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APPARATUS AND METHOD FOR GENERATING AND ACCELERATING IONS

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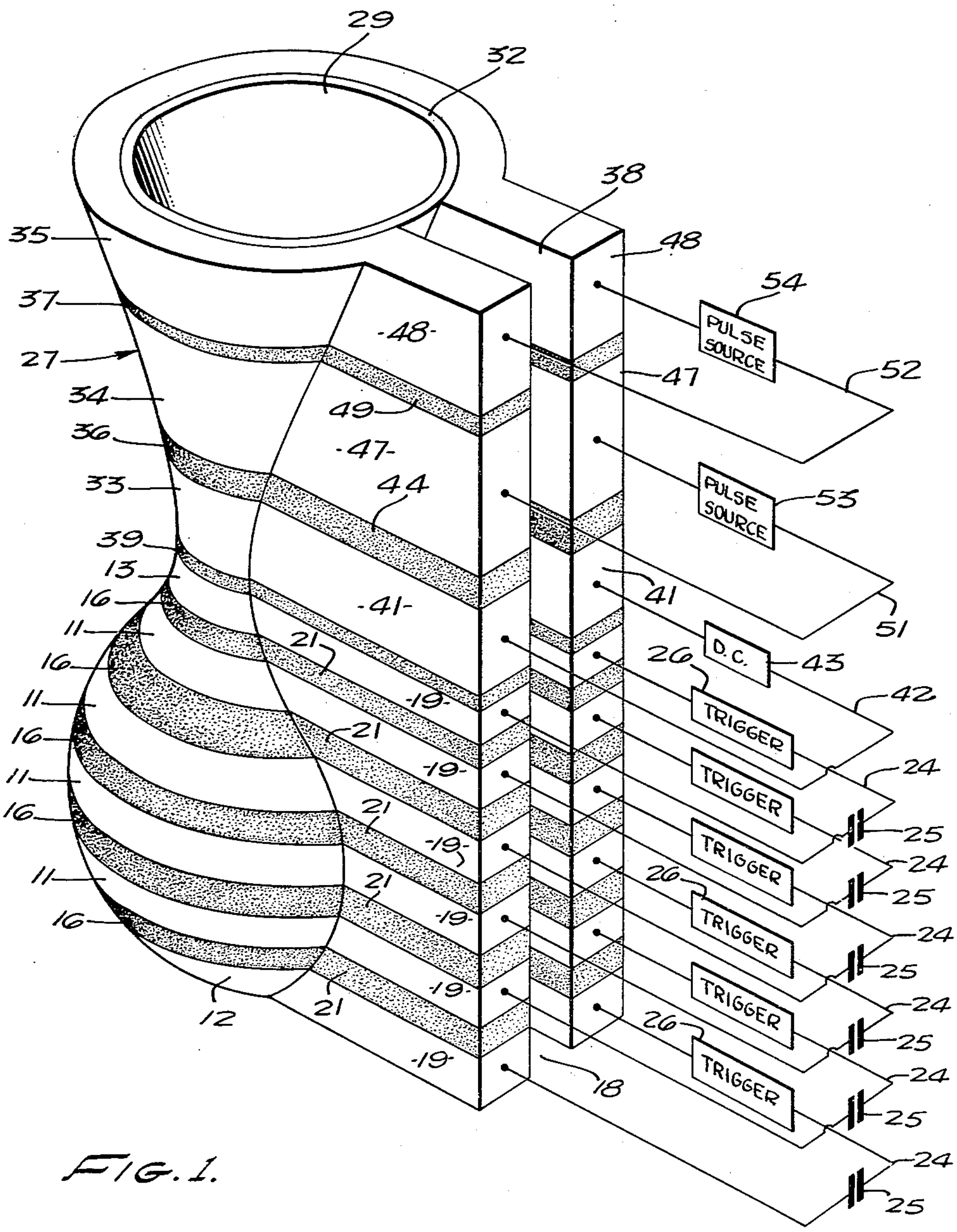

FIG. 1.

