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Abstract

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PROCESSES AT "COLD" CATHODES OF AN ARC DISCHARGE

One of the principal difficulties in the theory of the arc discharge is the explanation of the processes at "cold" cathodes, whose material boils at temperatures insufficient for appreciable thermionic emission (mercury, aluminum, copper, iron, etc.). The nature of the current at the cathode is unclear: for a thermionic mechanism of the current the cathode temperature is insufficient; for an electrostatic mechanism, the field strength at its surface is insufficient ([1]). The hypothesis of Slepian ([2]) of a purely ionic current to the cathode did not remove the difficulties either, since it could not indicate the source of the energy expended on ionization of the gas in the cathode region. Robson's latest hypothesis ([3]) on the possibility of extracting electrons from the cathode by excited atoms requires the assumption of a back pressure, under whose action the neutral gas would move continuously toward the cathode. Experiment, however, reveals motion of the gas away from the cathode.

We propose applying Einstein' s theory of induced radiation of atoms ([4]) to the cathode region of the arc, which gives more satisfactory results, better agreeing with experiment.

According to existing ideas ([5]), ions moving toward the cathode recombine with electrons at a distance of the order of 10^{-7} cm from its surface. The electrons penetrate into the ion region from the metal by tunneling through the potential barrier distorted by them. As a result, excited atoms are formed, moving toward the cathode with the velocity of the ions $v_j \cong 10^5$ cm/sec. Since the time of motion $t \cong 10^{-12}$ sec, the transition of such atoms to the normal state by spontaneous emission of one or several photons, whose probability is $A_c = 10^9$ sec^{-1}, was previously considered impossible.

However, at the current densities observed at arc cathodes, $j = (1 \div 5)\, 10^3$ A/cm^2, induced radiation is possible here. According to Einstein ([4]) its probability is

$$A_i = B\rho, \tag{1}$$

where $B = \frac{8\pi^3}{3h^2}|\mu|^2$ is a coefficient determined by Planck' s constant h and the transition matrix element μ; ρ is the density of electromagnetic energy.

For electronic transitions, when $\mu \gg 10^2\mu_0$ (μ_0 is the Bohr magneton),

$$B \gg 1.6 \cdot 10^{18} \text{ cm}^3/\text{erg} \cdot \text{sec}^2.$$

At ordinary excitation levels of atoms, $W_a = 3 \div 6$ eV and $j_k = 2 \cdot 10^3$ A/cm^2,

$$\rho = \frac{j_k W_a}{ec} = 2 \div 4 \text{ erg} \cdot \text{sec/cm}^3. \tag{2}$$

Here e is the electron charge, c is the speed of light in vacuum.

If the energy ρ is distributed over $10 \div 20$ frequencies, then each of them receives on average $\rho_1 = 0.2$ erg • sec/cm^3. In this case, from (1) one obtains $A_i = 3.2 \cdot 10^{17}$ sec^{-1}. Consequently, during the time of motion of the excited

atoms to the cathode, $t = 10^{-12}$ sec, almost all of them pass into the normal state by means of induced emission of photons.

With respect to neutral atoms of the same chemical nature as the excited ones, these photons are resonant. The optical cross section of atoms with respect to them, equal approximately to the square of the wavelength, for $W_a = 3 \div 6$ eV is $q_s \geq 10^{-9}$ cm^2. The mean free path of photons $\lambda = 1/q_s n$ at atmospheric pressure and $T = 3000°$K, when the concentration $n \simeq 10^{18}$ cm^{-3}, does not exceed $\lambda = 10^{-9}$ cm. Consequently, the induced radiation arising in the cathode region is absorbed here by the neutral gas, causing its excitation and ionization. As a result a new generation of ions and electrons is formed, carrying current to the cathode and into the column.

Let us consider the energy balance of this process.

The most probable recombination events are those [5] for which the condition is satisfied

$$eW_m - k = W_j - W_a, \tag{3}$$

where W_m is the height of the potential barrier at the metal surface; W_j is the potential energy of the ion; k is the energy of the electron in the metal.

The recombining ion transfers to neutral atoms, in the form of photons, the energy $W_a = W_j - eW_m + k$. Simultaneously with the ion, a free electron was also formed in due course, which, while traversing some average fraction $\bar{\varepsilon}$ of the cathode potential drop U_k, transfers to neutral atoms the energy $eU_k\bar{\varepsilon}$. For the formation of a new pair ion + electron, the energy W_j is necessary; therefore the total energy balance takes the form

$$W_j = eU_k\bar{\varepsilon} + W_j - eW_m + k. \tag{4}$$

Even if the cathode temperature is $T = 0°\mathrm{K}$, then $k = \zeta$, $eW_m - k = \varphi$, and from (4) one obtains $U_k = \varphi/e\bar{\varepsilon}$. Assuming an equal probability of ion formation throughout the entire thickness of the cathode region, it can be shown that $\bar{\varepsilon} = 0.5$. In this case the energy conditions for continuity of the ion current to the cathode are fulfilled at

$$U_k \geq 2\varphi/e, \tag{5}$$

where φ is the work function.

In all arcs with a "cold" cathode this condition is satisfied. An increase in the cathode temperature lowers U_k.

On the basis of the ideas presented, many features of the behavior of the cathode spot can be explained, including its "reverse" motion in a transverse magnetic field, rapid wandering over the cathode surface, fixation at solid protrusions, etc.

It is not difficult to see that for the occurrence of induced radiation and the formation of arc processes at "cold" cathodes, a certain initial ion current is necessary. Experiment shows that an arc on a steel cathode arises only when the ion current is not less than 4 A.

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CITED LITERATURE

1. S. S. Mackeown, *Phys. Rev.*, **34**, 611 (1929).
2. I. Slepian, *Phys. Rev.*, **27**, 407 (1926).
3. A. E. Robson, *Radio Engineering and Electronics*, **4**, 8, 1295 (1959).
4. A. Einstein, *Zs. Phys.*, **18**, 121 (1917).
5. V. L. Granovskii, *Electric Current in Gas*, 1952.

Note: Figure translations are in progress. See original paper for figures.