United States Patent

Hirsch

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[45] **May 23, 1972**

[54] **ELECTROSTATIC CONTAINMENT IN FUSION REACTORS**

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[73] Assignee: **International Telephone and Telegraph Corporation**, Nutley, N.J.

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[21] Appl. No.: **738,940**

[52] **U.S. Cl.** **176/1**, 176/2, 315/111, 313/61

[51] **Int. Cl.** **G21b 1/00**

[58] **Field of Search** 176/1, 2

[56] **References Cited**

UNITED STATES PATENTS

3,258,402	6/1966	Farnsworth	176/1
3,386,883	6/1968	Farnsworth	176/1

Primary Examiner—Reuben Epstein

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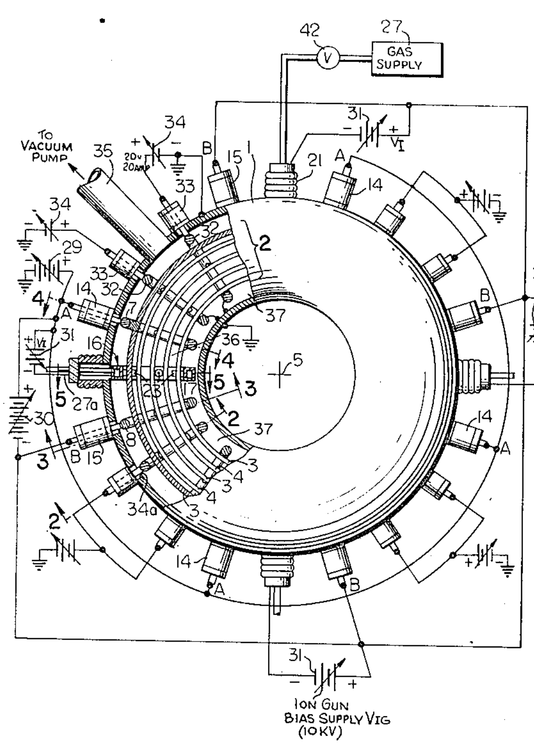
[57] **ABSTRACT**

Apparatus is disclosed for producing controlled nuclear-fusion reactions. A generally circular cathode has concentrically positioned therein a generally circular anode having multiple openings for the free flow of electrons therethrough. The anode encloses a volume free of tangible structure. An electron-emissive electrode in the interelectrode space between the anode and cathode emits electrons which penetrate the anode and enter the central volume, establishing a negative space charge therein. Ions of a fusion reacting gas are injected at a location within the volume, at a potential less than that applied to the anode, and are focused toward a common cross-over point in the central portion thereof. The magnitude of the negative space charge as well as the energies of the ions introduced into the volume are so controlled that collisions of the ions at or near the cross-over point result in the fusing thereof.

Electrons introduced in the interelectrode space traverse the cathodic space, thereby making a number of trips through the anode.

In this invention, the anode structure is effectively shielded such that electron interception thereby with consequent high energy electron losses can be made to approach zero. This is accomplished by creating a magnetic field around the portions of the anode which define the openings, this field serving to shield the conducting portions thereof.

