Jan. 5, 1960 P. R. BELL ET AL 2,920,235

METHOD AND APPARATUS FOR PRODUCING INTENSE ENERGETIC GAS DISCHARGES

Filed July 24, 1958 3 Sheets-Sheet 1

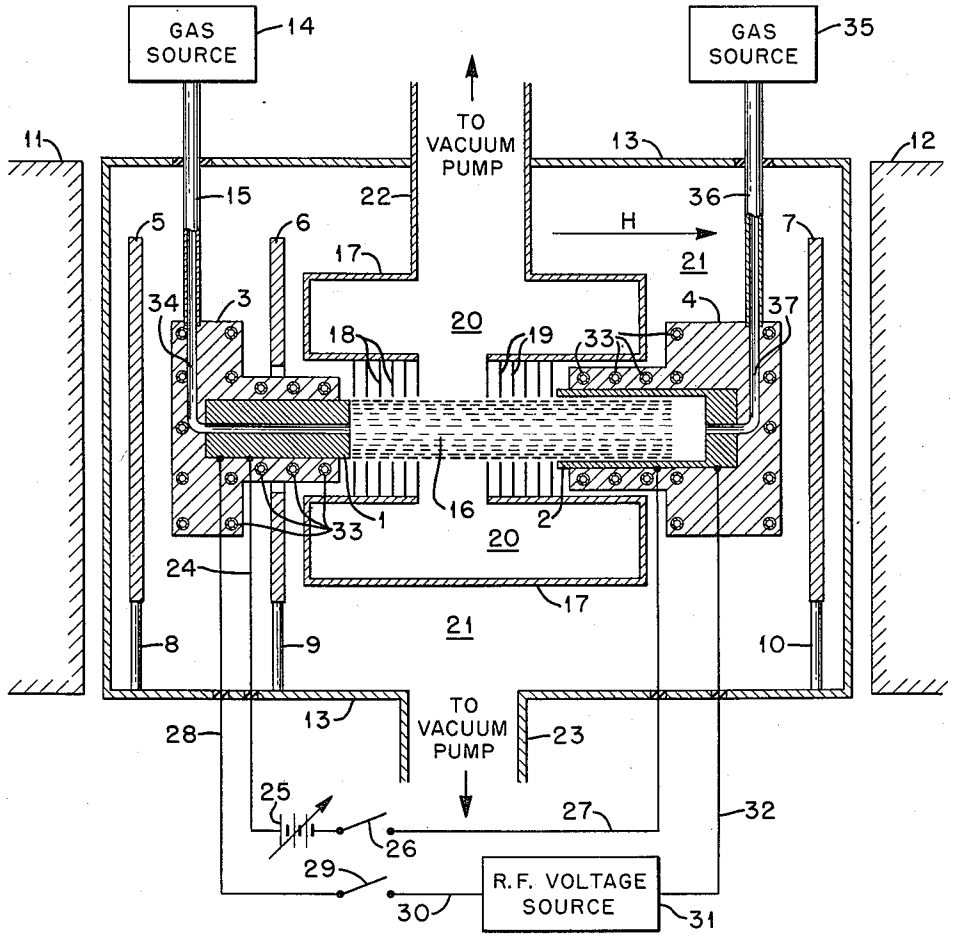


Fig. 1.

