The Characteristics of a Low Voltage Arc in a Magnetic Field

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For many disintegration experiments, as well as for other investigations, it is advantageous and often essential to have available an intense positive ion beam. During the last few years, the low voltage arc type of ion source has come into general use, for example, the arc sources of Tuve and Hafstad[1] and Zinn.[2] Livingston[3] recently adopted a modified Tuve and Hafstad arc source for use in the cyclotron. Following the work of Livingston, an arc of essentially the same type as that which is to be described was installed in the Purdue cyclotron. In order to investigate the properties of the arc, an experimental arrangement was constructed. The important feature of this arrangement is the use of a magnetic field to concentrate the discharge into a capillary.

The essential features of the experimental arc are shown in Fig. 1.

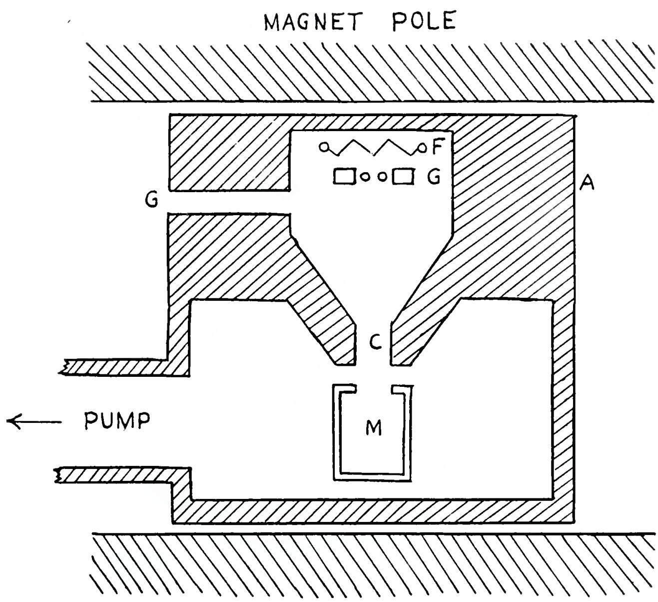

Fig. 1. Sectional drawing of the low voltage arc.

[1]Tuve, M. A., O. Dahl, and L. R. Hafstad, 1935. The production and focussing of intense positive beams. Phys. Rev. 48:241.

[2]Zinn, W. H., 1937. Low voltage positive ion source. Phys. Rev. 52:655.

[3]Livingston, M. S., M. G. Holloway, and C. P. Baker, 1939. Rev. Sci. Inst. 10:63-37.

A is a brass housing which serves as an anode for the discharge. The grid G, which consists of two 20 mil tungsten wires, parallel to each other and soldered across a rectangular hole cut in a copper disk, was inserted in order to determine whether it would have any effect on the characteristics of the discharge. The canal C is threaded so that capillaries, ranging in diameter from 20 mils to 200 mils, can be used. Hydrogen gas is admitted into the arc region through the inlet G, the flow of gas being controlled by a needle valve. Filament leads, grid, Faraday cage, and brass housing are all water-cooled. The magnet used gives field strengths up to 2500 gauss over an air gap of 3½ inches. The filament is heated by two 6-volt storage batteries connected in parallel. The arc voltage is obtained from a 220 volt D.C. line; the voltage for the Faraday cage is supplied by a rectifier unit. The pumping system consists of a Cenco megavac forepump and a modified Hickman oil diffusion pump, having a pumping speed of about 20 liters of air per second at a pressure of 10^{-4} mm. Hg. The discharge is struck between the filament F and the brass housing. The Faraday cage M is used to measure the strength of the ion current which issues from the capillary due to the action of the magnetic field.

Oxide coated and tungsten filaments have been used in this type of arc. The oxide coated filaments were made from platinum gauze having 70 wires per inch, the diameter of each wire being 0.003 inches, and were coated with a suspension of barium-strontium carbonates. The filament consisted of four layers of the gauze, a short length of 20 mil tungsten wire being spot-welded to each end perpendicular to its length to serve as a lead. The tungsten filaments were made of 20 mil wire in the form of a cone, with the apex of the cone directed towards the capillary.