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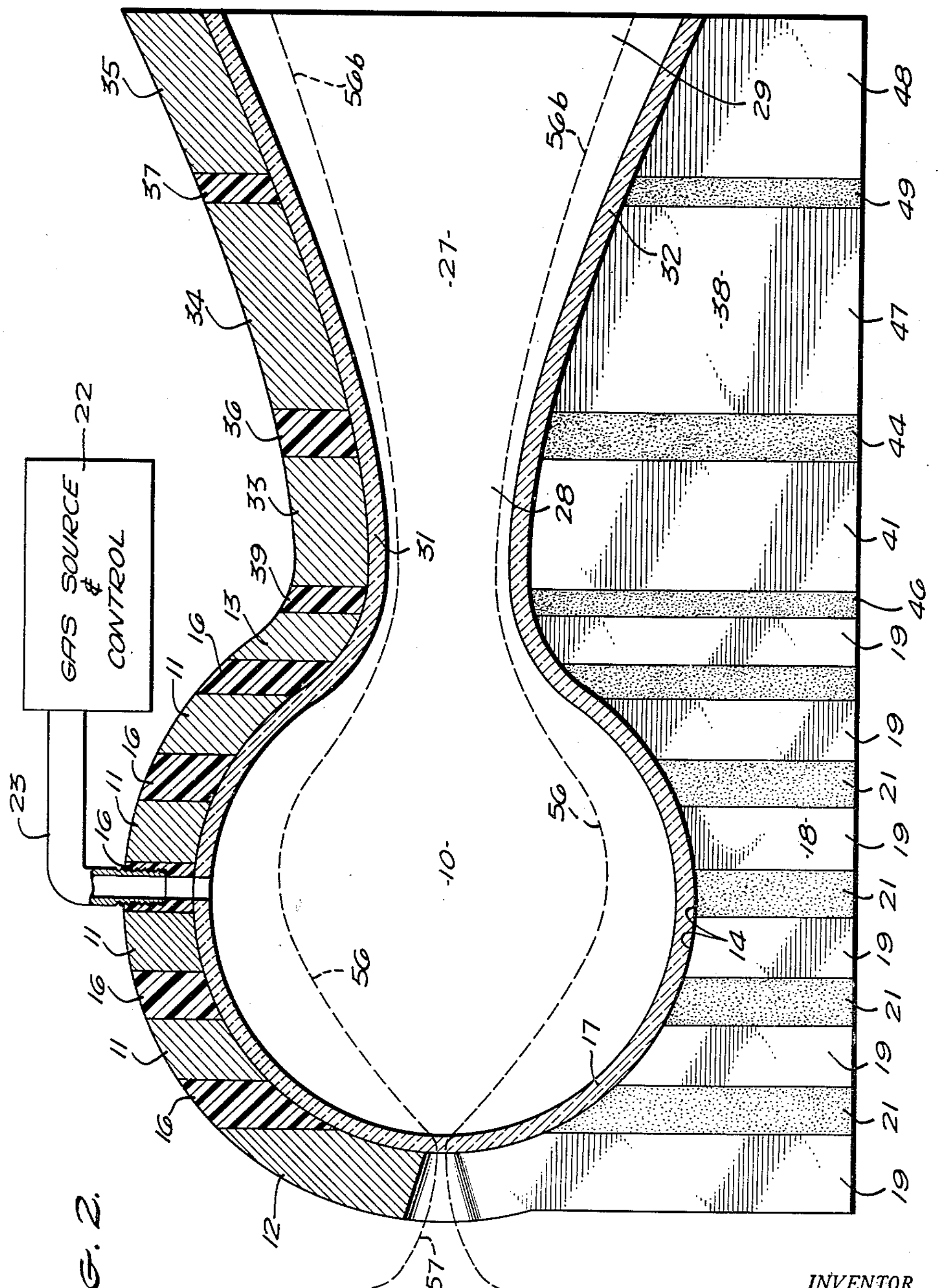

FIG. 2

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APPARATUS AND METHOD FOR GENERATING AND ACCELERATING IONS

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11 Claims. (Cl. 60—35.5)

This invention relates to an apparatus and method for generating and accelerating ions, particularly where such ions are to be discharged into an evacuated region.

It is an object of the present invention to provide an efficient and effective method and apparatus for generating ions and then accelerating such ions, together with neutral gas, into a region where a substantial vacuum exists.

A further object is to provide a method and apparatus for accelerating ions due to magnetic action, while simultaneously accelerating both ions and neutral particles due to the effects of heat and pressure created during the ion-generation operation.

These and other objects and advantages of the invention will be set forth more fully in the following specification and claims, considered in connection with the attached drawings to which they relate.

In the drawings:

Figure 1 is a perspective view schematically representing an ion generator and accelerator constructed in accordance with the present invention, and including a showing of the associated electric circuit means; and

Figure 2 is a longitudinal central section of the apparatus, and schematically representing the gas source and control.

