Low Voltage Positive Ion Source

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(Received July 19, 1937)

A positive ion source of the low voltage constricted arc type, which yields intense positive ion beams with small gas pumping, is described. Ion currents up to 4.3 milliamperes have been obtained using a probe canal 6 mm long and 1 mm in diameter. Magnetic analysis, when the arc was operated in hydrogen, showed a maximum of 15 to 20 percent protons.

INTRODUCTION

DURING the past few years a number of positive ion sources of the low voltage arc type for use with high voltage equipment in nuclear research have been described.[1-4] Of these, the capillary arc source gives the most promise of yielding large positive ion currents without prohibitive power consumption, enormous pumping speeds or too large and bulky apparatus. The source described herein is essentially a modification of the capillary arc design published by Tuve, Dahl and Hafstad.[1] It has been used as a source of deuterons for a relatively low voltage neutron generator. Ion currents at the target of 1.0 milliampere have readily been obtained using an outlet canal which limits the deuterium flow to an amount which is not excessive.

CONSTRUCTION

The source, drawn to scale, and the method of attaching it to the accelerating tube are shown in Fig. 1. This source differs from the capillary type of low voltage arc in that the arc instead of being confined in a cylindrical capillary passes through a narrow gap, which, in Fig. 1, is the space between the diaphragm B and the cylinder C. This gap can be made less than 1 mm wide without making the arc difficult to start or unstable in operation. The anode A is separated from the hot cathode F by the steel diaphragm B which is pushed into a thin-walled steel tube which forms the arc body. The flat nose of B is 12 mm in diameter and carries at its center a hole 3 mm in diameter and of no length. The filament is circular and surrounds the arc gap. The filament is insulated by a piece of glass tubing and it has been found that a short section of sylphon bellows (not shown) above the glass

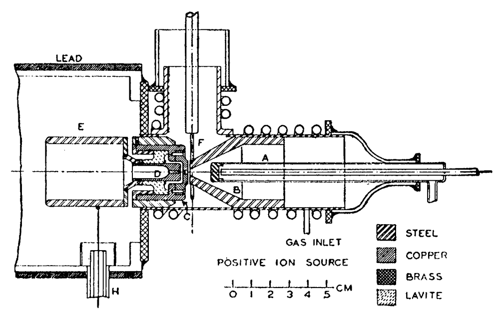


FIG. 1.

is of great assistance in centering the filament. The copper cylinder C slides in a steel sleeve soldered into the end of the steel pipe. A set-screw holds C in position; the width of the arc gap is varied by moving C. Because the gas flow around C should be a minimum a careful fit is necessary. The positive ions drift out of the arc gap through the exit hole in the face of C. An unfired lavite insulator inside C carries the probe D. Potentials up to 10,000 volts applied between D and C accelerate positive ions through the canal in the probe. The canal also limits the flow of gas into the accelerating tube. An insulated lead H in the side of the accelerating tube carries the probe potential to E. No special care has been taken to make the connection between the probe and the lavite insulator gas tight, except to seal the space between D and E with a small amount of insulute cement.

In order to facilitate the study of the dependence of the ion current on the dimensions of the exit hole, the face of C was made in the form of a

[1] Tuve, Dahl and Hafstad, Phys. Rev. **48**, 241 (1935).
[2] Lamar, Samson and Compton, Phys. Rev. **48**, 886 (1935).
[3] Lamar, Buechner and Compton, Phys. Rev. **51**, 936 (1937).
[4] Crane, Lauritsen and Soltan, Phys. Rev. **45**, 507 (1934).

TABLE I. *Output ion currents. Arc gap 1.2 mm. Probe canal 1 mm×6 mm. Exit hole (a) of Fig. 2.*

Arc Current amp.	Probe Voltage Volts 2000 ma	4000 ma	6000 ma	7000 ma	8000 ma	9000 ma
0.5	.27	.9	1.4	1.4		
1.0	.22	.7	1.5	1.9	2.2	2.2
1.5	.17	.7	1.9	2.6	3.1	3.2
2.0	.1	.6	1.7	2.4	3.3	4.3

plate held in place by two small screws. The glass insulators supporting the anode and filament are secured with red wax. A few turns of copper tubing provide water cooling. The source could probably be radiation cooled by making the arc-body and filament support out of stainless steel, lengthening them, and substituting a higher melting point cement.

Operating Characteristics

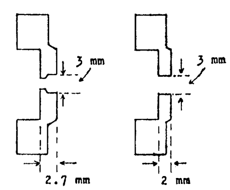
The arc is operated on 220 volts, the arc drop in general being 100 volts. It is started by connecting the arc-body to the anode through a resistance of 400 ohms. As the pressure, at which the arc is operated, is somewhat lower than the starting pressure, the starting procedure consists of letting in a small burst of gas and then momentarily connecting the arc-body to the anode. This invariably starts the arc even though the arc gap is less than 1.0 mm. After the arc is started the filament is connected directly to the arc-body, this seems to permit higher probe potentials without blowing out the arc. The source has been operated on both tank hydrogen and pure deuterium, and, in neither case, has it been found necessary to add any other gas to obtain a constant and persistent arc. The filament temperature is not critical but should be sufficiently high so that connecting the filament to the arc-body produces only a very small increase in the arc current.

