RESOLUTION OF THE ELECTRON-BEAM DIAGNOSTIC METHOD IN RAREFIED GASDYNAMICS

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As was noted in [1], the radiation capture effect can lead to a noticeable degradation in the geometrical resolution of measurements using the electron-beam excitation technique. We should stress that the effect usually appears, not because of reabsorption of the line investigated, but because of a dipole bond between the upper term of the chosen transition and the atomic ground state.

In order to improve the design, it is useful to derive the appropriate estimates for choosing correct conditions in a diagnostic experiment.

Let an electron beam, assumed, for simplicity, to be infinitely thin, be directed along the z axis; let the measurement of intensity of the line I(x) be performed along the line of sight, lying in the plane normal to the axis, and distant from it by an amount x. We introduce the characteristic dimension l, defining the boundary of emission of the main portion α of the line intensity ($\alpha \simeq 0.8$–0.9). If A is the strength of the line excitation source, then

$$\int_0^\infty I(x)\,dx = A/8\pi, \quad \int_{l/2}^\infty I(x)\,dx = (1-\alpha)\,A/8\pi. \tag{1}$$

Let ρ be the modulus of the two-component vector (x, y) giving the emission point. Then, from the axial symmetry of the problem, we have

$$I(x) = \frac{\gamma_1}{2\pi}\int_x^\infty n(\rho)\,\rho\,(\rho^2 - x^2)^{-1/2}\,d\rho, \tag{2}$$

where γ_1 is the probability of spontaneous emission for the measured line; and $n(\rho)$ is the density of excited states.

We can find $n(\rho)$ by using an analytical expression for Green's function of the diffusion equation for resonance radiation [2]. For our problem we may consider that the absorption coefficient profile $k(\nu)$ is Gaussian, and that the optical thickness of the layer at the line-center frequency ν_0 is quite large. In other words, the condition $\rho \gg k_0^{-1}$, where $k_0 = k(\nu_0)$ is valid, and, after certain manipulations, based on the formulas of [2], this gives

$$n(\rho) = \frac{Ag^2(\rho)}{\pi^2\rho^2\gamma_1}\int_0^\infty \frac{\xi^2}{1+\xi^2} K_0[\xi g(\rho)]\,d\xi,$$

where K_0 is the MacDonald function and $g(x) = (4k_0x\gamma_1/\gamma_0)(\ln k_0x/\pi)^{1/2}$.

Returning to Eq. (2), we find that

$$I(x) = \frac{Ag(x)}{4\pi^2 x}\int_0^\infty \frac{\xi}{1+\xi^2}\exp[-\xi g(x)]\,d\xi. \tag{3}$$

For $x \gg x_0$, where x_0 is determined from the condition $g(x_0) = 1$, we can simplify Eq. (3):

$$I(x) = A/4\pi^2 x g(x). \tag{4}$$

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Putting $\alpha = 0.8$, and taking into account that Eq. (4) is certainly applicable for $x > l/2$, from Eq. (1), we find that

$$l = \frac{40\pi v_0 g_0}{\gamma_1 \lambda_0^3 N g_1} \ln^{-1/2}(\gamma_0/\gamma_1). \tag{5}$$

Here we have used an explicit expression for the absorption coefficient at the center of the resonant (reabsorbed) line with wavelength λ_0, broadened due to the Doppler effect; $\nu_0 = (2kT/m)^{1/2}$; T is the gas temperature; N is the density of atoms in the ground state; and g_0, g_1 and γ_0 are the statistical weights and their probability of emission in a resonance transition.

We now introduce some estimates for the frequently used helium lines $\lambda_1 = 501.6$ nm (the $2^1S_0 - 3^1P_1$) transition frequently used for diagnostic purposes. Here $\gamma_1 = 1.34 \cdot 10^7$ sec^{-1} [3] and the upper term is linked with the parahelium ground state 1^1S_0 by a dipole-allowed transition: $\lambda_0 = 53.7$ nm; $\gamma_0 = 5.66 \cdot 10^8$ sec^{-1} [3].

