March 15, 1960 R. V. NEIDIGH 2,928,966

ARC DISCHARGE AND METHOD OF PRODUCING THE SAME

Filed July 9, 1958 3 Sheets-Sheet 1

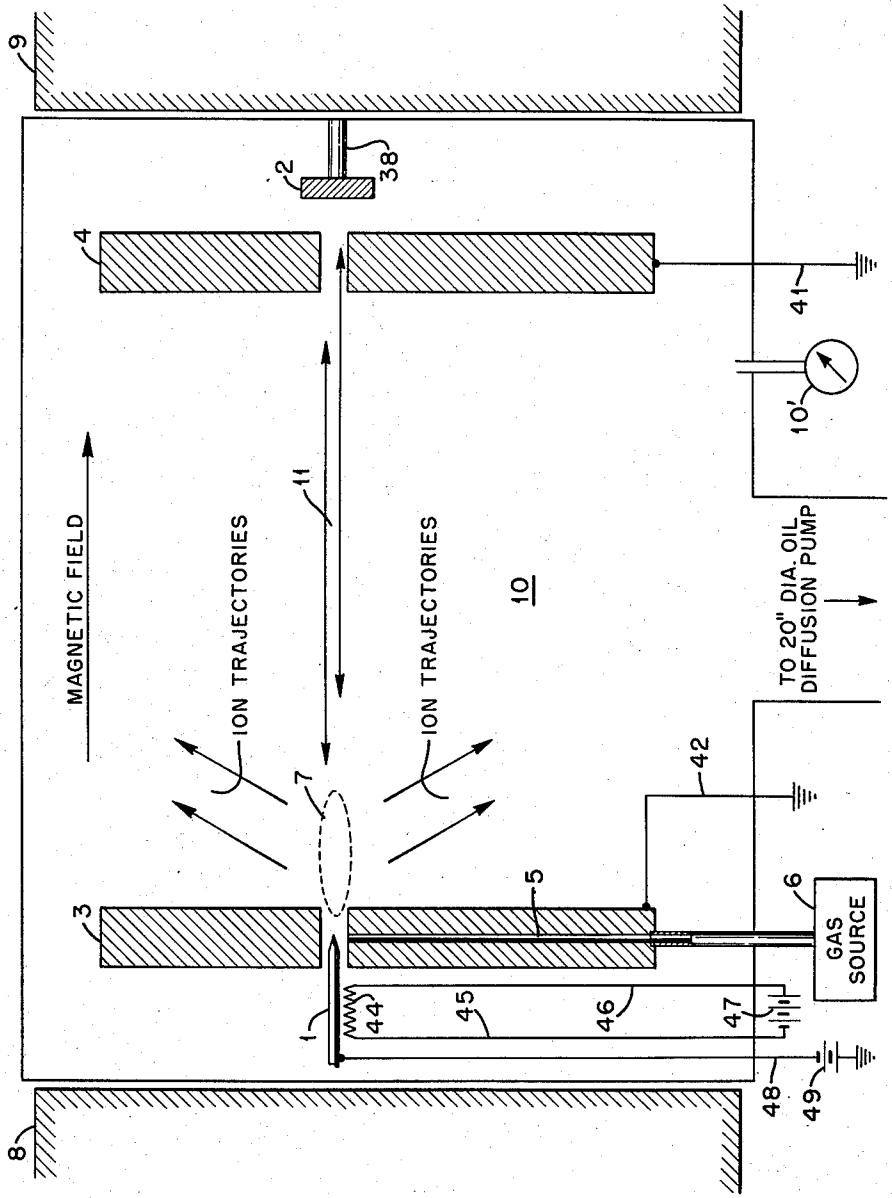


Fig. 1.