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METHOD AND APPARATUS FOR PRODUCING INTENSE ENERGETIC GAS DISCHARGES
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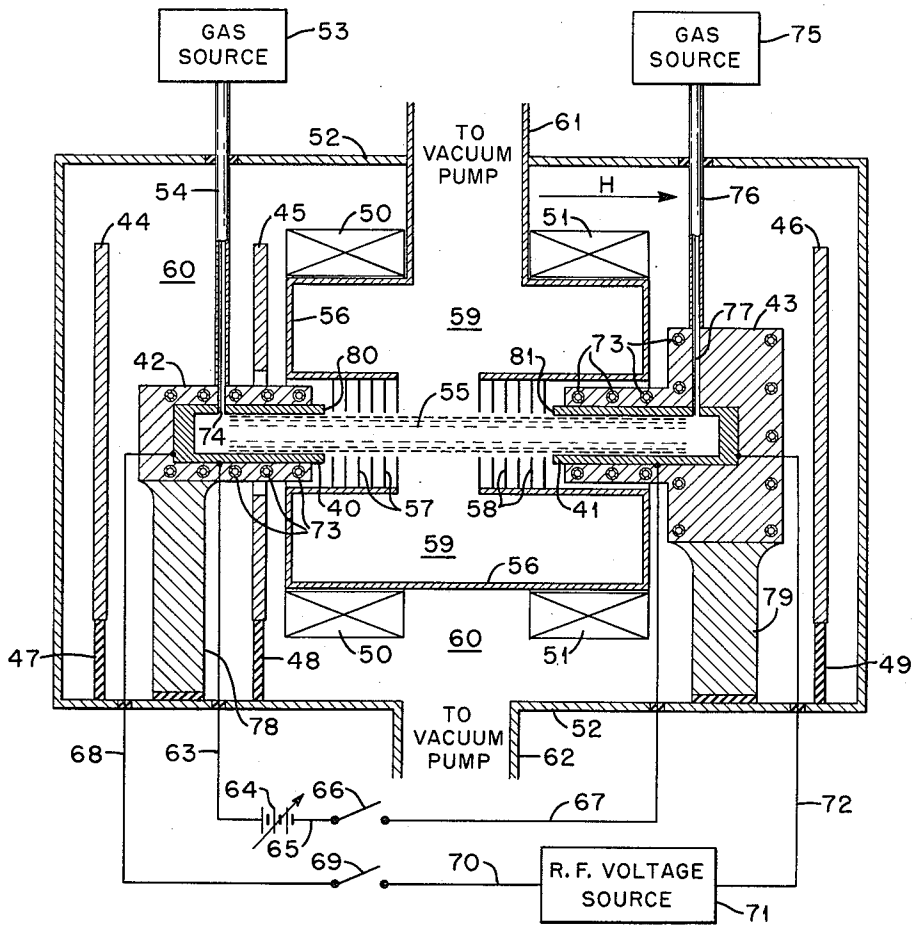


Fig. 2.

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Filed July 24, 1958 3 Sheets-Sheet 3

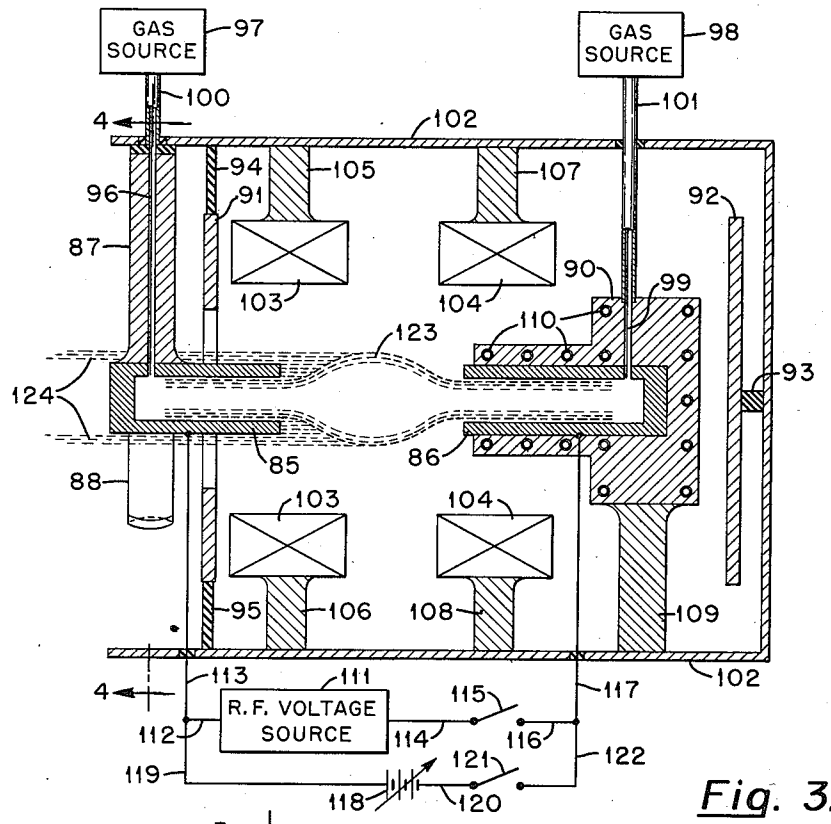


Fig. 3.