9 Claims, 11 Drawing Figures



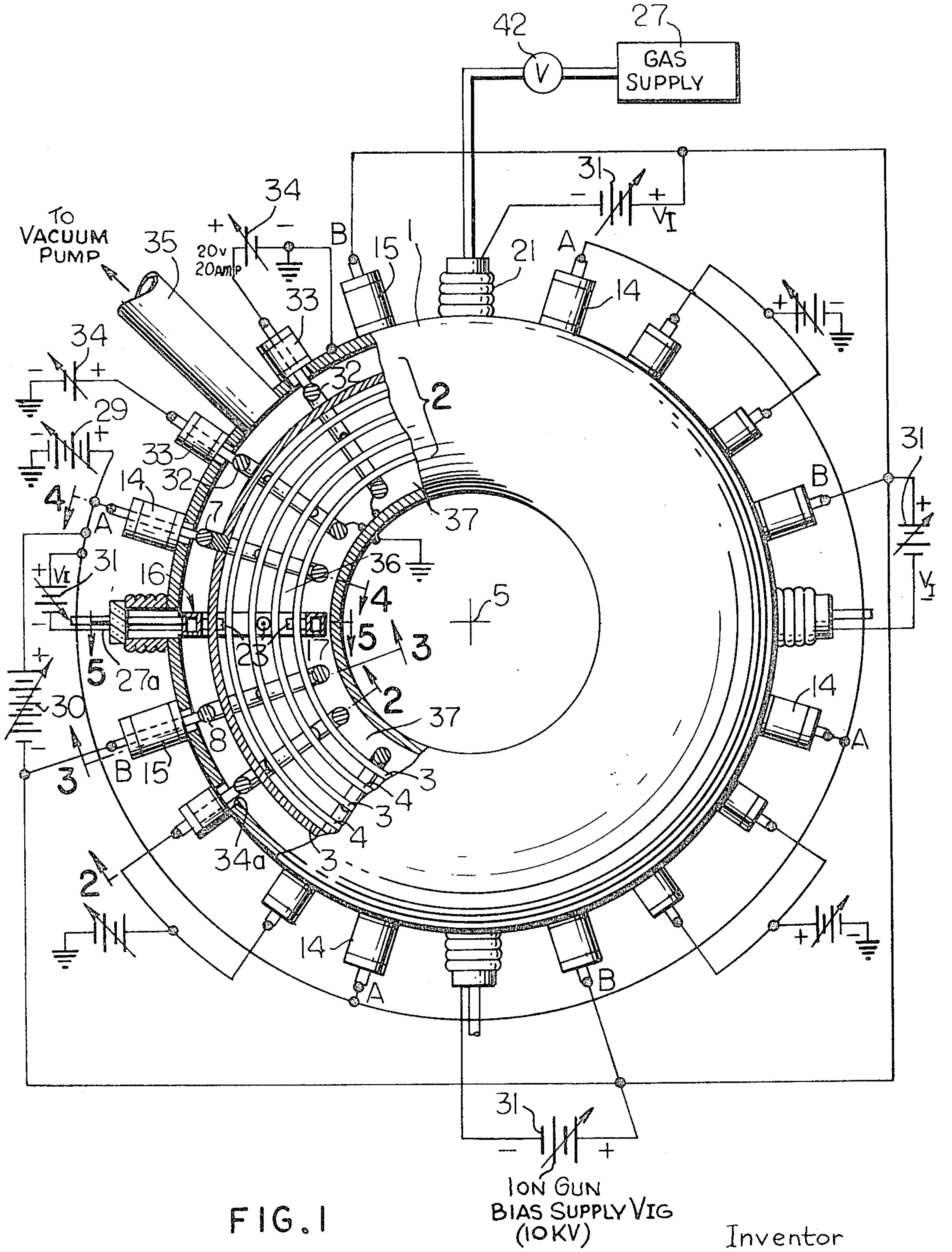


FIG. 1

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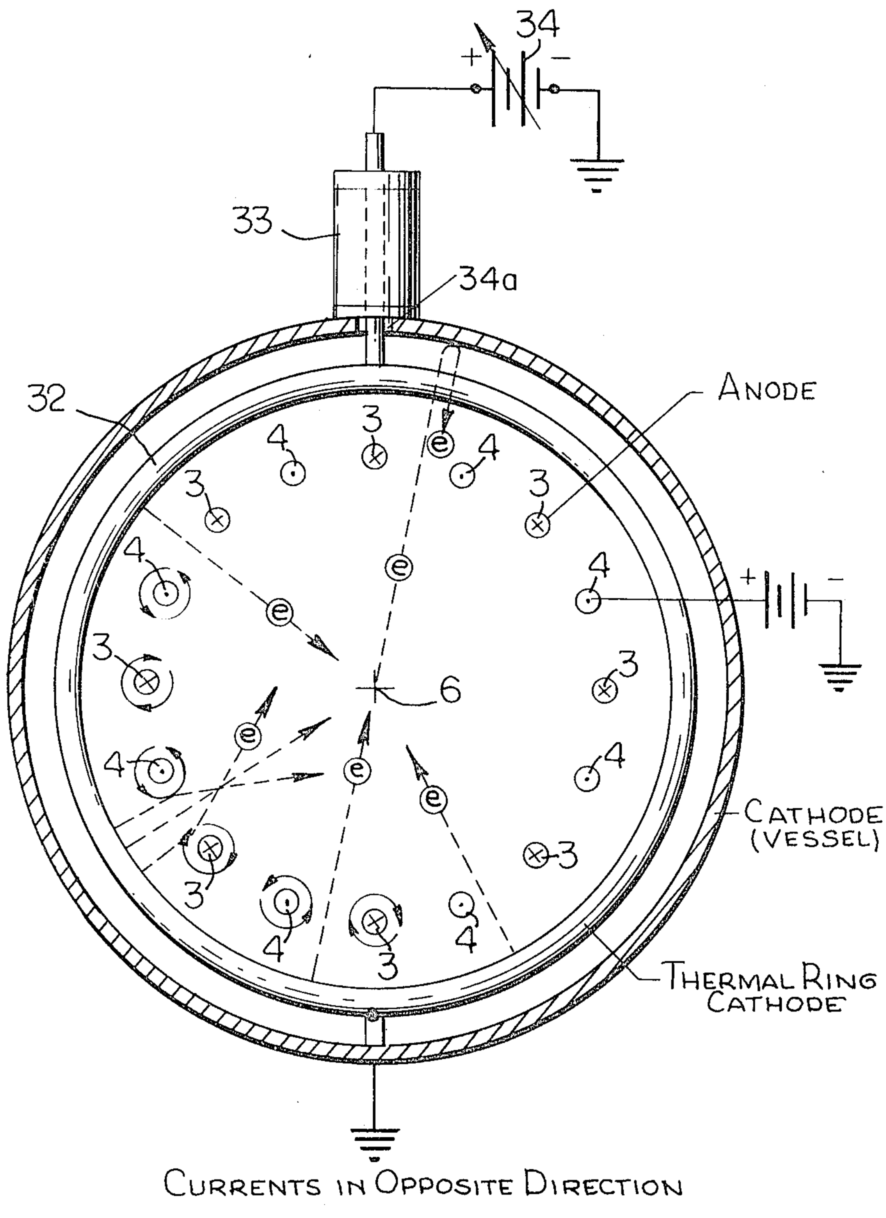

