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THE CONTINUUM RADIATION OF A MEDIUM PRESSURE NEON DISCHARGE

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Abstract
The continuum radiation of a medium pressure inert gasdischarge has been ascribed by some authors to be a molecular effect (ref.1) and by others to electron-atom Bremsstrahlung (refs.2,3). In the last few years most emphasis has been put on the latter hypothesis. Our experimental data on the continuum radiation of a 100 torr neon discharge (tube radius 3.2 cm) in the diffuse region (10-120 mA) do not entirely agree with the predictions from the present Bremsstrahlungs-theory. A decision between the two alternative hypotheses on the continuum radiation still remains difficult.

THEORETICAL DESCRIPTIONS FOR THE CONTINUUM RADIATION

Because of the observed proportionality between the continuum intensity and the discharge current (see refs.2,4) the electron-ion recombination and electron-ion Bremsstrahlungs effects can be dropped immediately. Contrary to the authors of ref.2 however , we think that the molecular radiation theory may explain the observed proportionality between continuum intensity and discharge current and pressure as well as the electron-atom Bremsstrahlungs-theory. We will discuss this below.

a) The molecular radiation model
The neon molecules are formed by three-body collisions of gas atoms with metastable $^3P_2(s_5)$ atoms. The molecules are destroyed by collisions with gas atoms and electrons. The balance equation for the molecules is thus given by:

$$\gamma N_g^2 N_m = z_m N_g M + z_e N_e M \qquad (1)$$

(N_g gas density , N_m metastable atom density , N_e electron density , M molecule density , γ three-body collision coefficient , z_x reaction coefficient for process x). Excited molecules are (because of the large energy gap) mainly formed by electron collisions. Thus:

$$M^* = z^* \tau N_e M \qquad (2)$$

(M^* excited molecule density , τ lifetime excited molecular state). The balance equation for the metastable atoms can (when we neglect coupling with other levels) be written as (ref.5):

$$z_a N_g N_e = N_m (z_{mi} N_e + \gamma N_g^2) \qquad (3)$$

From eqs. 1-3 we get for the molecular radiation intensity integrated over the spectrum:

$$I = \pi R^2 M^*/\tau = \pi R^2 z^* z_a \gamma N_g^3 N_e^2 / (z_m N_g + z_e N_e)(z_{mi} N_e + \gamma N_g^2) \qquad (4)$$

Where I is the continuum intensity and R the tube radius.
When we assume: $z_m N_g / z_e \ll N_e \ll \gamma N_g^2 / z_{mi}$

$$\text{Then } I = \pi R^2 z^* z_a N_g N_e / z_e \sim i p_o, \text{ because } N_e \sim i/R^2 \qquad (5)$$

Where i is the discharge current and p_o the filling pressure.

The authors of ref. 2 have taken $z_e N_e \gg z_m N_g$; this explains why they drop the molecular radiation hypothesis.

Thus if the metastable atoms are destroyed mainly by three-body collisions with gas atoms and the metastable molecules are destroyed mainly by electron collisions, then the molecular radiation intensity is proportional with discharge current and pressure. The molecular radiation model does not give quantitative predictions, and an expression for the wavelength dependence is not derivable because of the bad knowledge on the various coefficients. When z^* is taken equal to z_e and $z_a = 0.3\ 10^{-15}$ cm^3/s (see ref. 5) one obtains I = 500 erg/cm,s at 10 mA. If the radiation takes place constantly over a region of 5000 Å then I = 0.1 erg/cm,s,Å.