INVENTOR.
Rodger V. Neidigh

BY

Roland A. Anderson

ATTORNEY

March 15, 1960 R. V. NEIDIGH 2,928,966

ARC DISCHARGE AND METHOD OF PRODUCING THE SAME

Filed July 9, 1958 3 Sheets-Sheet 2

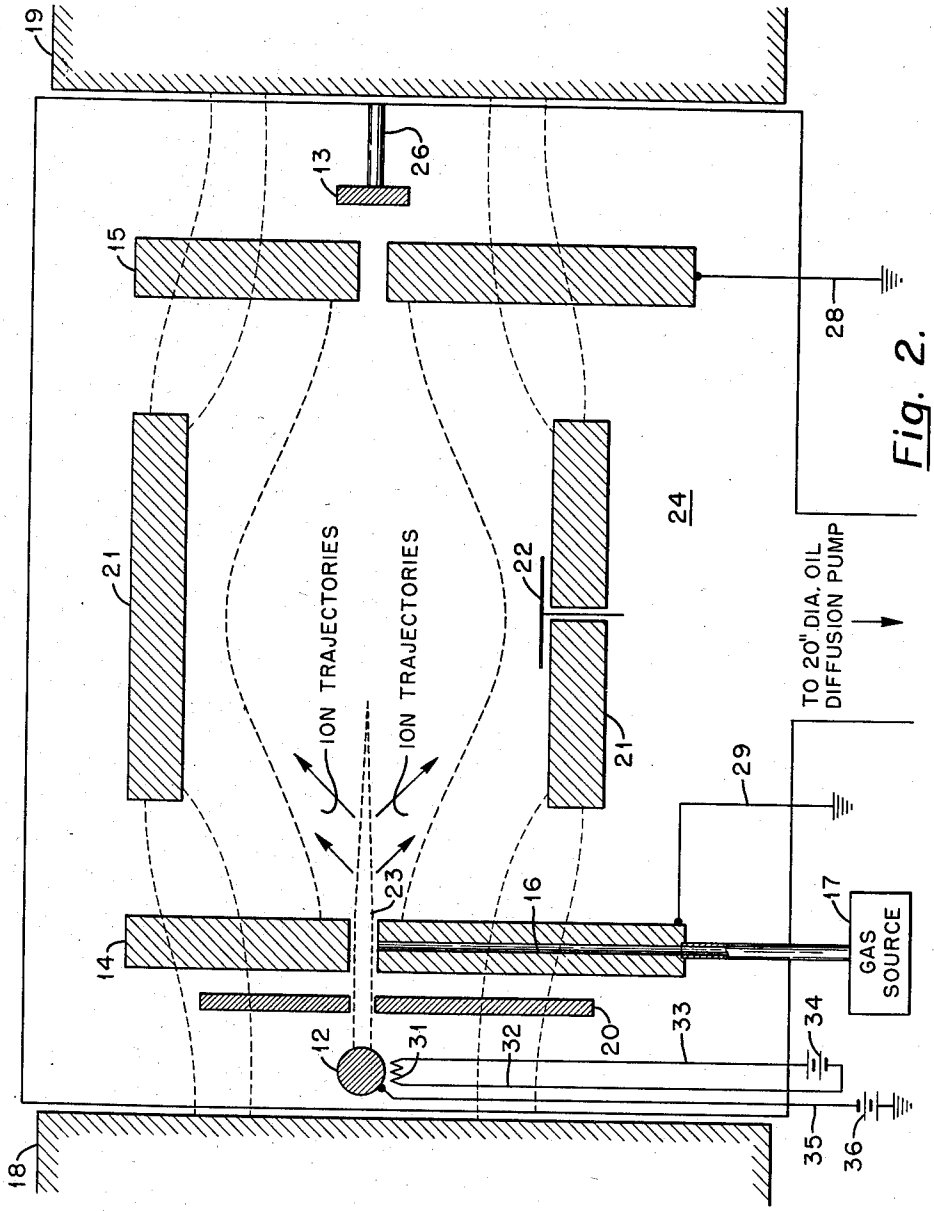


Fig. 2.