FIG. 2

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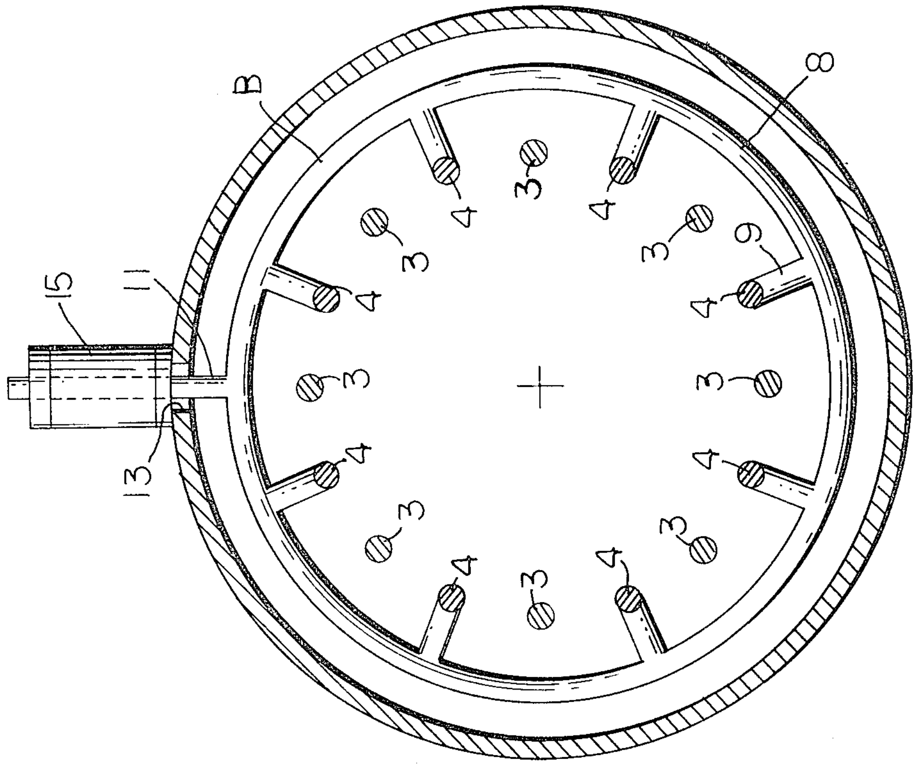

FIG. 3

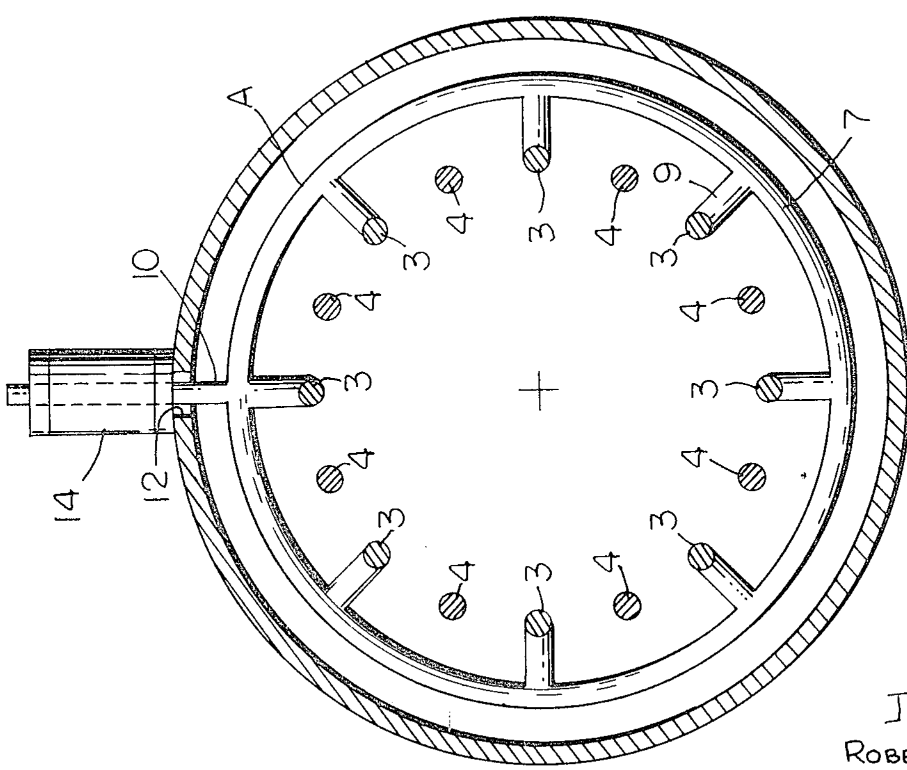

FIG. 4

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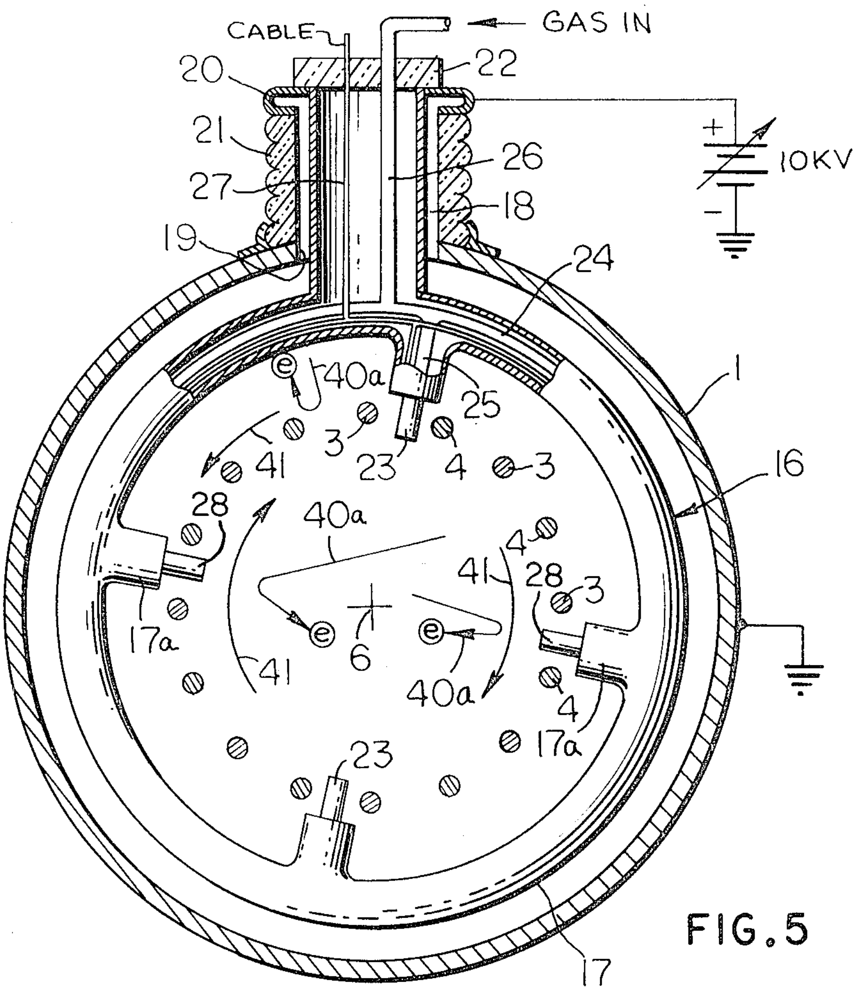

