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GAS PRESSURE AND ELECTRON DENSITY AT THE LEVEL OF THE ACTIVE ZONE OF HOLLOW CATHODE ARC DISCHARGES

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A model for the longitudinal variations of the partial pressures of electrons, ions, and neutral particles is proposed as a result of an experimental study of pressure variations at the level of the active zone as a function of the various discharge parameters of a hollow cathode arc. The cathode region where the temperature passes through its maximum is called 'active zone'. The proposed model embodies the very important variations which the partial electron and neutral particles pressures undergo at the level of the active zone.

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Translation

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PLASMA PHYSICS.—Gas pressure and electron density at the level of the active zone of hollow cathode arc discharges.

(*)By M. Habiboilah Minoo, presented by M. Alfred Kastler.

After an experimental study of the variation of pressure \( P \) at the level of the active zone (Z.A.) as a function of different discharge parameters, we are led to propose a model for the longitudinal variations of the partial pressures of electrons \( P_e \), ions \( P^+ \), and neutral particles \( P^0 \). According to this model, \( P_e \) and \( P^+ \) undergo very important variations at the level of the Z.A. Simple calculations show that, in this zone: \( P \approx P^+ \) and \( 0.5 < n_e < 3.5 \times 10^{15}/\text{cm}^3 \), where \( n_e \) is the electron density.

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Fig. 1.—Variation of $P_L$ as a function of $Q$ and $I$.

$P_L$ = gas pressure upstream of the Z.A. on the abscissa $L$ (cf. Fig. 4B); $Q$: volume flow of argon injected by the cathode (TPN); $I$: discharge current; $D$: interior diameter of the cathode.

Fig. 2.—Variations of $\Delta P$ as a function of $Q$ and $D$.

$\Delta P = P_1 - P_1'$: difference in pressure between the total pressure ($P_1$) and the neutral particle pressure ($P_1'$) at the level of the Z.A.
Fig. 3.—Variations in $\Delta P$ and $n_e$ as a function of $J$ and $Q$.
$J$: longitudinal current density in the cathode; $Q$: argon flux injected by the cathode ($\text{cm}^3/\text{cm}^2.s$; TPN); $n_e$: electron density obtained from relation (3).

1. INTRODUCTION.—Under normal operating conditions of hollow cathode arc discharge (1), the cathode tube (of tantalum, in our experiment) is heated to incandescent temperature by the discharge current ($I$). The region of the cathode where the temperature passes through a maximum is called the "active zone" (Z.A.) (cf. Fig. 4). The recent measurements of the fall of pressure in the cathode tube [(2), (3)] show that this loss of charge increases rapidly when one increases $I$. In this work we have studied this phenomenon for different values of the argon flow ($Q$) introduced by the cathode and the interior diameter of the cathode ($D$). We have attributed this increased pressure fall principally to that of the partial pressure of electrons at the level of the Z.A.
2. EXPERIMENTAL RESULTS.--An example of the variations of gas pressure upstream of the Z.A. as a function of $Q$ and $I$ is given in Figure 1. In this figure, $P_L(I)$ and $P_L(0)$ are the gas pressures at the entrance of the cathode (the abscissa $L$, Fig. 4b) where $I = 0$ and $I = 0$ respectively. Figure 2 shows the variations of $\Delta P = P_L(I) - P_L(0)$ as a function of $Q$ and $D$. From a series of curves similar to those presented in figures 1 and 2 we have determined the variations of $\Delta P$ as a function of the longitudinal current density in the cathode ($J$). The results are presented in Figure 3. In this figure, $\Phi = 4Q/\pi D^2$ and $J = 4I/\pi D^2$.

3. DISCUSSION.--From the results presented in Figure 1, one can show that the establishment of the discharge current is accompanied by an important increase of the pressure in the cathode. If we call $P_L$ the total pressure and $P'_L$ the neutral particle pressure at the level of the Z.A., we can show that (8):

$$\Delta P = P_L(I) - P_L(0) = P_I - P'_L.$$

This pressure increase ($\Delta P$) can be explained:

--either by a diffusion equilibrium such that the sum of the partial pressures of electrons, ions, and neutral particles is almost constant along the cathode tube. [There is a weak
decrease in pressure along the tube from the fact that there is an outflow of the gas \( Q \) in the tube and that the region of outflow is laminar and viscous \( \text{(3)} \); --or by more complex phenomena of ionic pumping.

After a rapid evaluation of the orders of magnitude, we were led to consider the first explanation. In this case, for the total pressure at the level of the Z.A. \( (P'_1) \) we can write

\[
P'_1 = K(n_e T_e + n_i T_i + n_e T_e) - P'_i = P'_i + P'_f,
\]

where \( n_e, n_i, n_e \) are the densities of the neutral particles, ions, and electrons; \( T_e, T_i, T_e \), their temperatures; and \( P'_i, P'_f \), their partial pressures, respectively. Outside of the sheath, or where \( n_e \approx n_i \), equation (2) becomes

\[
\Delta P' = P'_i - P'_i = K n_e (T_e + T_i).
\]

We have demonstrated that at the level of the Z.A. \( (3) \), \( T_e = 12 \text{ eV}, T_i = 0.2 \text{ eV} \), and thus relation (3) is reduced to

\[
n_e = 6.83 \times 10^{13} \cdot \Delta P' \quad (n_e \text{ en cm}^{-3} \text{ et } \Delta P' \text{ en torrs}).
\]

We make here the fundamental hypothesis that \( P_i = P'_i \) and \( \Delta P = \Delta P' \), which allows us to evaluate \( n_e \) from \( \Delta P \).
The results are given in Figure 3 with an experimental point by Lubin and Rose (4). One concludes therefore that the values of \( n \), so determined are not too large.

Also, in evaluating \( P'_1 \) and \( P'_1 \) from the results of Figure 3 and with \( T_i = 0.2 \text{ eV} \), \( T_r = 12 \text{ eV} \), we can establish that \( P'_1 \ll P'_1 \). On the other hand, according to the results of Figure 1 for \( P_L(0) \) and the fact that \( 1 \ll L \), we can see that \( P'_1 \) is also very weak and negligible compared to \( P_r \). Consequently, we can conclude that at the level of the Z.A. the increase in \( P'_1 \) is mainly related to that of \( P'_1 \).

This suggests to us a longitudinal variation of the pressure \((P)\) in the vicinity of the Z.A. such as that presented in Figure 4.
Figure 4. (A) Longitudinal variations of $T$, $P$, $P^e$, $P^i$ and $P'$ in the region of the Z.A. ($I = 15\, \text{A}, D = 2.6\, \text{mm}, Q = 1.5\, \text{cm}^3/\text{s}$; TPN.

$T$ = temperature of the exterior surface of the cathode tube ($T_M = 2150^\circ\text{C}$); $P$: total pressure; $P^e$, $P^i$: partial pressures of neutral particles, electrons and ions, respectively.

At the level of the Z.A. (abscissa $1$): $\Delta P = P - P^e = 17$ Torr ($\approx P$); $P^e = 16.7\, \text{Torr}$; $P^i = 0.3\, \text{Torr}$ ($\approx P'$); $T_0 = 12\, \text{eV}$; $T_e \approx T_i = 0.2\, \text{eV}$, $n_e = n_i = 10^{15}/\text{cm}^3$.

Upstream and near the Z.A.: $P = P^e, n_e = 8 \times 10^{18}/\text{cm}^3$ (where $T_e = 0.17\, \text{eV}$).

(B) Simplified diagram of the cathode region.


Fig. 4.

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