INVENTOR.
Rodger V. Neidigh

BY

Roland A. Anderson

ATTORNEY

March 15, 1960 R. V. NEIDIGH 2,928,966

ARC DISCHARGE AND METHOD OF PRODUCING THE SAME

Filed July 9, 1958 3 Sheets-Sheet 3

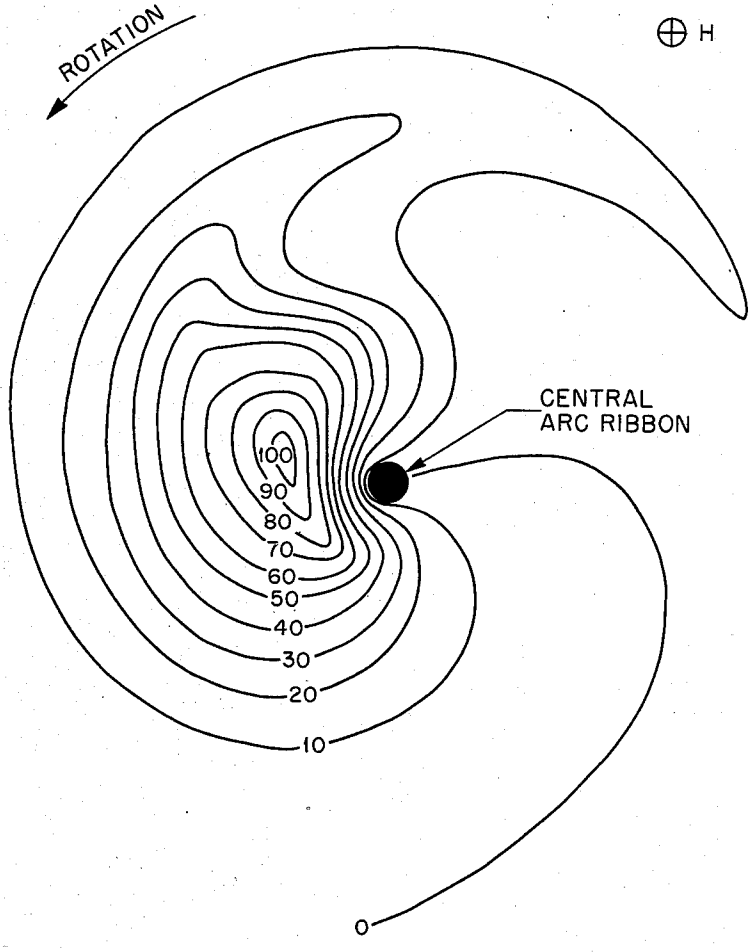


Fig. 3.

INVENTOR.
Rodger V. Neidigh

BY

ATTORNEY

United States Patent Office 2,928,966
Patented Mar. 15, 1960

2,928,966

ARC DISCHARGE AND METHOD OF PRODUCING THE SAME

Rodger V. Neidigh, Knoxville, Tenn., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application July 9, 1958, Serial No. 747,551

4 Claims. (Cl. 313—63)

This invention relates to a method of producing an arc discharge which is magnetically-collimated and wherein the electrons are very energetic and transfer this energy to ions, thereby causing the ions to be accelerated either parallel to or perpendicular to the magnetic field.

In conventional gas arcs which are magnetically collimated, a hot cathode is utilized to produce electrons and these electrons, collimated by the field, cause a feed gas to be ionized. The resultant arc follows the magnetic field lines, is generally passed through defining apertures, and terminates upon an anode. The pressure in the region of the arc is generally in the range near 10^{-3} mm. Hg and is nearly uniform throughout the length of the arc. If an insulated anode is used, the potential thereof is about the same as the cathode and the anode is subject to intense heating. Typical of such arcs are the arcs used in calutron source units and many spectrographic analysis equipments.

It has been discovered that if the pressure in the region of the arc is reduced while maintaining a constant rate of gas feed, the original arc will undergo an abrupt change in appearance and characteristics. This change occurs in the pressure range of 10^{-4} to 10^{-5} mm. Hg. The brightness of the arc decreases and a luminous plasma appears surrounding the new arc. The insulated terminal electrode is heated only slightly by this new arc, in contrast to the severe heating of the anode in the previously described conventional arc, and, unexpectedly, the potential thereof becomes much more negative than the cathode. Another characteristic feature of the arc described herein is the existence of a pressure gradient with ranges from about 10^{-3} mm. Hg near the point of gas feed to the arc, to about 10^{-5} mm. Hg in the volume surrounding the main body of the arc.

One outstanding characteristic of this new type of arc is the high efficiency of energy transfer from electrons to the ions formed in the arc, with greater than 90% of the input gas being converted into energetic ions. Also, the electrons accelerated from the heated filament possess an energy spread much greater than in the usual arc and the resultant ions are relatively energetic. At least equally important is the unique characteristic of this arc whereby ions are accelerated (without physical electrodes) with a radial velocity component; in fact, the greater portion of their energy is in a direction perpendicular to the magnetic field.

Accordingly, it is an object of this invention to provide an arc wherein the electrons are very energetic.

It is another object of this invention to provide highly energetic ions by collisions with electrons which are accelerated to relatively high energies within the arc.

These and other objects and advantages will become apparent from a consideration of the following detailed specifications and the accompanying drawings wherein:

Fig. 1 is a schematic drawing showing apparatus for the production of an energetic arc in a uniform magnetic field.