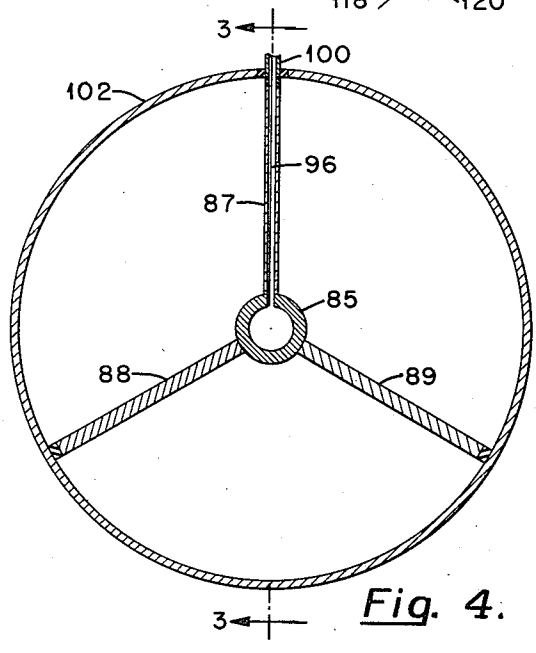


Fig. 4.

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United States Patent Office 2,920,235 Patented Jan. 5, 1960

2,920,235

METHOD AND APPARATUS FOR PRODUCING INTENSE ENERGETIC GAS DISCHARGES

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Application July 24, 1958, Serial No. 750,834

4 Claims. (Cl. 315—111)

This invention relates to devices for producing energetic deuterium or tritium arc discharges.

Energetic arcs have been developed for use as a dissociating mechanism in thermonuclear devices. An example of the efficiency of a high current or energetic arc as a dissociating mechanism is set forth in the applications of John S. Luce, Serial No. 728,754, filed April 15, 1958, entitled "Method and Apparatus for Trapping Ions in a Magnetic Field," and Serial No. 738,242, filed May 27, 1958, entitled "Device and Method for Producing a High Intensity Arc Discharge," now Patent No. 2,895,053, issued July 14, 1959. The latter application relates to an energetic carbon arc, and the former application relates to the use of the energetic carbon arc in a thermonuclear device. In one such thermonuclear device, high-energy molecular ions, such as D_2^+ for example, are injected into a confining magnetic field perpendicular to the lines of magnetic force. At some point in the orbit of these ions in the magnetic field, a portion of them are caused to be dissociated and/or ionized by the carbon arc to form atomic ions. These resultant atomic ions have one-half the momentum of the original molecular ions that have an atomic weight of two and hence have one-half the radius of curvature in the field. The radius of curvature of the atomic ions depends upon the atomic weight of the injected molecular ions. If the center of the orbits of these atomic ions coincides with the axis of the magnetic field, the ions will circulate in a ring. If the center of the orbits and the axis of the machine do not coincide, the atomic ion orbit will precess about the point of origin of the atomic ion. The ions will circulate until a charge exchange occurs with one of the neutral gas atoms in the system, or until some other process causes the ions to be lost.

The energetic carbon arc produces low pressures under normal operation which, in part, accounts for its being very energetic. Despite the many desirable characteristics of the carbon arc, basic disadvantages exist. Energetic ions in the carbon arc collide with carbon ions and lose much of their energy by Bremsstrahlung, scattering, and ionization. The amount of energy lost in such processes increases with the atomic number of the ions, so that for carbon ions the losses may be substantial, compared with deuterium, for example. It is very important in the process of building up a thermonuclear plasma that any losses of the energy imparted to the ions be held to a minimum.

Despite the disadvantages mentioned, the carbon arc has been utilized heretofore because conventional gas arc discharges cannot be operated in high magnetic fields at pressures low enough for them to become effective dissociating mechanisms. At operating pressures, such gas arcs cannot cause any trapping of atomic ions due to the large number of charge exchanges and to other processes that may cause loss of ions to occur.

Another problem associated with gas arcs is the intense heating of the electrodes with a consequent influx of impurities into the arc.

A characteristic of energetic gas arcs is that some of the ions that are accelerated toward the cathode escape and pass around the outer surface of the cathode assembly and strike the supporting structure for the cathode and heretofore have served no useful purpose.

With a knowledge of the problems associated with creating a thermonuclear plasma, the shortcomings of conventional gas arcs as dissociating agents, the electrode heating problem, and the disadvantage of the carbon discharge, applicants have as a primary object of this invention production of an energetic discharge or arc which is capable of dissociating molecular ions passed therethrough.

An important object of the invention is the production of a highly energetic arc which will not be characterized by large Bremsstrahlung, scattering, and ionization losses.

It is another object of this invention to provide a device for operating a deuterium or tritium arc discharge under low pressures, and with a minimum of electrode heating.

It is still another object of this invention to provide a use for the large quantity of energetic ions that are accelerated past the cathode.