The principal disadvantage of the oxide coated filament lies in the fact that the coating is removed in a relatively short period of time. The life of the coating was found to decrease with increased magnetic field strength, arc drop, and arc current. This can be explained by the fact that the positive ions in the arc region are accelerated towards the filament by the electric field and follow spiral paths due to the effect of the magnetic field. The destruction of the coating is believed to be due to bombardment of the filament by these positive ions. With an arc current of 1 ampere, a pressure in the arc region of about 3×10^{-2} mm.Hg., and a magnetic field strength of 2000 gauss, the average life of a coating was about 20 hours. A tungsten filament can only be destroyed by actually raising its temperature beyond the melting point. Since the filament must be maintained at a temperature near its melting point for large electron emission, any slight change in filament current or arc current is likely to melt it. Also, at high values of magnetic field strength the force exerted by the magnetic field on the turns of the filament tends to short circuit them. In general, a tungsten filament will give longer service than an oxide coated platinum filament, but more precautions are necessary in its use.

In the case of an oxide coated filament, the volt-ampere characteristic of the discharge (see Fig. 2) indicates operation far from saturation and, therefore, the presence of a double sheath in front of the filament.

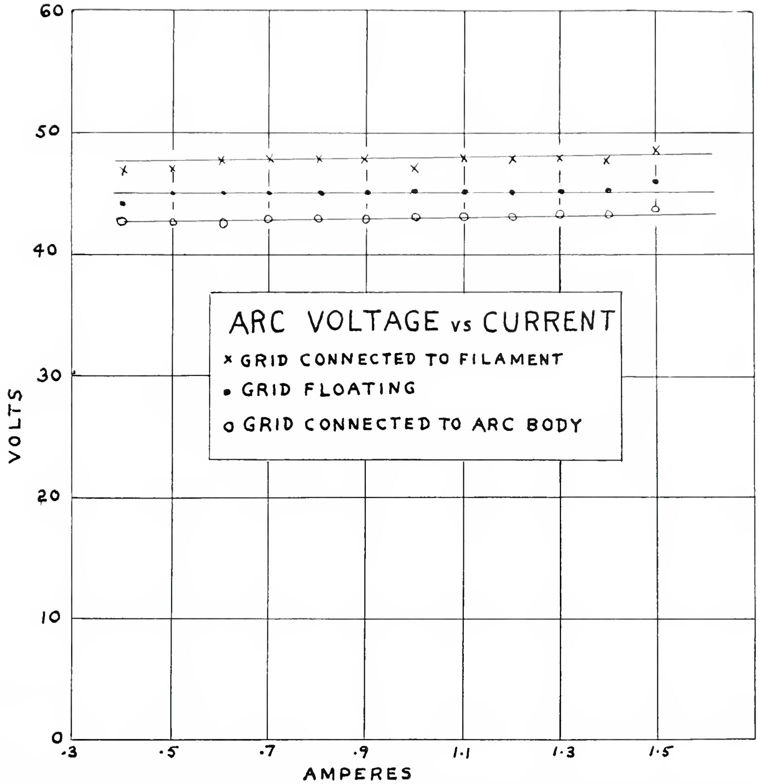

Fig. 2. Volt-ampere characteristics of the arc taken with an oxide coated filament at a pressure of 2.9 x 10^{-2} mm.Hg and a magnetic field strength of 1000 gauss.

It is to be observed that the manner in which the grid is connected has little effect on the characteristic. This can be expected if the grid behaves as a probe in the plasma of the arc. If a double sheath exists in front of the filament, it is to be expected that a change in magnetic field strength will not affect the characteristic of the discharge. The experimental results show that the arc drop is independent of the magnetic field strength.

The volt-ampere characteristic for the discharge with a tungsten filament is shown in Figure 3. The falling part of the curve shows that the filament is supplying a sufficient number of electrons to maintain a double sheath. The rising portion of the curve suggests that the filament is now unable to satisfy the demand for electrons and, therefore, the arc voltage must increase. This portion of the characteristic corresponds to operation of the filament at saturation. Since a double sheath does not exist in this case, a change in magnetic field strength should affect the characteristic. It was found that an increase in magnetic field resulted in a decrease in the arc drop, which follows directly from the idea of positive ion bombardment.

