A Source of Doubly Ionized Helium

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A magnetron type of low voltage arc has been designed to produce doubly charged helium ions by multiple electron impact. A magnetic field parallel to the axis of a cylindrical cathode makes it possible to operate the arc in pure helium with one ampere arc current and an arc drop of 50 to 100 volts, at a pressure of 10^{-2} mm. Ions are drawn out of the arc and focused on an ion gun by an auxiliary cathode fitted with a spherical grid. When the ion beam is analyzed with a mass spectrograph it is found that about 5 percent of the ions have a ratio of mass to charge equal to 2. At least part of these are H_2^+ ions appearing as an impurity which cannot be eliminated. However, with an ion beam of one milliampere which could be readily drawn from the arc, there is evidence to indicate that about 2 percent, or 20 microamperes, would consist of doubly ionized helium which would be available for nuclear investigations.

INTRODUCTION

An efficient source of doubly charged helium ions requiring moderate power for operation would be useful in nuclear investigations. It is known[1] that very few doubly charged ions are produced by single electron impact in helium even though the electrons have an energy of several hundred volts. Apparently, then, in order to obtain an efficient source, conditions in the discharge should be especially favorable for multiple impact; that is, a discharge should be employed in which the probability would be relatively great of an ionizing electron with sufficient energy striking a singly charged helium ion. A low voltage arc of the type described by Lamar and Luhr[2] offers one possibility, but a rough calculation indicates that in order to obtain complete ionization of the gas such an arc must be operated with one ampere arc current at 10^{-4} mm pressure. In pure helium the arc will not run at a pressure lower than 5×10^{-2} mm because of the breakdown of the positive ion space charge around the cathode when the mean free path of the ionizing electrons becomes greater than the distance between cathode and anode.

In the present investigation a magnetron type of discharge has been employed in order to lengthen the path of the electrons between cathode and anode, so that they would undergo an ionizing collision before they struck the anode. The arc would then operate at lower pressure, a larger percentage of the gas was ionized, and there was a better probability of double ionization by multiple impact.

APPARATUS AND EXPERIMENTAL PROCEDURE

The tube was designed as shown in Fig. 1. The anode *A* was a nickel cylinder 4 cm long and 4 cm in diameter. The oxide-coated cathode *C* was a nickel cylinder 4 mm in diameter and 3 cm long, coaxial with the anode. It was indirectly heated by a 7-mil tungsten filament about 10 cm long wound into a spiral on a 30-mil mandrel. The filament was insulated from the cylinder by an aluminum oxide tube. The oxide-coated cylinder itself served as the return lead for the filament current. An oxide-coated overwound (piano wire) tungsten filament wound on a 3-mm mandrel to form a helix 3 cm long was also tried, but did not seem to stand up under bombardment by positive ions as well as the nickel cylinder. An auxiliary cathode *B* consisted of two circular nickel plates covering the ends of the anode cylinder. A hole 1-cm in diameter in the top plate admitted the cathode leads, while a 3-cm hole in the bottom plate was covered with a 40-mesh nickel gauze spherical grid which served to focus the positive ions onto the ion gun *D*. The distance from the grid to the ion gun was 3.5 cm. The aluminum ion gun was constructed in the same way as that described by Lamar and Luhr,[2] and in the present experiment had in its upper face a hole 0.34 mm in diameter through which positive ions were admitted to the mass spectrograph. The tube was fitted with a

[1] W. Bleakney, Phys. Rev. **36**, 1303 (1930).
[2] E. S. Lamar and O. Luhr, Phys. Rev. **46**, 87 (1934).

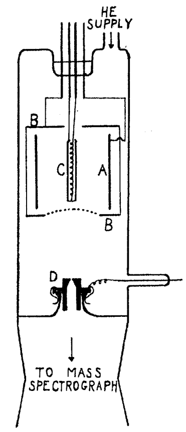

FIG. 1. Design of tube for producing doubly ionized helium.

ground joint at its lower end and was waxed to the Dempster-type mass spectrograph which has been described previously.[3] The whole tube was wrapped on the outside with three-sixteenths inch rubber tubing for water cooling. Fitting closely over the tubing was a solenoid 15 cm long consisting of 500 turns of No. 22 copper wire which was capable of producing a magnetic field at its center parallel to the cathode C, of the order of 100 oersteds with a current of 3 amperes in the coil. Water flowing in the rubber tubing served to cool both the discharge tube and the solenoid.