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

Fig. 1 shows a schematic cross-sectional view of one embodiment of a device for producing a very energetic deuterium or tritium arc discharge,

Fig. 2 shows a schematic cross-sectional view of another embodiment of a device for producing an energetic deuterium or tritium arc discharge,

Fig. 3 shows a cross-sectional view of a use for the arc discharge of Fig. 2, in the propulsion of energetic ions, and

Fig. 4 shows a cross-sectional view on the line 4—4 of Fig. 3 showing the manner in which the cathode is supported.

The objects stated above have been achieved in the present invention by providing novel means for producing unique energetic arcs in deuterium or tritium which have a low atomic number, and therefore low Bremsstrahlung, scattering, and ionization losses. These unique arcs have also proved capable of dissociation of molecular ions, unlike conventional deuterium or tritium discharges.

The apparatuses for producing the discharges described herein are similar to Fig. 1 of the application of John S. Luce, Serial No. 748,771, filed July 15, 1958. In said application, the arc discharge is controlled so that it terminates from within a hollow elongated cathode and the rate of gas feed is maintained at a value such that adequate space-charge neutralization is provided inside the cathode but not in the main volume. The arc discharge depends upon emission across the magnetic field within the hollow cathode.

In accordance with the present invention, in the embodiment illustrated in Fig. 1, the cathode electrode has a small hole bored through the center of the cathode and gas is fed to the face of the cathode where space charge neutralization occurs. In the embodiment illustrated in Fig. 2, the cathode is elongated, gas fed, and hollow and within which space charge neutralization occurs. An elongated hollow cup-shaped anode electrode is provided in both Fig. 1 and Fig. 2 which is designed to closely fit the discharge and gas fed in at the anode base has to pass through a considerable length of arc before it is emitted into the vacuum chamber and thus is essentially completely ionized. It is this anode design and the axial potential gradient that exists in the arc which permits the arc to be operated in low pressures and at voltages and currents that permit the arc to be energetic.

The arcs described herein operate under substantially high voltage and current, and as a result, heating of the electrodes is a problem. This problem has been solved by using electrodes which are tungsten or any other high melting point conductive material and that is also a good thermal conductor. The electrodes are inserted into thick water-cooled copper jackets. The bore of the jacket may suitably be undersized to the extent that heating to several hundred degrees is required for insertion of the electrodes. During operation of such a jacketed electrode, the differential expansion produces a very tight fit and therefore good heat transfer. Carbon may be used for the anodes but is undesirable for the reason that it is a poor thermal conductor under high temperature and it is not possible to provide sufficient cooling of the anodes to prevent them from partially vaporizing and emitting carbon particles into the arc volume. Such particles are undesirable because of losses caused by Bremsstrahlung, scattering, and ionization as discussed above.

Referring now to Fig. 1, which illustrates one embodiment of an apparatus in which the principles of this invention may be carried out, a centrally bored cathode electrode **1** is mounted in a copper block **3**, and a hollow elongated cup-shaped anode electrode **2** is mounted in a copper block **4**. Floating cathode shields **5** and **6** are mounted by insulators **8** and **9**, respectively, to an outer chamber wall **13**. Anode shield **7** is mounted by an insulator **10** to the chamber wall **13**. A strong magnetic field, for example, 6000 gausses, is provided by magnets **11** and **12**, the direction of the field indicated by the arrow H. Deuterium or tritium gas is fed from a source **14**, through tube **15**, and through the hole **34** to the face of the cathode. The cathode hole is of sufficient size to permit space-charge neutralization at the face of the cathode. The cathode and anode are cooled by a cooling fluid which is passed through tubes **33**, mounted in blocks **3** and **4**, from a source not shown. Deuterium or tritium gas is fed from a source **35**, through tube **36**, and through tube **37** to the inside and at the base of the anode **2**.

An outer vacuum chamber **21** is formed by the walls **13** and is connected to a vacuum pump by the tube **23**. An inner vacuum chamber **20** is formed by the walls **17**, as shown, and is connected to a vacuum pump by the tubular member **22**. Baffles **18** are provided adjacent to the cathode **1**, and baffles **19** are provided adjacent to the anode **2**. These baffles are insulatingly supported in the inside chamber walls. An arc initiating assisting means such as an R.F. voltage source **31**, which may be a conventional welding source, is connected at one end to anode **2** by a lead **32**, and at its other end to cathode **1** by lead **30**, switch **29**, and lead **28**. An operating potential is connected to the anode and cathode by a variable D.C. source, such as a variable-tap multi-cell battery **25**. Battery **25** is connected at one side to cathode **1** by a lead **24**, and is connected at its other side to anode **2** by a switch **26**, and lead **27**.

