Supersonic Wind at Low Pressures Produced by Arc in Magnetic Field

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THE properties of a low pressure discharge are greatly modified by the presence of a transverse magnetic field of several thousand gauss. The over-all behavior, here described, is believed to be unique to values of gas concentration for which the mean free time of the electrons is much greater than their cyclotron periodicity, and the mean free time of the ions much less than their cyclotron periodicity. The experiments were performed inside a large vacuum chamber having a volume of approximately one cubic meter. When the arc is in a large unconfined region, wind effects are observed which are not present when the discharge is in a small glass tube.

Figure 1 illustrates the general appearance of an arc at 0.5 millimeter pressure, transverse to a magnetic field of 6000 gauss. The voltage gradient is approximately 100 volts/cm, and the power input and the current density are many times larger than when the magnetic field is not present. The arc column, in air or nitrogen, is pale blue and quite transparent. Although the power dissipated in the positive column of the arc is more than one-half kw/cm of arc length, the gas temperature is surprisingly low because of the cooling effect of the wind. This temperature is greatly dependent on the manner in which the wind is circulating inside the chamber, and to what extent it is cooled during the recirculating process. Observations based on the melting point of chemical salts indicate that in most cases the arc temperature is less than 600 degrees centigrade.

When the air flow is blocked by placing a ceramic sheet on the "downwind" side of the discharge, the arc flattens out against the sheet and forms a white hot surface layer. If the sheet is placed on the "upwind" side of the arc, so as to block the air from entering the region, the arc then spreads out in all directions. Under such conditions, manometer pressure measurements show that the discharge is acting like an air pump. The air pressure on the side of the ceramic sheet which is adjacent to the arc is about 20 percent of the pressure on the opposite side of the sheet.

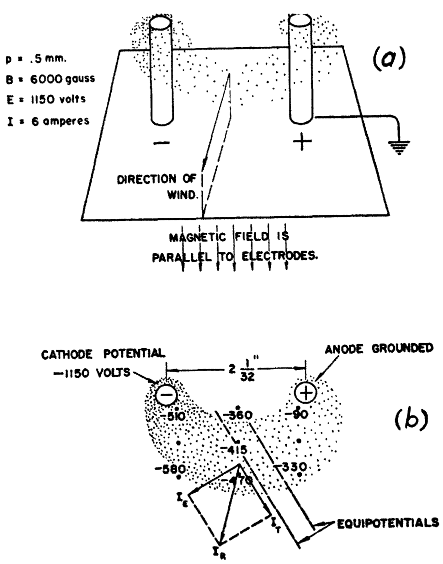


FIG. 1. (a) Arc between two copper rods. (b) Section of arc taken perpendicular to electrodes and probe measurements of potentials with respect to anode. I_E = component of ion drift velocity in direction of electric field. I_T = component of ion drift velocity transverse to electric field. I_R = resultant velocity in direction of wind.

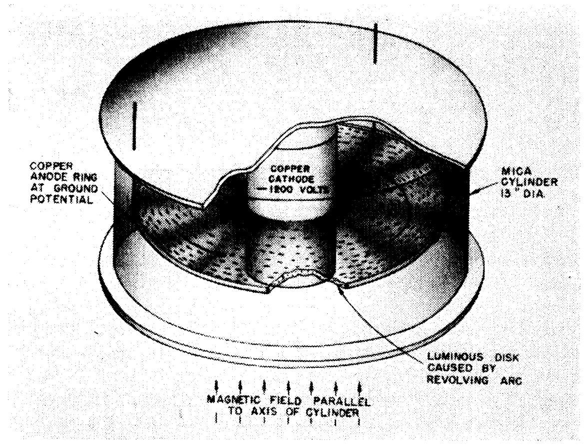
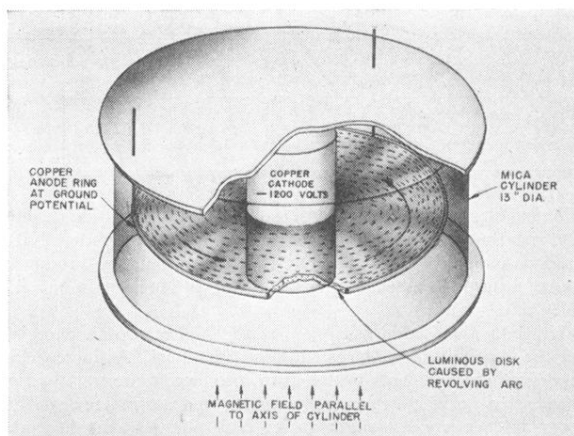


FIG. 2. Revolving arc inside a transparent mica cylinder.

A significant factor in this type of discharge is the low mobility of the electrons. It is believed that during each mean free path any electron makes many rotations about the magnetic flux lines and that its drift movement is almost entirely at right angles to the electric gradient. In contrast, an ion apparently does not follow a rotational or cycloidal path, because a collision will always occur before a fraction of one rotation is completed. As a result the ion mobility is not greatly reduced by the magnetic field. Available information as to the ion mobility to be expected under these conditions indicates that an assumption of nearly 100 percent ion conduction is quite consistent with the observed values of current density and electric gradient. For the conditions in Fig. 1, calculations predict that the component of the ion drift velocity, transverse to the electric gradient, has approximately the same magnitude as the component in the direction of the gradient. Because of the skewed position of the equipotentials, Fig. 1(b), the resultant ion current is believed to be perpendicular to the plasma boundary and in the same direction as the wind. This wind is presumably caused by the ion drift movement and the resultant interchange of momentum with neutral molecules. Since a substantial part of the energy which the ions receive from the field is utilized in producing directed momentum of gas molecules, this device appears to be a fairly efficient wind generator.

The electrons which are formed by the ionization processes throughout the discharge also move to the downwind edge of the plasma where they recombine with the ions. This electron drift is probably nearly parallel to the equipotential lines. A more detailed study of these experiments, now in progress, promises to provide a satisfactory explanation for the skewed position of these equipotentials.

Figure 2 is a sketch of an arc between a copper cylinder and a surrounding ring. An axial magnetic field causes this arc to revolve like a spoke in a wheel. The rate of rotation can be measured by means of a plasma probe connected to an oxcilloscope. When the air pressure and other variables are similar to those shown in Fig. 1, the rate of rotation is about 17,000 r.p.s. The air inside the cylinder also revolves, but its velocity is less than that of the arc. Measurement of the wind velocity is difficult because the air density is too low for the usual techniques. One method of measurement involved the sudden injection into the cylinder of a chemical vapor which colored the discharge. Stroboscopic observations of this experiment indicated that the color, caused by this vapor, spread downstream at a rate of at least 4500 miles/hr. Another experiment involved the measurement of the force on a small tungsten vane which was deflected by the air stream. On the basis of this latter data, the air speed was estimated to be approximately 3000 miles/hr.



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