Fig. 2 is a schematic drawing showing apparatus for the use of the energetic arc in a magnetic mirror type of device, and

Fig. 3 is a plot of equipotential lines in the energetic arc as determined by floating-probe measurements.

In Fig. 1, a uniform magnetic field is provided by magnets 8 and 9. A negatively biased tungsten filament 1, which is heated indirectly or by ion bombardment is disposed on an axis substantially paralleled to the magnetic field. A typical heating circuit is shown by the battery 47, lead 46, heater 44, lead 45 and back to battery 47. A floating electrode or electron reflector 2 is provided, and electrons, produced by the heated filament, travel parallel to the magnetic field through a pair of grounded, apertured collimating baffles 3 and 4, and strike the electrode 2. The baffle 3 is grounded through lead 42. Baffle 4 is grounded through lead 41. Electrode 2 is mounted by means of electrical insulator 38. Gas is fed from a source 6 through feed tube 5 to the region in the collimating aperture of baffle 3 nearest the filament 1. The chamber 10 is evacuated to a pressure described hereinafter. With a negative bias (—150 volts, for example, from ground through battery 49 and lead 48) applied to the filament 1 and a gas feed such that the pressure near the filament is about 10^{-3} mm. Hg, an arc is struck. The electron sheath 11 extends very near to the floating electrode; however, the arc plasma 7 extends only a portion of the distance to the second collimating baffle 4 when the gas pressure in the outer regions is maintained at about 10^{-5} mm. Hg. A vacuum gage 10' is connected to the chamber 10 for readily determining the pressure within said chamber. The potential of the floating electrode 2 unexpectedly achieves a value at least twice the bias applied to the filament during arc operation.

In one embodiment of the apparatus shown in Fig. 1, the baffles 3 and 4 are made of one-half inch copper, and are approximately six inches square. The circular holes in these baffles through which the arc passes are approximately one-fourth inch in diameter. A twenty-four inch oil diffusion pump may be used for evacuation of chamber 10. Arcs have been operated in uniform magnetic fields of 2000–7000 gauss. The maximum cathode bias used was 3.5 kv. at 8 amperes. Deuterium, hydrogen, nitrogen and most of the noble gases have been utilized as feed gases. The maximum deuterium ion energy observed has been 2.5 kv., while 5 kv. has been observed for ions of the heavier gases.

Some characteristics of the arc discharge are: first, positive ions are shot out of the region of the arc centerline, with velocity components across the field and toward the baffle plate 4; second, the energies associated with such ions can amount to as much as twice the numerical equivalent of the potential placed on the hot cathode; and third, a discharge is set up to one side of the arc centerline and rotates about the arc centerline, having a rough wedge-shape cross-section and extending between the baffles. The first characteristic mentioned above can be determined by sputtering patterns, Faraday cup collector signals, and doppler slant effects observed spectroscopically. The second characteristic above can be determined by sputtering patterns and collector currents obtained by use of a simplified mass spectrograph for a given gas and magnetic field. The third characteristic above can be determined by the use of a floating probe, such as shown in Fig. 2, disposed in the region adjacent to the arc. The rotating discharge is always in the direction a positive ion would take, and the speed of rotation is in the range of 20,000 to 100,000 revolutions per second. This can be determined by the frequency phase with respect to a fixed floating probe and shape of the electrical signals received by another floating probe. Floating probe measurements have been

made of the potential in the plasma surrounding the central arc column. An instantaneous plot of this potential is shown in Fig. 3. It is possible to formulate a tentative model of the rotating plasma effect external to the arc column. Thus at the onset of the arc discharge, positive ions are sprayed out into the region surrounding the column. Some of these ions charge-exchange with the neutrals in the region, forming slow ions, and thus a positive potential is built up. The ions that do not charge-exchange strike the baffle plate 4, causing sputtering and giving rise to free electrons. Thus the increasing potential and available electrons eventually cause a gas discharge along the magnetic field at some point away from the central column. The discharge now establishes itself in some mode compatible with the given boundary conditions. It cannot remain still, since it has destroyed the potential that established it. However, examination of Fig. 3 shows that a radial electric field directed outward is associated with the high potential. The numbers in Fig. 3 indicate positive potentials with respect to the end baffles. These are typical of the potentials assumed by a floating probe at any instant for given operating conditions. The field rotates as a unit about the arc in the direction indicated. The direction of the magnetic field "H" is into the paper. Referring now to Fig. 1, when electrons are accelerated into the high potential region from the end baffle, they are shifted in the direction a positive ion would rotate (counter-clockwise) by the effect of the electric field crossed with the magnetic field. Thus propagation of the discharge is favored in the direction of this shift, due to the ionizing effect of the shifted electrons at the edge of the discharge. The over-all picture of the rotating discharge is then as follows: The discharge always rotates into a high potential region, and leaves behind it a region of zero potential. However, the continuous spray of ions rebuilds this potential at a steady rate, thus maintaining the high potential region toward which the discharge moves. The speed of rotation is governed by the time necessary for the potential to rebuild at any one point, and thus is a function of system parameters.