The blocks **3** and **4** are insulatingly supported on the chamber wall **13** by means not shown. In one example of the apparatus, illustrated in Fig. 1, the cathode was about 5 inches long, had an outer diameter of 0.5 inch, and a gas-feed bore of 0.125 inch. The anode was 5 inches long, had an external diameter of 0.75 inch, and an internal diameter of 0.625 inch. With these dimensions, there is a clearance between the arc **16** and the inside surface of the hollow anode of approximately $\frac{1}{16}$ inch.

In one operation of the apparatus of Fig. 1 at startup, gas is fed from source **14**, through tube **15** and bore **35** of cathode **1** to the face of said cathode and gas is fed from source **35**, and through tube **36** to the inside of anode **2** at the base thereof until the pressure in the anode and at the face of the cathode and in the chamber **20** reaches a value of 3×10^{-3} mm. Hg, and then an R.F. voltage source **31** is applied across the electrodes **1**, **2**, and a D.C. voltage source **25** is connected across the

electrodes. After the arc **16** is initiated, the R.F. source **31** is disconnected by the switch **29**. The pressure in chamber **20** is then gradually reduced until it reaches a value of approximately 5×10^{-5} mm. Hg, or lower. The pressure in outer chamber **21** is maintained at a value of approximately 3×10^{-4} mm. Hg, or lower. The arc may be initiated at startup with a pressure lower than 3×10^{-3} mm. Hg provided the R.F. voltage **31** and the operating potential are correspondingly increased.

There are several other conventional methods for helping to initiate an arc discharge between the electrodes **1** and **2** other than that specified above, such as applying a very high starting potential between the electrodes, heating the electrodes until they are completely out-gassed and then applying a high starting potential between the electrodes, or by providing an auxiliary electrode adjacent to the cathode and momentarily touching the cathode with said auxiliary electrode while at the same time applying a voltage between the cathode and auxiliary electrode until an arc is struck between them and then gradually separating said electrodes while applying an arc potential between the cathode and anode, and then removing the auxiliary electrode.

During all stages of operation of a device having the dimensions referred to above, a magnetic field strength of a selected value in the range of 3000 to 6000 gausses is maintained by the magnets **11** and **12** as the pressure in chamber **20** is lowered, the voltage across the electrodes is increased and when the pressure in chamber **20** reaches a normal operating value, for example 5×10^{-5} mm. Hg, the voltage across the electrodes **1** and **2** is approximately 200 volts and the arc current reaches a value of approximately 150 amperes for a four inch arc.

In order for the arc to operate under the preceding conditions, the gas feed to the cathode face and to the inside of the anode is maintained at rates sufficient to cause space charge neutralization within and at the face of the cathode and to insure complete ionization of the gas within the anode. Also it is necessary that the bores of the cathode and anode are in accurate alignment with the magnetic field.

Under normal operating conditions, electrons are accelerated toward the anode and ions are accelerated along the magnetic field toward the cathode by an axial potential gradient in the arc. A large number of the ions that are accelerated to the cathode and that recombine will then be prevented from flowing back as neutral particles by the baffles **18** between the cathode and the working volume of the arc. Baffles **18** and **19** also serve as a means for preventing any gas particles that escape from the electrodes from entering into the working volume of the arc without first becoming ionized by the discharge.

The arc described above is an efficient dissociating device. It has been determined that this arc has break-up efficiencies of 15% when used for dissociating 20 kev. deuterium molecular ions.

Referring now to Fig. 2, which illustrates another embodiment of an apparatus in which the principles of this invention may be carried out, there is shown an example of a device in which an energetic deuterium or tritium gas arc discharge can be initiated and sustained between a hollow cup-shaped cathode and a hollow cup-shaped anode. The device set forth in Fig. 2 is similar to Fig. 1 of the application of John S. Luce, Serial No. 748,771, filed July 15, 1958, aforementioned, except for the following differences. Magnetic mirror coils are provided in lieu of end magnets. Also, gas is fed to the inside base of the follow anode in Fig. 2 of the instant application.