Both oxide-coated and pure tungsten filaments have been used. Filaments of the type described by Lamar, Samson and Compton[2] are quite satisfactory although the lifetime is rather short, an average filament lasting from 30 to 40 hours. A 0.020″ tungsten filament lasts about 25 hours and a 0.040″ tungsten upwards of 50 hours. Tungsten filaments are preferred because of the ease of replacement and, in addition, there is less likelihood of contaminating the ion beam with foreign ions.

The output currents are largest when the pressure in the arc chamber is only slightly higher than the smallest pressure at which the arc can be maintained. This pressure is approximately 0.03 mm. The flow of gas is such that a 1500 cc flask of deuterium at atmospheric pressure permits operation for one hundred hours.

Ion Currents

The output ion currents depend, in a critical fashion, on the width of the arc gap and the dimensions of the exit hole. In Table I are listed the output currents for various arc currents and probe potentials for a probe canal 1 mm in diameter and 6 mm long. The dimensions of the exit hole with which the currents of Table I were obtained are shown in Fig. 2 (a).



(a) (b)

FIG. 2. Exit hole dimensions.

An inspection of Table I shows that the ion currents for the higher probe potentials are two to four times greater than those of the Tuve, Dahl and Hafstad source although, in this case, the probe canal is 50 percent longer. The currents for small probe potentials can be increased by changing the dimensions of the exit hole as will be indicated later. The current to the face of the probe (including secondaries) varied from 2.0 and 7.0 ma for the probe potentials and arc currents of Table I. The increased output currents are probably due to the higher current density in that part of the arc gap close to the exit hole and to bringing the probe close to the condensed arc. Larger arc currents produce greater output currents, but correspondingly greater probe potentials are required. For comparison, it should be noted that the source of Lamar, Samson and Compton[2] gives about the same ion current for a 2-ampere arc but, in their case, the gas flow is much greater since the outlet hole is very short.

Measurements of positive ion currents are always complicated by the presence of secondary electrons. The method of measurement which was chosen as the one least likely to lead to spurious results is illustrated in Fig. 3. The ions are focused into a beam of smaller diameter than M by 10 to 50 kv placed across the focusing gap between L and E. All the electrodes of the accelerating tube, over a meter long, were connected and held from 90 to 300 volts positive with respect to L. The values listed in Table I are the currents to M and it is believed that very few secondaries have been counted, in fact, the true currents are probably greater since some secondary electrons from L enter M with the positive ions.

For a given arc gap and probe canal the output varies considerably with the length and diameter of the exit hole. The hole, whose dimensions are given in Fig. 2 (b), gives a current of 2.0 ma for a probe potential of 6200 volts and an arc current of only 0.4 ampere. However, the current to the probe itself was 11 ma. As the rectifier set which provided the probe potential was limited to this power, the output for larger arc currents was not measured. Larger currents than those of Table I for the smaller probe potentials are obtained by shortening the exit hole and increasing its diameter. This results in larger currents to the probe and reduces the maximum potential which can be used without extinguishing the arc. Also, decreasing the probe canal length would give greater currents for small probe potentials.[1] Holes having the shape of (a) Fig. 2 give the most satisfactory results in that the smaller diameter near the probe limits the current to the probe.

Arc gaps from 3.0 mm to 0.7 mm were investigated. The output current increases as the gap is decreased but not much was gained in using gaps less than 1.0 mm. The optimum gap is about 1.2 mm if ease of starting and steadiness are taken into consideration. The dimensions of the probe canal are determined by the available pumping speed. Systematic tests were not made to discover the way in which the ion current depends on the probe canal length or diameter. However, the conclusions of Tuve, Dahl and Hafstad[1] on this matter were roughly verified.

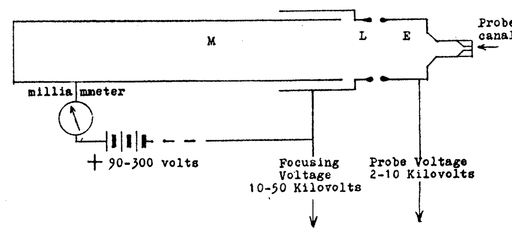


FIG. 3. Arrangement of electrodes and potentials for the measurement of output ion currents.

Magnetic Analysis

A magnetic analysis of the ion varieties was made, using dried tank hydrogen in the source. These measurements were made with a 4 mm long probe canal and showed 15 to 20 percent atomic ions. Others[1,2] have found similar results for the metal capillary arc and this yield apparently is all that can be hoped for from this type of source.

The source is very constant and reliable in operation. Once the pressure has been adjusted to a value slightly higher than the minimum at which the arc will run, the output current remains constant for long periods. The target currents in the accelerating tube remain constant to 1 to 2 percent although both probe and accelerating potential are turned off and on a number of times.

The author wishes to acknowledge his indebtedness to Professor Bergen Davis for making the necessary facilities available and for his helpful advice and suggestions.