In operation it was found that on first starting the discharge the arc would indeed run at a pressure well under 10^{-3} mm with an arc current of an ampere or more. There was always an optimum value of the axial magnetic field at which the arc operated best (that is, at minimum voltage and maximum current), and it would not run at all at this pressure when the current in the solenoid was much above or below 1.0 to 1.5 amperes. This is at least in qualitative agreement with the results of Van Voorhis, Kuper and Harnwell[4] who employed a similar device with a hydrogen discharge. Under these conditions the ions, when analyzed with the mass spectrograph, consisted almost entirely of impurities such as CO_2 and water vapor. After several hours of operation the impurities had almost disappeared, but the arc would no longer operate with a pressure lower than 10^{-2} mm. As it would not operate at less than 5×10^{-2} mm without the axial magnetic field, the path of the ionizing electrons had apparently been increased about 5-fold by spiralling around the cathode.

When operating at 10^{-2} mm the arc current was in the neighborhood of 1.0 ampere, with an arc drop ranging from 50 to 100 volts. The arc voltage could be conveniently increased from 50 to 100 volts either by decreasing the cathode heating current which was normally about 4 amperes, or by increasing the axial magnetic field. The auxiliary cathode B was at a negative potential of about 100 volts relative to the cathode and the positive ion current to B varied from 20 to 100 milliamperes, decreasing as the axial field was increased. Surprisingly, the decrease in current to B was accompanied by an increase of current to the ion gun D, which was held at a negative potential of about 100 volts relative to B. Apparently the magnetic field served to focus the ions on the ion gun and the current to D was at times greater than that to B, ranging as high as 30 milliamperes, though at least part of this current was undoubtedly due to secondary electrons. From a measurement of the current passing through the hole in D it appeared that the positive ion current density was at least 10 milliamperes per square cm at the center of the upper face of the ion gun.

RESULTS AND DISCUSSION

On analyzing the ion beam with the mass spectrograph it was found that from 2 to 10 percent of the ions had an m/e equal to 2, and that practically all the rest had a mass 4 and were therefore He^+ ions. The percentage of mass 2 ions tended to increase with increasing arc voltage and with decreasing pressure but at least part of these ions were always due to H_2^+ as indicated by the continued presence of a few protons. The helium was obtained highly purified from the General Electric laboratories and was passed through a charcoal trap cooled with liquid air, then through two additional liquid-air traps before admission to the chamber. However, even after many hours of operation, hydrogen continued to appear as an impurity, probably coming from the walls of the tube. It was ex-

[3] O. Luhr, Phys. Rev. **44**, 459 (1933).
[4] Van Voorhis, Kuper and Harnwell, Phys. Rev. **45**, 492 (1934).

tremely difficult to repeat results quantitatively as the arc was rather unsteady under these limiting conditions of operation. Furthermore, after about 30 hours of operation the oxide coating of the cathode was disintegrated as a result of bombardment by the 50 to 100-volt positive ions and it had to be replaced.

On the average, with an arc drop of 70 to 80 volts about 5 percent of the ions had a ratio of mass to charge equal to 2. This percentage dropped to about 2 or 3 when the arc voltage was decreased to 50 volts or less, or when the pressure was increased materially. The proton current was only about 2 percent as large as the current due to the mass 2 ions, and it should have been at least 5 percent if all the mass 2 ions were H_2^+. Therefore it is estimated that probably about 2 percent of the total ion current consisted of He^{++} ions. It should not have been more than this considering that on the average only about one percent of the gas in the plasma could be ionized under the conditions of operation. However, the ion concentration was probably greater near the cathode. With a current density of more than 10 milliamperes per square cm on the ion gun, a total current of at least one milliampere should be available for nuclear experiments, and perhaps 2 percent or a maximum of 20 microamperes would be the desired doubly ionized helium.

In order to determine with greater certainty whether at least part of the mass 2 ions were He^{++} and not all H_2^+, it would be desirable to examine the arc spectroscopically. A strong He II spectrum would indicate the presence of He^{++} ions. Preparations are being made to carry out such an investigation. An arc of the type described here might furnish an efficient source for obtaining the ionized spectrum of many gases.

Other types of discharge in which He^{++} ions might be found have been considered but have not been tried. Among these are the hollow cathode discharge (which is effective in producing the He II spectrum) and the capillary type of arc described by Tuve, Dahl and Hafstad.[5] While the capillary arc under certain conditions appears to produce one hundred percent ionization,[6] it seems unlikely that there are enough high speed electrons in the capillary to produce many doubly charged ions. Incidentally, the arc described in the present paper has been operated with hydrogen, and although it yields current densities comparable with those obtained with the capillary, not more than 5 to 10 percent of the ions are protons, which is the result expected on the basis of the work done by Lamar and Luhr.[2]

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[5] M. A. Tuve, O. Dahl and L. R. Hafstad, Phys. Rev. **48**, 241 (1935).

[6] I. Langmuir and H. Mott-Smith, Gen. Elec. Rev. **27**, 762 (1924).