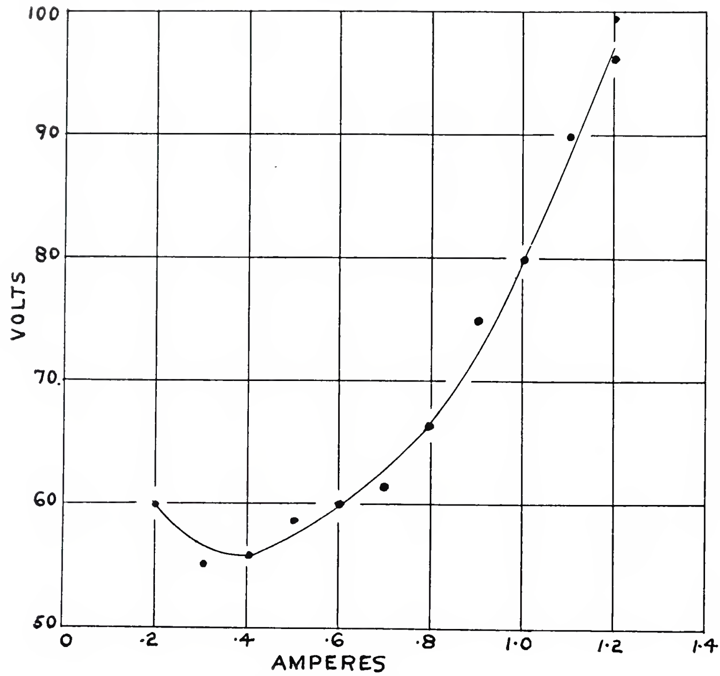

Fig. 3. Volt-ampere characteristic of the arc with tungsten filament at a pressure of 3 x 10^{-2} mm.Hg and a magnetic field strength of 1000 gauss.

It is believed that the ions collected by the Faraday cage are formed in the capillary itself since the potential gradient in the arc region will prevent ions from leaving that region and entering the capillary. The number of ions formed in the capillary should depend on the number of electrons entering it, and this in turn will depend on the cross-section of the capillary, on the value of the magnetic field strength, and on the value of the arc current. It was found that the ion current collected by the Faraday cage definitely increased with the size of capillary and strength of magnetic field. In making these measurements, a negative potential with respect to the filament was applied to the cage in order to prevent electrons from reaching it. Fig. 4 shows the relationship between cage current and arc current for the case of an oxide coated filament. Similar curves were obtained when tungsten filaments were used. The curves for the oxide coated filament show that the Faraday cage current increases almost linearly with the arc current. The manner in which the grid is connected has little effect on the curves obtained.

In order to obtain some idea of the number of secondary electrons being produced by positive ion bombardment of the Faraday cage, curves of cage voltage against cage current were plotted. Some typical curves are shown in Fig. 5. The shape of the curve was found to be practically independent of all variables except the arc drop. The steeply rising part of each curve corresponds to the case where electrons are able to reach the cage. The curve flattens out at about 100 volts on the cage, indicating that electrons having energies up to this value are reaching the cage. This voltage corresponds very closely to the arc drop. The portion of the curve for voltages above this value has a slight slope which is believed to be due to the production of secondary electrons by positive ion bombardment of the cage. The proportion of secondary electrons in the Faraday cage current was obtained by measurement of the slope of the curve, and the results agree fairly well with those of Healea and Chaffee.[4]

In order to obtain large ion currents then, one requires a large magnetic field strength, a large capillary, and a large arc current. The