b) Electron-atom Bremsstrahlung

In ref.6 the Bremsstrahlungs cross-section has been calculated quantummechanically for slow electrons. In ref. 2 the spectral Bremsstrahlungs intensity has been calculated with the Druyvesteyn electron energy distribution function and a linearized form of the above mentioned Bremsstrahlungs cross-section. When this approximation (linearization) is not made, and the electron energy distribution function calculated from the Boltzmann equation (ref. 7) is used, the expression for the spectral Bremsstrahlungs intensity does not relevantly change. Therefore we use for the discussion of the Bremsstrahlungs hypothesis the formula given in ref. 2:

$$I(\lambda)d\lambda = 10^{-23} N_e N_g \pi R^2 U_e^{3/2} (1-\mathrm{erf}(6185/U_e \lambda))/\lambda^2. \qquad (6)$$

Where $U_e = kT_e/e$, with T_e the electron temperature, k the Boltzmann constant, e the electron charge. (Ue in Volt), λ the wavelength (Å), N_e and N_g in cm^{-3}, R in cm, $I(\lambda)$ in erg/cm,s,Å.

Some conclusions now can be drawn:
1. The intensity of the radiation is proportional to electron and gas density.
2. The order of magnitude of the intensity at 10 mA discharge current is about 0.1 erg/cm,s,Å in agreement with experiment (ref.2).
3. One can write $I(\lambda) \sim x^2(1-\mathrm{erf}\ x)$ with $x = 6185/U_e\lambda$. Let x_1 be the value of x for which dI/dx=0. From the position of the Bremsstrahlungs maximum the electron temperature can then be determined according to $U_e = 6185/x_1\lambda$.
4. Another method to determine the electron temperature from the Bremsstrahlungs radiation is given by Golubovskii et al. (ref.3). The ratio of the continuum intensity at two different wavelengths yields (according to eq.6) the electron temperature.
The Bremsstrahlungs theory yields much more quantitative predictions than the molecular theory. Therefore it is much easier to compare with experimental data. Both mechanisms are likely to occur in the discharge, with even the same order of magnitude, thus the measured radiation may be a combination of the two effects.

DISCUSSION OF SOME EXPERIMENTAL RESULTS

As we have seen , the measured continuum intensity (refs.2,4) may be explained by both theories (where rough estimations have to be made for the molecular theory). Thus it seems that from the measured absolute intensity and from the current and pressure dependence no conclusions can be drawn to decise between the two theories. Furthermore the argument given in ref.2, that the intensity of molecular radiation must fall rapidly when contaminations of other gases (e.g. Kr)are added, is not quantitatively founded. When Krypton is added,the total ionization frequency in the discharge must stay the same, so that an equal amount of Kr metastable atoms must be formed, as there were Ne metastable atoms in the undisturbed discharge (at least in order of magnitude). Therefore for KrNe molecules the same set of equations as eqs.1-5 can be set up, leading to a simular radiation as in the undisturbed discharge.

We measured the spectra of the continuum at different currents and various radial positions. In these experiments the optical set up was calibrated by means of a hydrogen U.V. and a tungsten band lamp. The radial profiles were submitted to an Abel procedure (ref.8).
The spectra appeared to be nearby constant (independent of wavelength) for currents between 10 and 120 mA, and for all radial positions. Therefore it was impossible to measure the electron temperature according to the two methods described in b3 and b4. According to Bremsstrahlungs theory the spectra can not be so independent of discharge conditions. (see eq. 6). This can be explained either by rejecting the expression for the Bremsstrahlungs cross-section given in ref.6 as being not adequate for the electron energies occurring in this discharge, or by rejecting Bremsstrahlung as being the only continuum mechanism.

CONCLUSION

Our experimental results concerning the spectral dependence of the continuum radiation are not in agreement with present Bremsstrahlungs theory. However the use of the Bremsstrahlungs cross-section expression given by Kas'yanov and Starostin (ref.6), which is only valid for slow electrons , may not be justified in our discharge conditions. The molecular radiation hypothesis has not yet been fully rejected, though it is incapable at the moment of yielding quantitative predictions. As both theories predict linearity between the radiation intensity and the electron and gas density, we are justified to measure relative electron densities (for example radial profiles and current dependence) by measuring the continuum intensity.

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