FIG. 5

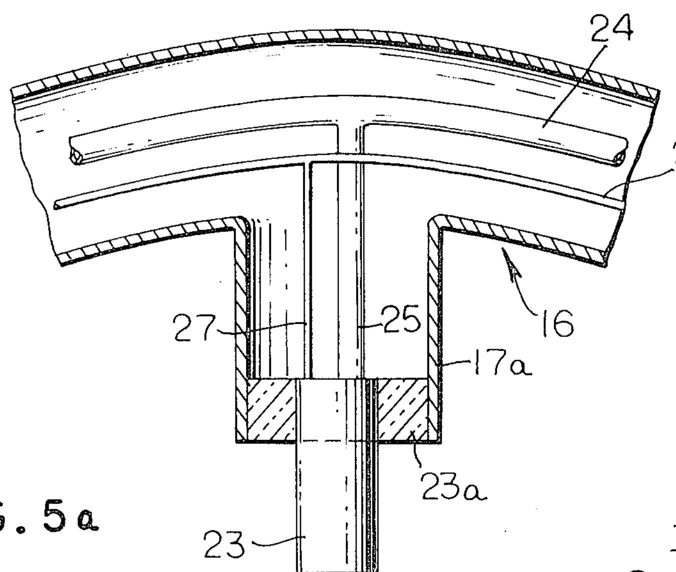

FIG. 5a

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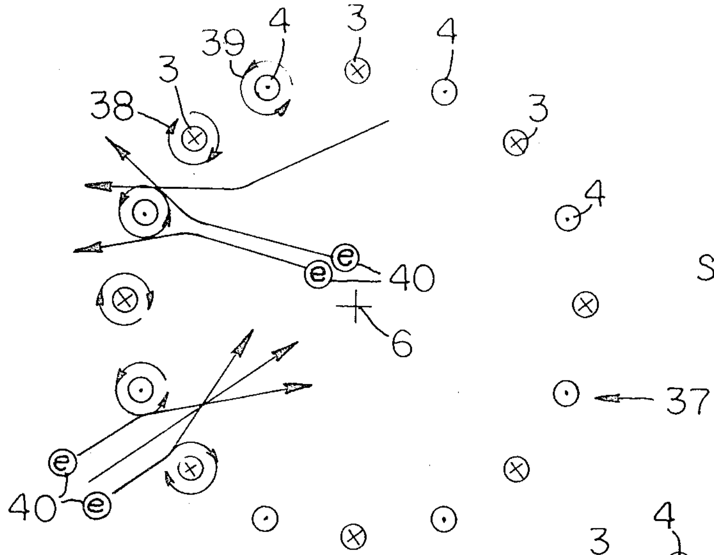

