНЕВОЇ ПЛАЗМИ ПРИ КОНЦЕНТРАЦІЯХ ЕЛЕКТРОНІВ $N_e \leq 3 \cdot 10^{19}$ см$^{-3}$

О.А. Федорович

Наведено результати експериментального визначення випромінювальної здібності воднево-кисневої плазми імпульсних розрядів у воді і їх порівняння з розрахунковими. Показано, що при $N_e > 3 \cdot 10^{18}$ см$^{-3}$ спостерігається «просвітлення» воднево-кисневої неідеальної плазми. Різниця може становити більше порядка при $N_e = 3 \cdot 10^{19}$ см$^{-3}$ і підсилюється зі збільшенням концентрації електронів.