In Fig. 2, an elongated hollow cup-shaped cathode electrode **40** is mounted in a copper hub **42** which is insulatingly supported by member **78** to the outer chamber wall **52**. An elongated hollow cupshaped anode electrode **41** is mounted in a copper block **43** which is insulatingly supported by member **93** to the chamber wall **52**. Float-

ing cathode shields 44 and 45 are mounted by insulators 47 and 48, respectively, to the outer chamber wall 52. Floating anode shield 46 is mounted by an insulator 49 to the chamber wall 52. A strong magnetic mirror field, for example, 6000 gausses, is provided by the magnetic mirror coils 50 and 51, the direction of the field indicated by the arrow H. Deuterium or tritium gas is fed from source 53, through tube 54, and through tube 74 to the inside of the hollow cathode 40 in an area adjacent to the base thereof. Deuterium or tritium gas is fed from a source 75, through tube 76, and through tube 77 to the inside of the hollow anode 41 in an area adjacent to the base thereof. The cathode 40 and anode 41 are cooled by a cooling fluid which is passed through tubes 73, mounted in the members 42 and 43, respectively, from a source not shown.

An outer vacuum chamber 60 is formed by the walls 52, and is connected to a vacuum pump by the tube 62. An inner vacuum chamber 59 is formed by the walls 56, as shown, and is connected to a vacuum pump by the tubular member 61. Apertured baffles 57 are provided adjacent to the cathode 40, and apertured baffles 58 are provided adjacent to the anode 41. These baffles are insulatingly supported and are designed to closely fit the arc discharge the same as the hollow anode. An arc initiating assisting means such as an R.F. voltage source 71, which may be a conventional welding source, is connected at one end to anode 41 by a lead 72, and at its other end to cathode 40 by a lead 70, switch 69, and lead 68. An operating potential 64 is connected between the anode and cathode. Potential 64, which may be a variable-tap, multi-cell battery is connected at one side to cathode 40, by a lead 63, and at its other side to anode 41, by a lead 65, switch 66, and lead 67.

In one example of the device, illustrated in Fig. 2, the cathode was 5 inches long, had an outer diameter of 0.75 inch, and an inner diameter of 0.375 inch. The anode was 5 inches long, had an outer diameter of 0.75 inch, and an inner diameter of 0.5 inch. As in Fig. 1 above, there is clearance between the arc discharge 55 and the inner surface of hollow anode 41 of approximately $\frac{1}{16}$ inch.

In accordance with the invention, as illustrated in Fig. 2, by regulating the rate of gas flow to the hollow cathode, it is possible under proper pressure conditions to provide an arc discharge which runs from the inner surface of the cathode. Under these conditions, substantially complete space-charge neutralization is provided inside the cathode. Under low pressures, for example 3×10^{-5} mm. Hg. or lower, the arc in the modification of Fig. 2 is a hollow cylinder and the arc current is carried in this cylinder close to the inside cathode wall. The arc depends upon emission across the magnetic field within the hollow cathode, no decrease in emission occurs when the arc is operated in a strong magnetic field, for example, a field of 6000 gausses.

There are at least three unique characteristics of the deuterium or tritium arc discharge, illustrated in the apparatus of Fig. 2, which distinguishes it from other arcs and which permits it to be very energetic. The first characteristic is the cross field emission, achieved by provision of a large surface area from which electrons may enter the system. The deuterium or tritium gas which is fed into the inside of the hollow cathode is substantially completely ionized before it leaves the cathode. Since there is adequate space-charge neutralization inside the cathode, it is possible to decrease the pressure without affecting the emission characteristics of the arc. The second distinguishing characteristic of the arc of Fig. 2 is the existence of an axial potential gradient in the arc. Electrons are accelerated radially from the inside wall of the cathode. Some of those electrons which suffer collisions before returning to the wall are trapped close to the cathode inside wall and thereupon are drawn out of the cathode by this axial potential gradient. The third

distinguishing characteristic of the arc of Fig. 2 is the fact that it fits very close to the inside wall of the hollow anode and gas that is fed into the base of said anode is substantially completely ionized before it leaves the anode.

In one operation of the device of Fig. 2, having the dimensions referred to above, at startup, gas is fed from source 53 and through tubes 54 and 74 to the inside of cathode 40, and gas is fed from source 75, and through tubes 76 and 77 to the inside of anode 41 until the pressure in the cathode 40, in the anode 41, and in chamber 59 reaches a value of approximately 3×10^{-3} mm. Hg, and a R.F. voltage source 71 is then applied across the electrodes 40, 41. Also, a D.C. voltage source 64 is connected between the electrodes. The arc is initiated at the faces 80 and 81 of the cathode 40 and anode 41, respectively. After the arc 55 is initiated, the R.F. source 71 is disconnected and the gas feed from sources 53 and 75 is reduced until the arc moves from the faces 80 and 81 of the electrodes into the interior of the electrodes which may be observed visually. The gas feed to the arc is maintained at a rate just sufficient to provide complete space charge neutralization within the hollow cathode 40 and to provide substantially complete ionization of the gas within hollow anode 41, while the pressure in chamber 59 is gradually reduced until it reaches a value of approximately 3×10^{-5} mm. Hg or lower. The pressure in outer chamber 60 is maintained at a value of approximately 3×10^{-4} mm. Hg or lower.