Stated generally, the apparatus comprises means to define an implosion chamber, magnetic means to create an implosion in such chamber, and discharge or nozzle means to discharge both ions and neutral gas therefrom. Means are provided to effect, in combination with the implosion means, acceleration of ions out the nozzle means and also to maintain the ions out of contact with the walls of the apparatus.

Proceeding first to a description of the means for defining the implosion chamber, which has been given the reference numeral **10**, this comprises a plurality of continuous loop-like electrical conductors disposed in generally parallel relationship and having such shapes that a sphere or spheroid is formed. The conductors between the poles of the sphere have been given the reference numeral **11**, and the conductors at the poles have been given the reference numerals **12** and **13**. The implosion chamber **10** thus has a generally spherical or spheroidal wall **14** formed by the inner surfaces of conductors **11—13** and of insulators **16** which separate the conductors. A spherical or spheroidal envelope **17** is provided in the implosion chamber, preferably having its outer wall closely adjacent the wall **14**. The envelope is formed of quartz or other suitable non-conductor.

Stated with greater particularity, the illustrated conductors **11—13** comprise spherical segments of a single hollow sphere or spheroid, and the insulator **16** also comprise segments of such hollow sphere or spheroid. The conductors **12** and **13** constitutes the polar spherical segments of the sphere or spheroid, and the conductors **11** constitute the intermediate segments. In the illustrated form, the outer surfaces of the elements **11—13** and **16** comprise zones of a first sphere, and the inner surfaces thereof comprise zones of a second sphere having a smaller diameter but a common center. The last-mentioned sphere is the one which comprises the wall **14** of chamber **10**.

Each of the conductors **11—13** forms part of a single-turn electrical circuit which extends, from one side of a gap or split **18** therein, around the chamber **10** to the other side of such gap or split. In order to conduct current to and from the electrical conductors on opposite sides of the gaps **18**, conductor bars or arms **19** are provided. The bars **19** are preferably integral with the conductors **11—13**, respectively, and all are formed of a good electrically-conductive metal such as copper. The insulators **21** separating the bars **19** are illustrated as being integral with the insulators **16** between the various conductors **11—13**.

When a high-current pulse is passed substantially simultaneously through each conductor **11—13**, during a very short period of time and in the same direction, a strong magnetic field is formed to result in acceleration of ionized particles in chamber **10** toward the center portion thereof. This effect, which may be characterized as an inwardly-directed blast or implosion, generates a high temperature in the chamber **10**, particularly at the center or axis portion thereof. In order to maintain the conductors and insulators in assembled condition despite the strong magnetic forces involved, it is within the scope of the invention to suitably reinforce the apparatus such as by embedding the same in a large block of insulating material, which may be jacketed and reinforced with metal at a location remote from the implosion chamber.

The gas particles which are the subject of the implosion are introduced into the chamber **10** from a suitable gas source and control indicated schematically at **22** in Figure 2. Source **22** is shown as communicating through conduit means **23** with the chamber **10** at the equatorial portion of the sphere. Suitable means, not shown, may be provided to effect a certain degree of pre-ionization of the gas injected from the source into chamber **10**, thereby aiding in the above-described implosion effect. It is to be understood, however, that the implosion greatly increases the degree of ionization of the gas, and furthermore effects acceleration of the ionized particles, and also neutral particles, out the discharge or nozzle means to be described hereinafter.

From the above it will be understood that the conductors **11—13** constitute portions of the magnetic means to generate the implosion in chamber **10**. Proceeding next to a description of additional portions of such implosion-generating means, and with particular reference to Figure 1, electrical conductors **24** are connected between the two bars **19** for each of the spherical segments **11—13**. Interposed in each conductor **24** are a capacitor means **25** and a trigger **26**. Means, not shown, are provided to effect charging of the capacitor means **25** to corresponding polarities, so that upon discharge of the capacitor means currents will flow through the above-described single-turn circuits and in corresponding directions. It is to be understood that the various triggers **26** may be suitably related by appropriate electronic apparatus in order to effect simultaneous or substantially simultaneous discharge thereof. The discharge currents flow, as stated above, in the same direction about the axis of the sphere.

The discharge and nozzle means for discharging both ionized and neutral gas from the implosion chamber **10** is indicated generally at **27**, having a narrow or throat portion at **28** and a wide or divergent portion at **29**. Such means **27** is adapted to discharge the gas into an evacuated region, for example outer space in situations where the present apparatus is employed as a propulsion means.

