SPECTRAL CHARACTERISTICS OF AN ANNULAR ELECTRODELESS DISCHARGE

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Results are given for the 4844 Å spark line of Xe in long cylindrical tubes. The mean electron temperature is deduced for a discharge in He, and the effects of He on the intensity of the Ne line at 6328 Å are considered.

1. The first studies of annular electrodeless discharges were made in 1913, and results of such studies have appeared from time to time, the most notable being those of Thomson [2]. Important features are the excitation conditions [3] and the amplitude and phase characteristics of the field [4]. Of recent work we may note the theoretical study [5] of diffusion on the fields and electron distribution, and also an experimental study [6] on the skin effect at low pressures. The tubes are usually of large diameter (commonly D > 30 mm and length l ~ D), but practical interest occurs particularly for l >> D (as in lasers). Some tests are reported here for long tubes of various D, mainly the range of existence of the discharge as a function of Xe or Ne pressure P and the response to D and current i for certain lines of Xe II. The electron temperature in a discharge in He is also reported.

2. The measurements were made on a line free from reabsorption whose intensity I was governed mainly by electron impact; I as a function of i, p, and D was recorded.

Figure 1 shows the apparatus. The inductors L_1 and L_2 serve to monitor the discharge current provided by an IO-60 source (750 kHz), whose drive coil L_0 had an inductance of about 1.2µH. The tests were done with quartz tubes with D of 30 and 40 mm, and also glass tubes of D 12 and 17 mm; I was recorded with a DMR-4 monochromator working into an FEU-15.

3. Two aspects of the occurrence of a discharge were examined: the dependence of p and the dependence on D. The p dependence was recorded with D = 40 mm and l = 900 mm, while the D dependence was recorded with the set of tubes mentioned above.

Figure 2a shows I for the 4844 Å line of Xe II as a function of p, there being a peak at about 0.02 mm Hg, followed by a fairly constant level at lower pressures until 10^{-3} mm Hg is reached, where the annular discharge suddenly goes over to an ordinary HF discharge, with an accompanying drop in I. Further, the HF discharge also appears at about 0.1 mm Hg. The peak at 0.02 mm Hg represents the optimal conditions for an annular discharge, where the effects of field scanning [6] are also the greatest. Figure 2b shows the variation with radius for this line; there is a marked plateau, especially at about 0.02 mm Hg, which is related to skin effect. A minimum in I at the axis is expected, on account of screening, but diffusion is effective over such distances (~10 mm) and so produces a plateau rather than a sharp minimum, though the latter is present at 0.48 mm Hg (Fig. 2b). Above this the ordinary HF discharge tends to displace the annular one, and so it is difficult for a minimum to arise.

These results show that an annular discharge exists over the range 0.1 to 0.001 mm Hg, outside which we get an HF discharge. Under these conditions we have

\[ V_e \gg V_{\phi}, \]  

in which \( V_e \) is the longitudinal electric field while \( V_{\phi} \) is the azimuthal component of the electric field. We expect [7] to find that

\[ V_e/V_{\phi} = 2\pi na^2/b, \]  

in which \( n \) is the number of turns on the coil, whose radius is \( a \), with \( b \) the internal radius of the discharge tube.

\( V_e \sim V_{\phi} \) in the annular range, so \( V_{\phi} \) plays a major part in maintaining the discharge, which tends to shorten as \( p \) increases, usually tending to become localized near the grounded part of the coil or near nonuniformities in the tube. Shortening also occurs as D is reduced; for instance, the length \( L_p \sim 100 \) cm for \( D = 30 \) mm and \( p \sim 0.03 \) mm Hg, whereas \( L_p \sim 35 \) cm under the same conditions for \( D = 17 \) mm, and \( L_p = 15-17 \) cm for \( D = 12 \) mm.
Hence

\[ I_p \sim \frac{D}{p}, \quad (3) \]

with \( D \) in cm and \( p \) in mm Hg.

This shortening also occurs as \( i \) is reduced; in addition, the usual HF discharge then tends to be accentuated, as is implied by (1).

Fig. 2. Intensity \( I (\mu A) \) for the 4844 Å line of Xe II as a function of:

a) \( p (\text{mm Hg}) \) at \( i (\text{A}) \) of: 1) 4; 2) 7; 3) 12; b) radius (mm) at \( p (\text{mm Hg}) \) of: 1) 0.02; 2) 0.048.

4. The processes are largely governed by the electron temperature \( T_e \), about which our information is rather restricted. It has been shown [6] that \( T_e \) is inversely related to \( p \). The relation of \( T_e \) to \( i \) was recorded for a discharge in He, \( T_e \) being deduced from the ratio of the \( I \) for the 5048 Å \( (^4S_{\frac{3}{2}}-^2P_{\frac{1}{2}}) \) and 4713 Å \( (^4S_{\frac{3}{2}}-^2P_{\frac{3}{2}}) \) lines of He, since these \( I \) are governed by electron impact up to \( N_e \approx 10^{13} \text{ cm}^{-3} \) [5]. Figure 3 shows the ratio of the \( I \) as a function of \( i \), which implies that \( T_e \) does not exceed 4–5 eV and is inversely related to \( i \). The \( T_e \) for the positive column of a glow discharge under analogous conditions are somewhat higher than the present \( T_e \); the reason for this appears to be as follows. An axial magnetic field tends to suppress electron diffusion to the wall, but the average probability of collisions with atoms and ions is increased, which leaves the mean \( T_e \) nearly unaltered. The dependence of \( T_e \) on radius is very slight, except for a region \( \sim 2 \text{mm} \) wide near the wall, where \( T_e \) falls sharply.

Fig. 3. Relation of intensity ratio to discharge current \( I (\text{A}) \) at \( p = 0.08 \text{ mm Hg} \) of He.

I for 4844 Å of Xe II was recorded as a function of \( i \); the most marked dependence on \( i \) (nearly cubic) occurred at \( p \sim 0.02 \text{ mm Hg} \), the dependence at other \( p \) being nearer to quadratic. There is here no marked difference from the results for glow discharges.

5. Annular discharges in Ne and Ne + He are of interest, especially for the lines 6328 Å \( (3S_{\frac{1}{2}}-2P_{\frac{3}{2}}) \) and 6096 Å \( (2P_{\frac{1}{2}}-1S) \). The lowest \( p \) at which an annular discharge occurs in Ne is 0.005–0.006 mm Hg; the discharge gradually goes over to the HF type at \( p \sim 0.5 \text{ mm Hg} \). As for Xe at 0.0005 to 0.1 mm Hg, Ne shows a maximum \( I \), which occurs near 0.05 mm Hg.

The very marked effects of He on an annular discharge in Ne were examined (Fig. 4); the effects are very different from those for HF or glow discharges, where \( I \) (especially for Ne 6328 Å) is unaffected by the He content. This response to gas mixtures was found in other cases, primarily in relation to striking; for example, slight gas release from the tube greatly attenuated or even suppressed the emission from the annular discharge.