During all stages of operation of the device of Fig. 2 having the dimensions above, a magnetic field strength of about 6000 gausses is maintained by the magnetic mirror coils 50 and 51. As the pressure in chamber 59 is lowered, the voltage across the electrodes is increased and when the pressure in chamber 59 reaches a normal operating value, for example 3×10^{-5} mm. Hg, the voltage across the electrodes 40 and 41 is approximately 400 volts and the arc current reaches a value of approximately 100 amperes.

As in Fig. 1 above, there are several other conventional ways, as discussed above, for striking the arc and at lower pressures.

In order for the arc of Fig. 2 to operate from within the cathode and under the preceding conditions, it is necessary that the gas flow be maintained at a rate sufficiently low that adequate space charge neutralization is provided inside the cathode, and that the bore of the cathode is in accurate alignment with the magnetic field.

The baffles 57 and 58 of Fig. 2, referred to above, serve the same purpose as the baffles 18 and 19 of Fig. 1.

The arc described for Fig. 2 above is an efficient dissociating device. It has been determined that this arc has break-up efficiencies of 25% when used for dissociating 20 kev. deuterium molecular ions.

The arc formed by the device of Fig. 2, as discussed above, is substantially a hollow arc. In addition to its usefulness for dissociating and/or ionizing of molecular ions, this arc is useful in reducing the instreaming of cold neutrals from the vessel walls into the plasma of a thermonuclear machine such as disclosed in the application of John S. Luce, Serial No. 728,754, aforementioned. In using the deuterium or tritium arc of Fig. 2 in the machine therein described, the magnetic mirror coils at the ends of said machine permit the hollow arc to be enlarged in the center portion where the molecular ions are injected. Under such conditions, the thermonuclear plasma is confined within the hollow arc and some of the energetic particles from the plasma will penetrate the arc and strike the walls of the machine. However, low energy neutrals resulting from this bombardment and other processes cannot pass back through the arc barrier and enter the plasma without being ionized in the arc. The ions thus formed are then collimated by the magnetic field and accelerated out of the arc by the potential gradients that exist in the arc discharge.

It has been determined that a substantial quantity

of the energetic ions that are accelerated toward the cathode of Fig. 2 by the large potential gradients in the arc spread out on their way to the cathode and strike the end baffle **57**. This propulsion of energetic ions may be useful in the ion propulsion of space vehicles in regions of negligible atmospheric pressure. Fig. 3 shows a use for the discharge of Fig. 3 for propulsion of energetic ions. The baffles, the end cathode shield, the hub around the cathode, and the end wall of the device of Fig. 2 have been removed, as illustrated in the device of Fig. 3. Also, the cathode is supported by a plurality of radially-extending spokes, and no vacuum pump is connected to the chamber since the device, when used in a space vehicle, will be connected directly to the negligible atmospheric pressure in space through the open end wall of the chamber. With the provision of spokes for mounting the cathode and the elimination of the baffles, end shield, and end wall of the chamber, the energetic ions that spread out on their accelerated return toward the cathode will be propelled past the outside of the cathode and through the spokes into space.

Referring now to Fig. 3, which illustrates an apparatus for propulsion of energetic ions, an elongated cup-shaped cathode electrode **85** is mounted to a plurality of radially extending spokes **87**, **88** and **89** which are in turn insulatingly supported to the chamber wall **102**. An elongated hollow cup-shaped anode electrode **86** is mounted in a copper block **90** which is insulatingly supported by a member **109** to the chamber wall **102**. The anode **86** is cooled by a plurality of cooling tubes **110**, mounted in block **90**, by passing a cooling fluid through these tubes from a cooling source, not shown. Gas is fed from a source **97**, through tube **100**, and through tube **96** to the interior of hollow cathode **85** at the base thereof. Gas is fed from a source **99**, through tube **101**, and through tube **99** to the interior of hollow anode **86**. An annular cathode shield **91** is mounted to the chamber wall **102** by insulators **94** and **95**. Annular magnetic mirror coils **103** and **104** are provided. Mirror coil **103** is mounted to the chamber wall **102** by insulators **105** and **106**. Mirror coil **104** is mounted to the chamber wall **102** by insulators **107** and **108**. An anode shield **92** is mounted to chamber wall **102** by an insulator **93**.