First, from the data of [1] we may state that in an actual experiment it is practically impossible to create conditons where the gas layer at wavelength λ_0 will be optically thin and the intensity of the measured line will be sufficient for reliable recording. Thus, we must clearly allow for the radiation capture effect. If the density N is measured in cm^{-3}, then, for $\lambda_1 = 501.6$ nm at room temperature Eq. (5) gives

$$l = 1.45 \cdot 10^{15} N^{-1}. \tag{6}$$

If we are investigating the region at a shock wavefront (WF) in a mixture of two gases: light He and a heavy gas, e.g., Kr, Xe, or Ar, then we can estimate the geometrical resolution of the measurements from the condition

$$\eta = l/L \ll 1. \tag{7}$$

For a rarefied gas flow L means the Prandtl thickness of the WF [4], and $L \sim (N + N_1)^{-1}$, where N, as before, means the partial density of He, and N_1 is the partial density of the heavy component of the mixture. Then it follows from Eqs. (6) and (7) that $\eta \sim (1 + N_1/N)$, and we must therefore look carefully at the choice of the gas concentration in the mixture, since the measurement resolution may prove unacceptable for $N_1/N \gg 1$. In turn, this may have a strong bearing on the accuracy and reliability in generating the interatomic potentials, and on the correctness in checking the methods of solving the Boltzmann equation, etc., if the study of the WF structure was undertaken with these objectives. Here we do not exclude the possibility that, in [5], where the ratio N_1/N reached 15 (a mixture of Ar and He), the considerable discrepancies between experiment and theory [6] recorded may be explained by the above.

In conclusion, it is relevant to use the criteria of Eq. (5) obtained above relating to choice of lines to investigate certain transitions in the singlet and triplet parts of the He spectrum, for which the radiation capture effect cannot play an appreciable part, and the intensity of lines may be entirely acceptable for measurement:

$$2^1P_1 - 3^1D_2 \ \lambda = 667.8 \text{ nm}, \quad \gamma = 6.4 \cdot 10^7 \text{ sec}^{-1},$$
$$2^1P_1 - 4^1D_2 \ \lambda = 492.2 \text{ nm}, \quad \gamma = 2.0 \cdot 10^7 \text{ sec}^{-1},$$
$$2^3P_0 - 4^3S_0 \ \lambda = 471.3 \text{ nm}, \quad \gamma = 1.1 \cdot 10^7 \text{ sec}^{-1},$$
$$2^3P_{1,2,3} - 3^3D_{1,2,3} \ \lambda = 587.6 \text{ nm}, \quad \gamma = 7.0 \cdot 10^7 \text{ sec}^{-1}.$$

These lines lie in a part of the spectrum that is convenient for recording, and for some of them there are data on the excitation functions [1].

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UNIFORMITY OF A VOLUMETRIC DISCHARGE CONTROLLED BY AN ELECTRON BEAM IN A TRANSVERSE MAGNETIC FIELD

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The unique properties of electric-ionization CO_2 lasers, the possibility of the direct convesion of the energy of an electric field into coherent radiation with an efficiency of ~ 30%, and the high specific characteristics of the active medium open up broad prospects in the field of the creation of powerful installations with energies of 1-10 kJ per pulse [1-3]. The use of superpowerful CO_2 laser systems for the solution of a number of scientific and technical problems [4, 5] imposes rather strict limits on the quality of the optical characteristics of the beam of coherent radiation, determined primarily by the uniformity of the volumetric discharge. The investigation of the main physical processes responsible for the uniformity of the absorption of electrical energy in the volume of the discharge gap is urgent in this connection.

It was shown in [6, 7] that in volumetric discharges of high power excited by an electron beam it is necessary to allow for the influence of the intrinsic magnetic field of the current of the primary discharge on the distribution of ionization losses of the beam of fast electrons. Actually, the magnetic field produced by the current of a volumetric discharge, with allowance for its typical geometry $d \approx h \ll l$ (d is the distance between the electrodes, h is the width of the discharge, and l is its length), is described by the relation

$$H = \frac{4\pi}{c} \int_0^{h/2} j\,dh \simeq \frac{2\pi}{c} j_0 h,$$

where j_0 is the average current density of the volumetric discharge. Consequently, in the approximation $j_0 \simeq$ const over a cross section of the discharge H grows linearly from the center to the boundary of the discharge. For typical parameters of an electron beam of 0.2-0.5 MeV and a size $d \approx 10$ cm for the discharge gap a magnetic field of 0.5-1 kOe can assure the capture of electrons into Larmor orbits of $r_L < d$ regardless of ionizing collisions with neutral gas molecules. In this case the drift of the injected electrons must lead to constriction of the beam into the region of the minimum value of H.

The results of preliminary experiments on a study of the influence of a constant transverse mangetic field on the electrical characteristics and current distribution of a volumetric discharge are reported in the present article. The magnetic field configuration was chosen as close to the actual one produced by the current of the discharge.

A schematic diagram of the experimental installation is presented in Fig. 1. An electron beam with a current of up to 100 A, a maximum energy of 150 keV, a duration of 10^{-8} sec, and a cross section of 8 × 80 mm, produced by a special electron accelerator [8], was injected through titanium foil 12 μm thick into the discharge gap, formed by a high-voltage electrode 1 and a metal grid 2 with a transmittance of 0.6. The distance between the electrodes was regulated within limits of 3-7 cm. To measure the current distribution

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