As discussed above, the potential of the floating electrode **2** reaches a value at least twice the bias applied to the filament **1** during arc operation. A portion of the ions are accelerated to energies numerically equivalent to this floating electrode potential by time-varying electric fields which exist in the central arc region. Ion energies increase linearly with cathode bias, and the perpendicular component of the ion energy is comparable with and increases with increased floating electrode potential. This acceleration of ions is always associated with the pressure gradient in the arc column and occurs only when electrons are contained by the potentials at the ends of the arc, and when the loss of ions is restricted by the extra large sheath dimension imposed by the low pressure. An increase in the pressure gradient is also known to increase the ratio of the floating electrode potential to the cathode potential.

The time-varying electric fields which cause the radial ion acceleration are, in fact, related to the rotational effect discussed above with reference to Fig. 3.

The device set forth in Fig. 2 shows the use of the arc of Fig. 1 in a mirror type device. Electrons are produced by a heated filament **12** which is heated by a heater **31** connected to a battery **34** by leads **32** and **33**, and travel in a path as determined by an applied magnetic field formed by magnets **18** and **19** and a hollow iron cylinder **21** disposed between the magnets. The field configuration between the magnets **18**, **19** and iron cylinder **21** is shown by the dotted lines in the figure. Magnetic field strengths at the ends of the apparatus are approximately twice those within the central portion of the apparatus. The electrons pass through an apertured grid **20** and through a pair of grounded, apertured collimating baffles **14**, **15**, and strike an insulated (floating)

electron-reflector electrode **13**. The purpose of grid **20** is to pulse the arc by a high negative bias so that plasma decay times could be measured. The baffle **14** is grounded by lead **29**. Baffle **15** is grounded by lead **28** and electrode **13** is mounted on electrical insulator **26**. Gas is fed from a source **17**, through a feed tube **16** to the region in the collimating aperture of baffle **14** nearest the filament **12**, and the chamber **24** is evacuated. With a negative bias (−150 volts, for example, from ground through battery **36**, and lead **35**) applied to the filament **12**, and a gas feed such that the pressure near the filament is about 10^{-3} mm. Hg, an arc is struck. The electron sheath extends nearly to the floating electrode **13**, however, the arc plasma **23** extends only a portion of the distance to the collimating baffle **15** when the gas pressure in the outer regions is maintained at about 10^{-5} mm. Hg. In marked contrast to results from normal operation with a reflecting electrode, the potential of the floating electrode **13** reaches a value at least twice the accelerating potential applied to electrons from the filament. Ions in the arc will achieve many times the energy normally expected from normal arc operation. The probe **22** just inside the iron cylinder **21**, but just outside the orbit of the most energetic ions, is used, when desired, to record the decay of the plasma when the arc is extinguished. The decay time has been found to vary from 50 to 250μ seconds and it varies inversely with the density of neutral gas. As in Fig. 1 the arc of Fig. 2 operates under a pressure gradient and all other characteristics are the same as those described above for linear magnetic fields. Sputtering patterns on the end walls in Fig. 2 after the arc is operated indicate that some of the ions were multiply reflected by the mirrors.

The device of this invention can be used as an ion gun suitable for use in injecting molecular ions into the working volume of a thermonuclear device such as disclosed in the application of John S. Luce, Serial No. 728,754, filed April 15, 1958, or the application of Persa R. Bell et al., Serial No. 753,846, filed August 7, 1958, with energy and density sufficient to accomplish complete ionization and randomization of the plasma. Also, another use of the arc of this invention would be to make it an integral part of the thermonuclear devices of the aforementioned applications wherein the arc is struck along the axis of the devices and accelerates atomic ions directly into the working volume and nearly perpendicular to the magnetic field. The ions are trapped by virtue of their possessing the greater portion of their energy perpendicular to the magnetic field. The arc is a virtual source; that is, there are no solid electrodes at the point of ion emission. Therefore, the ions are not lost on their eventual return passage through their origin which is within the confining volume of the thermonuclear devices.