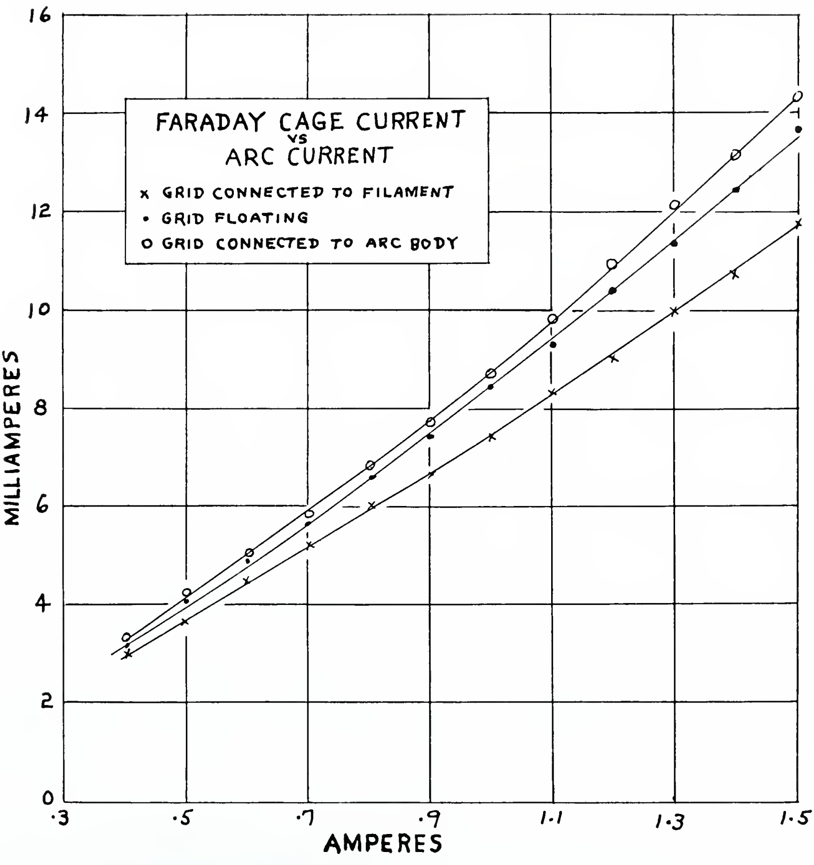

Fig. 4. Dependence of Faraday cage current on arc current for the case of an oxide coated filament. Pressure in the arc region = 2.6 x 10^{-2} mm.Hg. Magnetic field strength = 1000 gauss. Arc current = 1.5 amperes.

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[4]Healea, M., and E. L. Chaffee, 1936. Secondary electron emission from a hot nickel target due to bombardment by hydrogen ions. Phys. Rev. 49:925-930.

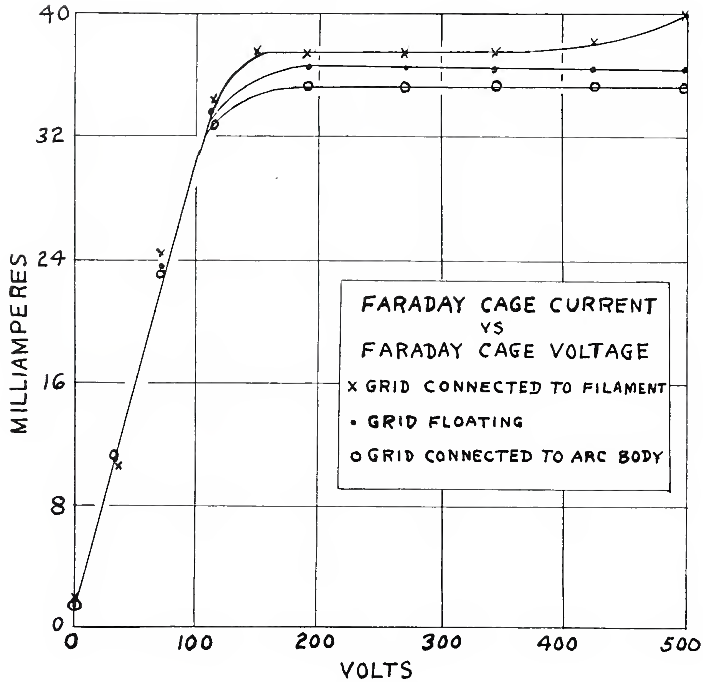

Fig. 5. Dependence of Faraday cage current on Faraday cage voltage for the case of an oxide coated filament. Pressure in the arc region = 2.9 x 10^{-2} mm.Hg. Magnetic field strength = 1000 gauss.

values of these quantities must be chosen to give a reasonable filament life and at the same time satisfy the pressure requirements outside the arc region and give a reasonable rate of gas consumption. With an oxide coated filament, it is quite feasible to use an arc current of 1 ampere, a pressure in the arc region of 3×10^{-2} mm.Hg., a magnetic field strength of 2000 gauss, and a capillary of 200 mils diameter in order to obtain a Faraday cage current of about 25 milliamperes with a reasonable filament life. With a tungsten filament, currents as high as 50 milliamperes have been obtained.

In the near future, this arc will be used as an ion source for the D-D reaction. Following this, an attempt will be made to take the beam out of the magnetic field and analyze it by means of a magnetic spectrograph.

Acknowledgment

It is indeed a pleasure to record our indebtedness to Professor W. J. Henderson, who suggested the problem and gave much valuable assistance.