Stated more definitely, the throat portion 28 is enclosed by a relatively small-diameter non-conductive envelope portion 31 which forms an extension of the previously-described envelope 17 and is located at one pole thereof, generally adjacent the polar conductor 13. Envelope portion 31 may be integral with the portion 17 and also with a divergent envelope portion 32 which is generally frustoconical in shape and which surrounds the wide or divergent nozzle portion 29. Nozzle portion 29 is open to a region, such as outer space, where a vacuum exists.

Proceeding to a description of the means which, in combination with the implosion means, accelerate ions out the discharge or nozzle means 27, and which maintain the ions out of contact with the envelope portions 31 and 32, this comprises a plurality of single-turn annular conductors 33—35 disposed concentrically around the axis of the nozzle means 27 and separated by insulators 36 and 37. The conductors 33—35 are each formed with a split or gap 38, such splits or gaps being shown in alignment with the previously-indicated gaps 18.

Conductor 33 is disposed at the throat 28, being separated from the previously-described polar conductor 13 by means of an insulator 39. Bars or arms 41 are connected to the conductor 33, on opposite sides of the gap or split 38 therein, and extend outwardly for connection to a conductor 42. The conductor 42 has interposed therein a suitable current source 43 adapted to deliver a high direct current through the conductor 42, the bars 41, and the annular conductor 33 in single-turn relationship. The flow of direct current creates a magnetic field which aids in maintaining the ionized particles out of contact with the interior wall of envelope portion 31. Insulators 44 and 46 are provided on the sides of the bars 41, being integral, respectively, with the insulators 36 and 39.

The remaining annular conductors, 34 and 35, are mounted closely around the divergent envelope portion 32, being split as indicated at 38 and having bars or arms 47 and 48 respectively connected thereto. Such bars or arms are insulated from each other by insulators 49 formed integral with the insulator 37. Conductors 51 and 52 connect the bars or arms 47 and 48 for each annular conductor 34 and 35, and have interposed therein suitable sources 53 and 54 of high-current pulses. These sources are adapted to deliver high-current pulses in timed relation to the operation of triggers 26, to the introduction of gas from source 22, and to each other. The polarities of the pulse sources 53 and 54 should correspond to the polarity of D.C. source 43 and to the polarities of capacitor means 45, so that all of the currents flow about the axis of the apparatus in the same direction.

In summary, the pulse source 53, upon becoming operative, creates a momentary flow of large current through the conductor 51, one of the bars 47, annular conductor 34, the other bar 47, and back through conductor 51 to the other terminal of the source 53. Pulse source 54, upon becoming operative, effects momentary flow of a large current through conductor 52, one of the bars 48, annular conductor 35, the other bar 48, and back through the conductor 52 to the other source terminal.

When current is flowing simultaneously in all of the described conductors, and in corresponding directions as stated, lines of magnetic force are generated as partially indicated at 56, for example, it being understood that the lines of force have unshown portions located externally of the illustrated apparatus so that closed loops result. The lines of force pass through a relatively small opening 57 located in polar conductor 12 coaxial with the throat portion 28 of the nozzle or discharge means. It is emphasized, however, that the opening 57 has a substantially smaller diameter than the inner diameter of throat conductor 33, so that the portions of lines of force 56 in opening 57 are spaced much farther apart than are the portions passing through the throat 28.

It is to be understood that the amount of current passed through throat conductor 33 is insufficient to generate a magnetic field great enough to pinch the lines of force 56 closely together when they pass through throat 28, and thereby destroy the above-indicated relationship whereby the lines of force are spaced farther apart in the throat than in opening 57. It is also to be understood that other and unshown lines of force may be present in the apparatus which do not pass the full length thereof but instead pass out between various ones of the annular conductors. The latter is particularly true where the pulse sources 53 and 54 are operated subsequently to triggers 26 instead of at the same time. In this connection, it is pointed out that the sources 53 and 54, triggers 26, and control 22 may all be associated through a master control and timing network adapted to provide pulsing at the exact desired times and in correlation to the flow of gas into the implosion chamber.

Description of the method

The method of the invention may best be described with reference to the apparatus shown in the drawings, although it is to be understood that the method may be performed with other apparatus as well.