This invention has been described by way of illustration rather than limitation and it should be apparent that the invention is equally applicable in fields other than those described.

What is claimed is:

1. A device for producing energetic ions by transfer of energy from energetic electrons to said ions, comprising a chamber, means for establishing a magnetic field oriented in a selected direction within said chamber, a filament electrode mounted within said chamber, an electron reflector electrode mounted to said chamber in spaced relation to said filament electrode in axial alignment therewith, said electrodes being in axial alignment with the direction of said field, a source of negative electrical potential connected to said filament electrode, means for heating said filament electrode disposed adjacent thereto for causing said filament electrode to emit a copious quantity of electrons which are collimated by said magnetic field to reflux between said insulated reflector electrode and said filament electrode, a pair of grounded apertured collimating baffles disposed between

said electrodes, one each adjacent to each of said electrodes, a gas source, a feed tube disposed in the baffle adjacent to said filament electrode and connected between the aperture in said baffle and said gas source to inject gas normal to said collimated electrons, evacuating means connected to said chamber to maintain the pressure therein at a selected low pressure, means for feeding gas from said source to said aperture at a constant selected low pressure, a central gas arc discharge being thus established across only a portion of the distance to the reflector electrode, the low pressure of said feed gas being maintained at a relatively higher pressure than the pressure maintained in said chamber to thereby establish a pressure gradient along the arc discharge, said pressure gradient and said field establishing rotating time varying radial electrical fields in the volume surrounding said discharge to thereby establish a rapidly rotating arc discharge about said central arc discharge, the electrons in said central arc and said rotating arc discharge being accelerated by said fields and causing a major portion of said feed gas to be ionized, and a portion of the ions thus formed being accelerated by said electric fields to an energy equal to at least twice the potential applied to said filament electrode, said ions having a major radial velocity component perpendicular to the direction of said magnetic field.

2. A device for producing an improved gas arc discharge, comprising a chamber, means for establishing a selected magnetic field oriented in a predetermined direction within said chamber, electrode means disposed in said chamber for providing an energetic refluxing stream of electrons in alignment with the direction of said field, evacuation means connected to said chamber for maintaining the pressure therein at a selected low pressure, a source of gas, means connected to said source for feeding gas into the path of said stream of electrons at a constant selected pressure higher than the pressure maintained within said chamber to thereby establish an arc discharge and meaintain a pressure gradient along the thus formed discharge, said pressure gradient establishing rotating time varying, radial electrical fields in the volume surrounding said discharge to thereby cause said discharge to rotate about the arc center line, whereby a portion of the electrons in said discharge are caused to be accelerated by said electric fields and to transfer their energy to ions in said volume, said ions having a major, radial velocity component perpendicular to the direction of said magnetic field.

3. The device set forth in claim 2, wherein the means for establishing the magnetic field includes means for providing magnetic mirrors adjacent to said electrode means, such that the energetic ions in said volume are multiply reflected by said mirrors.

4. In an evacuated chamber evacuated to a selected low pressue and provided with containing magnetic mirror fields, a heated, negatively biased filament electrode, an electrically floating electron reflector electrode, and a pair of grounded apertured collimating baffles disposed between said electrodes, one each adjacent to each of said electrodes, for collimating a stream of refluxing electrons between said electrodes; improved means for producing very energetic ions by said electrons comprising, a source of gas, means connected to said source for feeding gas at a selected constant pressure into the path of said electron stream and substantially normal thereto to thereby establish an arc discharge along the path of said electron stream, the pressure of said feed gas being maintained at a value higher than the pressure in said evacuated container to thereby provide a pressure gradient along said discharge, said pressure gradient establishing rotating, time varying, radial electrical fields in the volume surrounding said discharge to thereby cause said discharge to rotate about the arc center line, said rotating discharge including electrons which are accelerated by said electrical fields to an energy at least twice the bias on said filament electrode, said accelerated electrons transferring their energy to the ions in said volume, said energetic ions having a major, radial velocity component perpendicular to the direction of said magnetic fields.

References Cited in the file of this patent

UNITED STATES PATENTS

2,764,691	Hipple	Sept. 25, 1956
2,772,364	Washburn	Nov. 27, 1956
2,826,708	Foster	Mar. 11, 1958
2,831,996	Martina	Apr. 22, 1958