FIG. 6

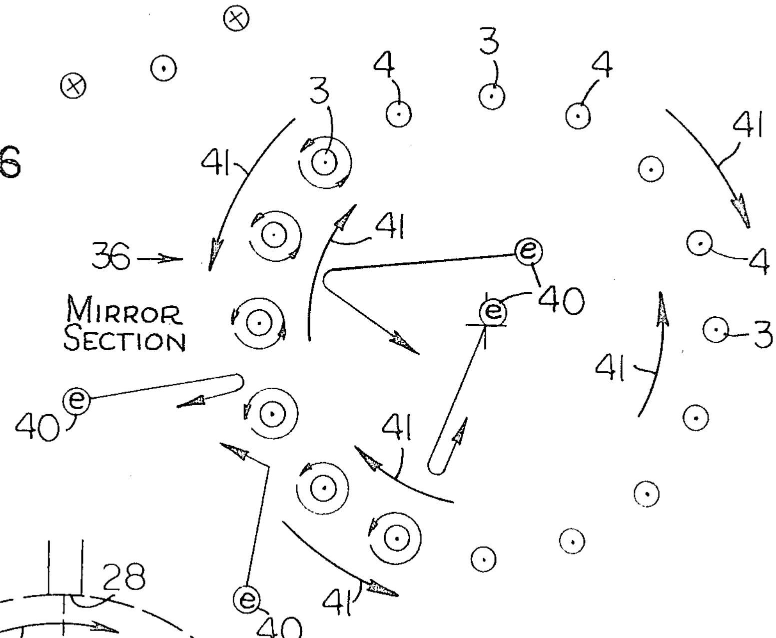

FIG. 7

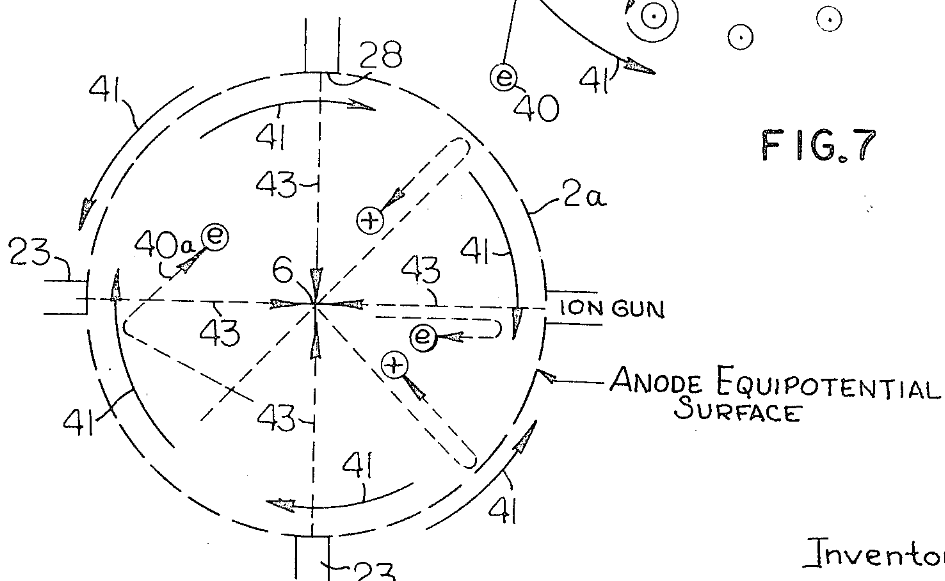

FIG. 10

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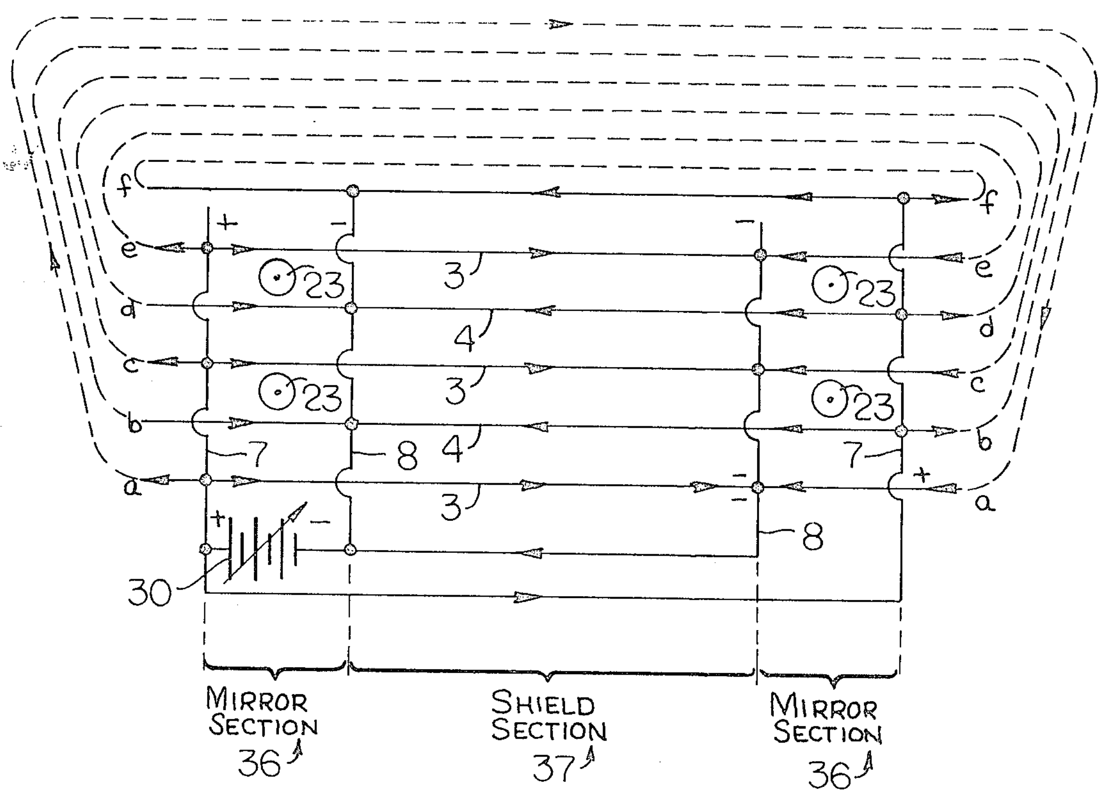
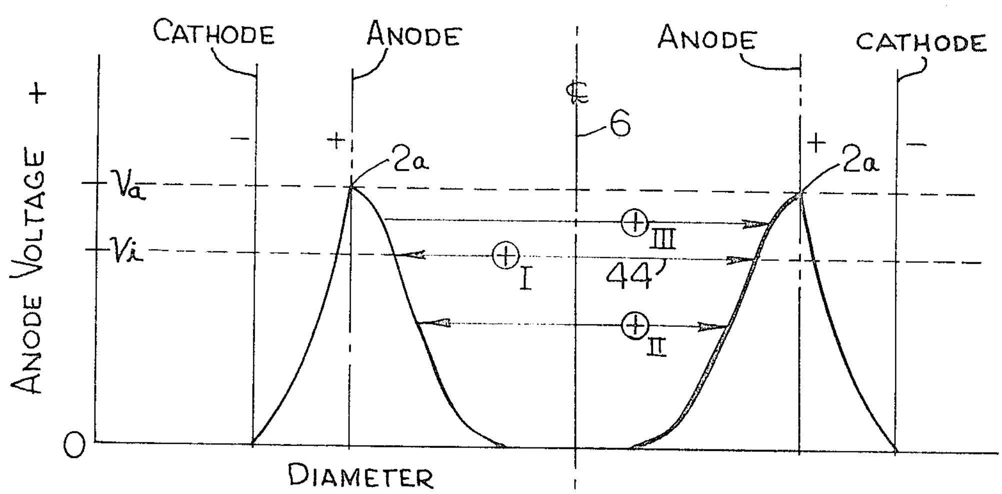


FIG. 8



CLASS I IONS – AT INJECTION POTENTIAL Vi
CLASS II IONS – SCATTERED DOWNWARDLY IN POTENTIAL
CLASS III IONS – SCATTERED UPWARDLY IN POTENTIAL

FIG. 9

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ELECTROSTATIC CONTAINMENT IN FUSION REACTORS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to apparatus for producing controlled nuclear-fusion reactions, and more particularly to improvements in such apparatus wherein the plasma is electrostatically contained.