The gas source 22 is first employed to introduce through conduit 23 a small charge of a gas, such as argon, which is readily ionized. Before the gas charge is introduced, the capacitor means 25 are charged, with corresponding polarities, from the unshown voltage source or sources. Such charging is effected when the triggers 26 are in open-circuit condition. Triggers 26 are then operated to closed circuit condition, either at the same instant at time or at slightly different times, to discharge the capacitor means 25. It is to be understood that the capacitor means have large capacities, and that the single-turn circuit means have very low inductances. Thus, the current flow through each single-turn circuit lasts for only a short period of time (such as a millionth of a second) but is large (such as thousands or millions of amperes).

The corresponding current flow through the annular conductors 11—13 results in the formation of an induced current sheet flowing in the opposite direction and through the gas. Such induced current sheet is located within the chamber 10 and is initially relatively close to the interior wall of portion 17 of the non-conductive envelope.

The sheet of induced current, composed of ions and electrons, acts as a barricade through which the lines of magnetic force (generated by flow of current in conductors 11—13) may not pass in quantity. This is particularly true where, as in the present situation, the rate of change of magnetic field strength is great. This being the case, at least a majority of lines of magnetic force initially pass (in a spheroidal configuration) between the wall 14 and the current sheet—or largely through the envelope portion 17.

The generally spheroidal magnetic field acts as a piston to drive (implode) the current sheet, that is to say the ions and electrons, radially-inwardly toward the center portion of chamber 10. As the current sheet collapses toward the center, in a shock wave, the lines of magnetic force collapse toward the center (in the above-indicated piston action) to compress the gas and greatly elevate its temperature because of the speed and collision of the particles. The inward movement continues until the external magnetic pressure is counterbalanced by the internal pressure resulting from compression and temperature increase. It is pointed out that the illustrated lines of magnetic force 56, in chamber 10, are in partially-collapsed condition, that is to say they are illustrated during an intermediate portion of the implosion.

The pressure created by the implosion results in the outflow of gas, both ionized and neutral, through the discharge or nozzle means **27**. Thus, the implosion operates, as such, to effect acceleration of gas out the discharge means **27** and into the evacuated space. However, there is an additional means for accelerating the ionized particles from the implosion chamber **10** into the throat **28** of the nozzle means. Such means is magnetic, and results from the fact that the lines of magnetic force **56**, etc., may not flow through the electrical conductor **12** while it is conducting a rapidly-varying current. Accordingly, the lines **56** must bunch together at the opening **57**, such bunching being much greater than that effected at the nozzle throat **28**, as previously stated. The portions of the lines of magnetic force inwardly adjacent opening **57** act as a mirror, known as a Fermi mirror, to reflect the ionized particles toward the discharge means **27**.

As previously indicated, the method also comprises passing direct current from source **43** through the throat conductor **33**. This generates a magnetic field in the throat portion **28** which tends to maintain the ionized particles away from the portion **31** of the envelope, it being understood that ionized particles do not pass in quantity across lines of magnetic force. It follows that the ionized particles will flow generally through the central portion of the nozzle throat **28** and thence out the divergent portion **29** to the evacuated space. It is to be remembered, however, that the strength of the current flowing through the throat conductor **33** is not sufficient to effect such bunching of the adjacent portions of the lines of magnetic force as to destroy the previously-described Fermi mirror effect.

The method further comprises effecting flow of large currents from both sources **53** and **54** through the annular conductors **34** and **35** at the same time that the ionized particles enter the divergent portion of the nozzle or discharge means **27**. Such current flows operate, in the manner of flow of current through a solenoid, to generate the portions of the lines of magnetic force indicated at **56*b***. Since the annular conductors **34** and **35** diverge away from throat **28**, in frustoconical relationship, the magnetic line portion **56*b*** also diverges to reflect the ionized particles out into the evacuated region.

In view of the above, it will be understood that the apparatus produces two ion-reflecting effects, one adjacent the opening **57** and the other in the divergent portion **29** of the discharge opening. Such reflection of the ions, in combination with the above-described discharge action produced by the pressure of the implosion, result in a highly-efficient flow of ions, and also neutral particles, out of the apparatus.

It is within the scope of the method to pulse the operation, with a high rate of repetition. Thus, the gas source and control is operated at a predetermined instant of time to inject a charge of gas into implosion chamber **10**, such gas being substantially immediately subjected to the implosion due to operation of the triggers **26**. As soon as the resulting "puff" of gas begins to emerge from the nozzle throat **28**, the pulse sources **54** are operated to act upon the gas puff and aid in ejecting it into the evacuated region. All of the described apparatus is thus operated in timed relationship to produce a large number of puffs. The resulting reaction produced in the apparatus may be employed to propel a satellite, for example, after it reaches outer space.

