Studies of electric breakdown in a high vacuum involving liquid-metal (mercury and gallium) cathodes, whose surfaces are stabilized by centrifugal forces, have shown that an increase in the angular velocity at which the experimental apparatus rotates causes an increase in the breakdown field; the mechanism for the vacuum breakdown is found to be independent of the voltage across the electrodes. According to the Frenkel theory, vacuum breakdown results from a disruption of the steady state on the liquid-cathode surface in an electric field. Drops of liquid metal on the anode degrade the dielectric properties of the vacuum gap. Under these conditions, the breakdown mechanism becomes dependent on the voltage across the electrodes. Oxide films on the cathode surface also degrade the dielectric properties of the vacuum gap. It is suggested that the dielectric may be charged by positive ions emitted from the cathode.

INTRODUCTION

It has been established that vacuum breakdown develops in the vapor of the electrode materials as a result of a succession of elementary erosion acts [1-3]. However, the mechanism for the local heating of an electrode to such high temperatures and its subsequent evaporation has not been clearly established. The results of the many studies of this subject [4, 5] can be divided into three basic groups: 1) results indicating that the evaporation of the cathode material results from Joule superheating of cathode defects, at which the electric field reaches maximum values, and from field-emission currents, while the evaporation of the anode material may be due to bombardment by a highly collimated electron beam from cathode nonuniformities; 2) results which indicate that the breakdown is caused by the transfer of macroscopic charged particles from the electrode surface in high electric fields; 3) results consistent with the assumption that an electron emitted from the cathode forms A positive ions and C photons when it collides at the anode. If a positive ion forms B secondary electrons, while each photon forms D secondary electrons at the cathode, a discharge will develop when AB + CD ≥ 1.

Studies of electric breakdown of short vacuum gaps (up to 1 mm) have shown that the probability for the latter two mechanisms is slight, the vacuum breakdown being governed primarily by the field intensity at the cathode surface. The microstructure of the cathode and the uncertainty regarding the nature of the defects produced at the cathode during its mechanical treatment complicate the study of physical phenomenon occurring during vacuum breakdown. It has been shown [5] that the microscopic electric field at cathode defects may exceed the macroscopic field between the electrodes by a factor of 10-400, depending on the cathode state; the macroscopic field in the case of plane electrodes is taken to be V/d, where V is the voltage across the electrodes and d is their separation.

Use of liquid metals as cathodes makes possible experiments with ideally smooth cathodes. According to the theory derived by Frenkel [6], however, a liquid metal is perturbed in an electric field, and hydrodynamic capillary waves propagate over its surface. The critical field intensity $E_0$ above which the liquid metal is perturbed is...
where \( \alpha \) is the surface tension of the liquid metal, \( \rho \) is the metal density, and \( g \) is the acceleration collinear with the electric field lines. By imparting a radial acceleration \( \omega^2 R \) to the liquid metal, where \( \omega \) is the angular velocity at which the experimental apparatus is rotating and \( R \) is the distance from the rotation axis to the surface of the liquid cathode, one can stabilize the surface of the liquid metal.

When the critical electric field intensity on the liquid-metal surface is exceeded, a protuberance forms whose maximum height is

\[
h = \frac{10.8 \pi \alpha}{E^2},
\]

The time required for the protuberance to reach its maximum height is

\[
\tau = \frac{45 \pi \rho^2}{E^2} \left( 3.25 \log \frac{\alpha}{E^2 h_0} + 2.7 \right).
\]

We report in this paper a study of the mechanism for vacuum breakdown by means of liquid-metal cathodes whose surfaces were provided additional stabilization by radial acceleration. It is assumed that the electric field does not build up at points on the surface.

EXPERIMENTAL

High-vacuum electric breakdown was studied in a metal apparatus \( 2.5 \cdot 10^{-3} \, \text{m}^3 \) in volume which was evacuated by an oil vapor diffusion pump; there were cold traps for the oil vapor. The steady-state residual gas pressure in the apparatus, before its filling with the liquid metal, was no greater than \( 10^{-6} \, \text{torr} \). The resistance in the discharge circuit was \( 16 \, \text{k}\Omega \), and the shunting capacitance was \( 0.01 \, \mu\text{F} \). The experimental apparatus was rotated at an angular velocity continuously adjustable over the range \( 0-250 \, \text{sec}^{-1} \), corresponding to radial accelerations of up to \( 700 \, \text{g} \), where \( g = 9.8 \, \text{m/sec}^2 \).

Figure 1 shows a cross section of the experimental apparatus, which consists of a cylindrical metal housing \( 1, \, 21 \) cm in diameter, with a depression \( 2 \) which is partially filled with the liquid metal when the apparatus is rotated. When mercury is used, a cooling jacket \( 3 \) is used to cool the mercury to \(-25 \) to \(-30^\circ \text{C} \), corresponding to a mercury vapor pressure of \( (5-8) \cdot 10^{-6} \, \text{torr} \); for operation with gallium, a heater \( 4 \) is used. The cathode temperature was continuously recorded by a temperature-sensitive element. The anode \( 5 \), mounted on an oilless bearing \( 6 \), could be rotated synchronously with the experimental apparatus or held at rest with respect to the rotating cathode. The filaments \( 7 \) heated the anode to \( 150^\circ \text{C} \).