2. Description Of The Prior Art

In Farnsworth U.S. Pat. No. 3,258,402, issued June 28, 1966, as well as Farnsworth U.S. Pat. No. 3,386,883, issued June 4, 1968 there are disclosed methods and apparatuses capable of producing continuous fusion reactions. Generally speaking, the apparatuses of these prior patents utilize a spherical geometry in which two generally spherical electrodes, one a cathode and the other an anode, are concentrically positioned with one inside the other. Whichever of the anode and cathode is innermost, it is provided with a multiplicity of openings through which charged particles may flow. In the case in which the anode is innermost, energetic electrons circulating through the anode provide a negative space charge inside the anodic cavity, while in the second case in which the cathode is innermost, this involves energetic ion circulation through the cathode for creating a periodic space charge.

Principal problems characteristic of both of these are (1) power loss due to particle interception by the inner electrode, (2) mechanical failure due to overheating of the electrode as well as other parts, and (3) impurity liberation due to sputtering and vaporization.

Since as between the two cases mentioned in the foregoing a much lower ion current, as compared to the electron current, is required to produce a saturated space charge in the central volume, ion injection into the central volume has been preferred in order to minimize the aforementioned problems.

SUMMARY OF THE INVENTION

In accordance with the broader aspects of this invention, there is provided an apparatus for generating fusion reactions in which a circular cathode concentrically envelopes a circular anode which in turn encloses a volume free of tangible structure. The anode is a gridwork permeable to the flow of electrons therethrough, but is substantially impervious to the flow of ions. Means are provided for applying a potential to the anode and cathode for establishing an electric field of high order magnitude therebetween. Electrons are introduced into the interelectrode space between the anode and cathode which pass through openings in the anode enter the volume to form a negative space charge. Ions are injected into the volume at a potential less than that applied to the anode such that the ions are thereby contained in the volume electrostatically while the electrons are free to traverse the entire cathodic space, passing through the anode in transit.

The anode is a gridwork of current-conducting self-supporting bars which extend substantially parallel to each other and which are spaced apart to provide the openings. Means are provided for passing currents through the bars for providing magnetic shields thereabout which inhibit electron interception. In one region of the device, currents in adjacent bars are opposite to provide anode regions permeable to electron flow while in another region the currents in adjacent bars are in the same direction so as to provide a magnetic field on the anode (mirror section) impervious to electrons. Ions may be injected into the anodic volume at the mirror section. Inasmuch as the magnetic fields effectively retard electron interception by the anode, high energy electron loss to the anode is rendered negligible, thereby preserving the electron circulatory current for developing the necessary negative space charge within the anodic volume which serves in establishing the necessary difference of potential therein for imparting fusion-reacting energies to the contained ions.

OBJECTS OF THE INVENTION

It is an object of this invention to provide apparatus for producing nuclear fusion reactions with greater efficiency than has heretofore been achieved in similar apparatuses.

It is another object of this invention to provide improvements in the electrostatic confinement of plasmas in apparatus for producing fusion reactions by conserving the high energy electrons used in developing the necessary entrapping electric field.

It is another object of this invention to provide the apertured anode of the above-described fusion-producing apparatus with effective shielding which inhibits interception of the electrons by the anode, thereby conserving not only the electrons themselves but also the energies thereof.

DESCRIPTION OF THE DRAWINGS

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

FIG. **1** is a side view, partially broken away and sectioned for clarity of illustration, of one embodiment of this invention;

FIG. **2** is a cross-section taken substantially along section line **2—2** of FIG. **1**;

FIGS. **3**, **4** and **5** are cross-sections taken substantially along section lines **3—3**, **4—4** and **5—5**, respectively, of FIG. **1**;

FIG. *5a* is an enlarged, fragmentary view, partly sectioned, of the ion gun assembly;

FIGS. **6** and **7** are diagrammatic illustrations used in explaining the operation of this invention;

FIG. **8** is a schematic illustration, developed into a flat plane, of the anode structure of FIG. **1**;

FIG. **9** is a graph showing the potential distribution diametrically of the device of FIG. **1**; and

FIG. **10** is a diagrammatic illustration used in explaining the operation of the ion guns shown in FIG. **1**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, and more particularly to FIGS. **1** through **5**, the embodiment of this invention shown is of toroidal shape; however, it should be understood that shapes such as cylindrical and spherical may be used without departing from the spirit and scope of this invention. In the illustrated embodiment, a stainless steel vessel **1**, hermetically sealed so that it can be evacuated, serves as the cathode. Within the cathode **1** is centrally and concentrically positioned an anode structure, generally indicated by the numeral **2**, in the form of a gridwork of a plurality of self-supporting annular bars or wires **3** and **4** which are spaced apart and arranged (when viewed in cross-section) in a circular pattern as shown more clearly in FIGS. **2** through **5**. These bars **3** and **4** are equally circumferentially spaced in a circular pattern having an axis **6** as shown in FIG. **2**, and extend parallel to each other and concentric about the axis **5** of the torus (FIG. **1**).