The amount of gas employed may be small, since the pressure in chamber **10** immediately subsequent to injection of gas need only be on the order of 10^{-3}–10^{-5} millimeters of mercury, or lower.

Various embodiments of the present invention, in addition to what has been illustrated and described in detail, may be employed without departing from the scope of the accompanying claims.

I claim:

1. An ion generator, comprising means to define an implosion chamber, current-conductor means provided around said chamber, discharge means extending from said chamber generally coaxial with said current-conductor means, means to charge said chamber with gas at a pressure which is a small fraction of atmospheric pressure, and means to pass through said current-conductor means a large current having an order of magnitude of at least thousands of amperes for a brief period of time on the order of microseconds to thereby generate an implosion in said chamber with consequent outflow of gas through said discharge means.

2. Ion apparatus, comprising single-turn electrical conductor means shaped to define a generally spheroidal cavity, said conductor means being generally coaxial with a given axis of said cavity, outlet means located at one pole of said axis for discharge of gas from said cavity, means to charge said cavity with gas, and power supply means to effect flow of a high current through said conductor means and in a single direction about said given axis, said current flow being rapidly varying in nature to thereby cause an implosion in said cavity with consequent flow of ionized gas therefrom through said outlet means.

3. The invention as claimed in claim 2, in which said conductor means comprises a substantial number of conductors shaped generally as spherical segments, in which means are provided to insulate said segments from each other, and in which said power supply means comprises means to feed current to each of said segments for single-turn flow therethrough in the same direction as the flow of current through each other of said segments.

4. The invention as claimed in claim 2, in which said electrical-conductor means extends substantially to the other pole of said given axis, and in which an opening is provided adjacent said other pole and has a cross-sectional area substantially smaller than the cross-sectional area of said outlet means, whereby the lines of magnetic force generated due to said current flow tend to bunch at said opening adjacent said other pole to create a Fermi mirror effect reflecting ions towards said outlet means.

5. Ion generation and acceleration apparatus, which comprises means to define an implosion chamber, outlet means to discharge gas from said implosion chamber into an evacuated space, means to charge said implosion chamber with gas, and electromagnetic means to generate an implosion in said implosion chamber and simultaneously create a Fermi mirror directed from the inside of said chamber toward said outlet means, whereby said implosion and said Fermi mirror combine to effect flow of gas through said outlet means and into said evacuated space.

6. The invention as claimed in claim 5, in which means are provided on the opposite side of said outlet means from said implosion chamber to create a second Fermi mirror operating to reflect ionized particles away from said implosion chamber after passage thereof through said outlet means.

7. The invention as claimed in claim 5, in which means are provided at said outlet means to maintain the ionized particles out of engagement with the interior wall of said outlet means.

8. Propulsion apparatus, which comprises electrical conductor means shaped to define a generally spheroidal cavity and to effect flow of current around a given axis of said cavity in a single direction, nozzle means communicating with said cavity at one pole of said given axis, said nozzle means having a throat portion adjacent said cavity and a divergent portion diverging away from said cavity, second electrical conductor means disposed generally coaxially with said first-mentioned conductor means to effect flow of current in a single direction about an extension of said axis which extends through said

nozzle means, means to charge said cavity with gas, capacitor means connected to said first-mentioned conductor means, means to discharge said capacitor means through a low-inductance circuit including said first-mentioned conductor means to thereby effect flow of a large current for a short period of time in said single direction about said axis to create an implosion in said cavity, and means to feed a pulse of electric current to said second conductor means at approximately the time gas reaches said nozzle means due to said implosion, said second conductor means and the current supply means therefor operating to produce a Fermi mirror effect to reflect ionized particles away from said cavity and out said divergent portion of said nozzle means.

9. The invention as claimed in claim 8, in which said first-mentioned conductor means adjacent the other pole of said given axis is provided with a relatively small-diameter opening smaller than that of said electrical-conductor means at said one pole, whereby a Fermi-

mirror effect is created in said cavity to reflect ionized particles outwardly through said nozzle means.

10. The invention as claimed in claim 9, in which all of said conductor means comprise a plurality of generally parallel, single-turn conductors disposed coaxial with said axis and said extension of said axis, and each having a gap or split at one point therein.

11. The invention as claimed in claim 8, in which means are provided to effect flow of direct current around the throat portion of said nozzle means to thereby maintain the ionized particles away from the wall of said throat.

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