A source of R.F. voltage **111** is connected at one end to cathode **85** by leads **112** and **113**, and at its other end to anode **86** by lead **114**, switch **115**, lead **116**, and lead **117**. A source of operating potential **118**, such as a variable-tap multi-cell battery, is connected at one side to cathode **85** by a lead **119** and lead **113**, and at its other side to anode **86** by lead **120**, switch **121**, lead **122**, and lead **117**.

The arc discharge **123** of Fig. 3 may be initiated in any of the conventional ways as discussed above. As in Fig. 2, the discharge of Fig. 3 is terminated from within the hollow electrodes and said electrodes closely fit the discharge so that the feed gas fed to the interiors of both electrodes is substantially completely ionized before it leaves the electrodes. The arc discharge **125** is made up of substantially completely ionized ions, and electrons. These energetic ions are accelerated toward the cathode by the potential gradients in the arc and are collimated by the magnetic field. As discussed above, a portion of these ions are propelled past the cathode as indicated by the streams **124** of ions. As indicated above, these streams of energetic ions may be propelled into outer space when the device is used in a space vehicle.

Fig. 4 shows a sectional view of the cathode supporting structure when viewed from the sectional line **4—4** of Fig. 3. As shown on the drawing the radial spokes **87**, **88** and **89** are shown mounted to the cathode **85** and to the chamber wall **102**.

The arcs described above have been operated with other gases, for example, air, hydrogen, argon, nitrogen and helium, and may be operated with most other gases. However, the use of deuterium or tritium is preferred for thermonuclear reactions since they introduce the least amount of extraneous material into the discharges.

The arcs described above can also be used to provide a source of energetic ions and electrons.

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 establishing a high-intensity or energetic gas arc discharge which comprises a containing vessel, means for evacuating said vessel to a selected pressure, an elongated cathode electrode provided with a central axial chamber, and an elongated hollow cup-shaped anode electrode having a larger inner diameter than that of said cathode, said anode and cathode having a common axis and being widely spaced apart in confronting relation within said vessel; a plurality of annular baffles disposed adjacent to the confronting faces of said anode and cathode and having an inner diameter substantially equal to that of said anode; means for establishing a magnetic field within said chamber oriented parallel to said axis, means for feeding gas at controlled rates to the interiors of both said electrodes so that space-charge neutralization occurs at said cathode, means for striking and maintaining an energetic arc discharge between said electrodes, and means for cooling said electrodes, said discharge forming a cylinder extending into said anode chamber so that gas fed to said anode is completely ionized therewithin.

2. The device as set forth in claim 1 in which the cathode chamber is hollow and cup-shaped, and the feed gas rate is controlled so that the arc discharge terminates from within said hollow cathode and substantially complete space-charge neutralization occurs within said hollow cathode.

3. The device as set forth in claim 1 in which the cathode chamber is a small axial aperture, and the feed gas rate is controlled so that the substantially complete space-charge neutralization occurs within said aperture and at the face of said cathode.

4. A device for producing a directed stream of energetic ions for ionic propulsion comprising a vessel having an open end, an elongated hollow cup-shaped cathode electrode and an elongated hollow cup-shape anode electrode having a common axis and being widely spaced apart in confronting relation within said vessel, said anode having a larger inner diameter than that of said cathode, means for establishing a magnetic field within said vessel oriented parallel to said axis, means for feeding gas at controlled rates to the interiors of both said electrodes, means for striking and maintaining an energetic arc discharge of ions and electrons between the inner surfaces of said electrodes, said arc substantially completely ionizing said feed gas within the hollow electrodes, said cathode being supported within said chamber by a plurality of radially extending members affixed to said cathode and chamber, said energetic ions being accelerated toward said cathode by a potential gradient in the discharge established so that a portion of said ions are accelerated around the outside of said cathode, through said members, and through the open end of said vessel in a collimated stream directed approximately parallel to said magnetic field.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,920,235 January 5, 1960

Persa R. Bell et al.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, lines 25 and 26, for "Patent No. 2,895,053, issued July 14, 1959" read -- Patent No. 2,920,234, issued January 5, 1960 --.

Signed and sealed this 26th day of July 1960.

(SEAL)

Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents

UNITED STATES PATENT OFFICE

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