Supporting the bars **3** and **4** rigidly inside the cathode **1** are a plurality of annular, conductive, supporting members, termed headers **7** and **8**. These headers **7** and **8**, as shown more clearly in FIGS. **3** and **4**, coaxially surround the anode structure **2** and are provided with a plurality of radially inwardly directed stubs **9**. It should be noted that the bars **3** and **4** are alternated around the circumference of the anode **2** and that the header **7** is connected to the bars **3** while the header **8** is connected only to the bars **4**. Both of the headers **7** and **8** are rigidly mounted in position by means of the central conductive rod of a respective standoff insulator, header **7** being supported on the inner end of such a rod **10** and the header **8** on a rod **11**. Both rods **10** and **11** pass through companion apertures **12** and **13**, respectively, which are hermetically sealed by insulators **14** and **15**.

As shown more clearly in FIG. **1**, the two headers **7** and **8** are mounted relatively close to each other so as to receive therebetween an ion gun assembly indicated generally by the numeral **16**. There are four pairs of headers **7** and **8** equally spaced around the structure, each pair of headers having an ion gun assembly disposed therebetween.

One ion gun assembly **16** is shown in more detail in FIGS. **1**, **5** and **5***a*. This assembly includes an annular, hermetically sealed chamber or plenum **17** having a hollow stem **18** that projects through an opening **19** in the cathode **1**. The upper end of the stem **18** is secured to a metallic mounting ring **20** hermetically secured to the upper end of a hollow standoff insulator **21** which in turn is hermetically secured to the cathode **1** in registry with the opening **19**. The upper end of the stem **1** is sealed by means of a ceramic or the like cap **22**. This structure is of adequate rigidity to secure firmly the plenum **17** concentrically about the anode **2**.

Four ion guns **23** equally circumferentially spaced apart are mounted on the inside of the plenum **17** as shown, and are so aligned as to emit beams of ions radially inwardly toward the axis **6**. Four inwardly directed tubular portions **17***a* on the plenum **17** mount the guns **23**, respectively, by metallic mounting plate **23***a* fitted into the respective portions **17***a* securing the guns **23** in place. While four such guns are shown, it should be understood that a larger or smaller number may be used without departing from the spirit and scope of this invention.

Each of the guns **23** receives a supply of fusion-reactive gas from an annular manifold **24** fitted inside the plenum **17**. A branch conduit **25** leads from the manifold **24** to each of the guns **23** for supplying neutral gas thereto.

A combination mounting and inlet tube **26** is secured at one end to the manifold **24** and extends outwardly through the stem **18** and cap **22** for connection to a suitable source of fusion-reactive gas as indicated by the numeral **27***a* in FIG. **1**. The tube **26** is sealed hermetically to the cap **22** to prevent leakage. The inlet **26** as well as the manifold **24** are of sufficient strength and rigidity to be self-supporting inside the plenum **17**.

Electrical leads for the various ion guns **23** are also fed through the plenum **17**, these leads passing to the outside of the cathode **1** via the stem **18** and the insulator **21**. A cable containing the necessary number of wires for supplying operating potentials to the ion guns **23** is indicated by the numeral **27**.

The ion guns **23** may be of any suitable design, typical structures being those disposed and claimed in Hirsch-Meeks application, Ser. No. 585,901, filed Oct. 11, 1966, entitled "Ion Gun Improvement."

As seen in FIG. **5**, the bars or conductors **3** and **4** are equally spaced apart and define a circle into which the ion guns **23** project. The inner ends **28** of the ion guns **23**, from which ion beams issue, are disposed inside the circle defined by conductors **3** and **4** as shown. The guns **23** are adapted to emit beams toward the center **6**, this center being the common cross-over point for all of these beams. It may be stated at this point that conductors **3** and **4** produce an equipotential surface which is circular and substantially coincident therewith. The ends **28** of ion guns **23** are disposed inside this equipotential surface, and the ions issuing therefrom are at a potential less positive than that of this equipotential surface. Thus, the ions will be trapped inside this surface which may be regarded as a virtual anode.

Potentials are applied to the various electrodes as shown in FIG. **1**. A high voltage supply indicated by numeral **29** and adjustable between zero (0) and 150-kv, for example, is connected between the cathode **1** and anode **2** as shown, the cathode **1** being grounded. The positive side of the supply **29** is connected to the anode **2** via the feedthrough insulators **14** and headers **7**. Headers **8** have the same voltage applied thereto by means of the connection provided by the low voltage power supply **30**. Thus, all of the conductors **3** and **4** have high voltage applied thereto as will be explained in greater detail hereinafter.

A high current, low voltage power supply **30** capable of supplying, for example, 10 volts at 4,000 amperes, is connected between the headers **7** and **8** as shown for the purpose of producing current flow in each of the conductors **3** and **4**. The precise manner of connection of the supply **30** to the headers **7** and **8**, and the headers **7** and **8** themselves to the conductors **3** and **4**, is more clearly shown in the planar diagram of FIG. **8**. The two pairs of headers **7**, **8** shown in FIG. **8** represent circumferentially adjacent pairs in FIG. **1**. This diagram in FIG. **8** shows only two of these header pairs as well as only a total of six (6) conductors **3**, **4** as illustrative of the pattern of connection between all of the headers **7** and **8** and the conductors **3** and **4** of FIG. **1**. This will be further explained later on.

The positive terminal of the high voltage supply **29** is also connected to the ion guns via a biasing battery **31**. This battery **31** is of low voltage and maintains the ion guns **23** and the ions emitted thereby at a slightly lower voltage than that of the anode **2** for reasons already mentioned herein.

A plurality of electron-emissive, ring cathodes **32** are mounted in the interelectrode space between the cathode **1** and anode **2** between header pairs **7**, **8** as shown. These cathodes **32**, shown more clearly in FIG. **2**, coaxially surround the anode **2**. Suitable standoff insulators **33** are used to mount rigidly the cathodes **32** in place, the conducting bars of these insulators **33** passing through clearance holes **34***a*, in the cathode **1** as shown. The insulators **33** themselves are suitably hermetically sealed to the cathode **1**.

The cathodes **32** are thermionic, one point thereof being grounded to the cathode **1** as shown and another point 180° removed therefrom is connected to the conductor surrounded by a feedthrough insulator **33** for connection to a suitable filament supply **34** as shown more clearly in FIG. **2**. These cathodes **32** may be indirectly heated oxide cathodes with heaters inside. The cathodes **32** are designed to be emissive of electrons around the entire circumference thereof. While eight such cathodes **32** are illustrated in FIG. **1**, it should be understood that a greater or fewer number of such cathodes may be used without departing from the spirit and scope of this invention. The number of such cathodes **32** required will depend upon the size and operating characteristics desired of the completed apparatus, but suffice it to say, a sufficient number are required as will establish a negative space charge in the central volume encircled by the anode **2** as will be explained in more detail later on.

One or more exhaust connections **35** are connected to the cathode **1** as shown for evacuating the interior thereof.

Considering for the moment only the anode **2** and the operation thereof, reference to FIG. **8** indicates that currents flow in the conductors **3** and **4** in the directions shown. Between each pair of headers **7** and **8**, the currents in all of the conductors **3** and **4** flow in common directions. However, between adjacent headers **8**, the currents flow in opposite directions. The same is true for those conductors between two adjacent headers **7**. Thus, the anode **2** may be considered as being composed of two different sections, repeated circumferentially about the core, one being characterized as an "electron mirror" and the other as an "electron shield." In FIG. **8**, the numeral **36** indicates the "mirror sections," while the numeral **37** indicates the shields. More specifically, the mirror sections **36** of the anode are those in which the currents are flowing in the same direction in the conductors **3** and **4**, as, for example, those portions of the conductors **3** and **4** between headers **7** and **8**. The shield sections **37** are those portions of the anode **2** between headers in which the currents and conductors **3** in **4** are flowing in opposite directions. In FIG. **8**, one such section **37** is indicated as extending between the adjacent headers **8**.

Now referring to FIG. **1**, it will be seen that all of the ion gun assemblies **16** are mounted in the mirror sections while all of the cathodes **32** are in the regions of the shield sections **37**.

In FIGS. **6** and **7** are diagrammatic illustrations in cross-section of the shield and mirror sections **37** and **36**, respectively. Considering the shield section **37** first, in which the currents in the conductors **3** and **4** are flowing in opposite directions, each conductor will have a magnetic field thereabout as indicated by the field lines **38** and **39**, respectively. Around the conductor **3**, the magnetic field lines are clockwise while around the conductor **4** the field lines **39** are counterclockwise. Electron trajectories initially directed toward the conductor circle from both inside and out as shown pass through the spaces between the conductors **3**, **4**. Electrons **40**, upon approaching a conductor **3** or **4**, are deflected by the magnetic field thereabout thereby avoiding interception, it being remembered that each of the conductors **3** and **4** is positive with respect to the cathode from which the electrons originate. Thus, it may be generalized that in those sections of the anode in which the currents in the conductors **3** and **4** flow in opposite directions, the conductors are effectively shielded such that the electrons flow freely through the anode openings; hence, all of the conductors **3** and **4** are characterized as being shielded from electron interception by virtue of the magnetic fields **38** and **39**.

In FIG. **7**, the conductors **3** and **4** have the currents flowing in the same direction, thereby setting up an anode-enveloping field which is impervious to electron flow. This enveloping magnetic field is indicated by the field lines **41**, these extending substantially concentrically with respect to the circle defined by the conductors **3** and **4**. Thus, any electrons traveling toward the circle from either inside or outside the anode **2** will be reflected and will not penetrate the anode openings.

These mirror sections **36** provide regions wherein ions may be inserted into the volume inside anode **2**. If ions were injected into the interelectrode space between the cathode **1** and anode **2**, these ions would immediately be attracted to the cathode **1** and lost.

If any ion guns were installed in the cathode **1** in the interelectrode space occupied by the shield sections **37**, the intense electron circulatory current would impinge and perhaps destroy them. Thus, it is necessary to install the ion guns **23** at a location, namely in the region of the mirror sections **36**, in the apparatus where electron circulatory currents will do the least damage (see FIGS. **5**, **7** and **8**). The encircling magnetic field **41** (FIG. **7**) inside the conductor circle **3**, **4** (see FIG. **10**) reflects electrons away from the ion guns minimizing electron impingement thereon, this condition being shown in FIGS. **5** and **10** by the electron trajectories indicated by the numerals **40***a*.

The plenums **17** in the interelectrode space are near anode potential but do not intercept electrons since they are prevented from entering the space outside of the mirror sections.

Recapitulating, the purpose of the mirror sections **36** in the anode **2** is to provide a convenient and effective means for injecting ions into the volume inside the anode **2** without causing damage to the guns **23**. The purpose of the shield sections **37** is to prevent electron interception by the anode **2**, the reason for this becoming apparent from the description that follows.

Explaining now the operation of the total apparatus, the vessel **1** is initially evacuated to a pressure in the vicinity of 10^{-8} to 10^{-9} torr. Potentials are applied to the electrodes as already described and fusion-reactive gas, such as deuterium, tri-tium or a combination of the two, is admitted to the various ion guns **23** by means of valves indicated by the numeral **42** in FIG. **1**. Potentials are applied to the conductors **3** and **4** of the anode **2** for establishing the magnetic fields previously described, and the thermionic cathodes **32** are energized. Because of the high difference of potential in the interelectrode space between the cathode **1** and anode **2**, the electrons emitted by the cathodes **32** flow inwardly toward the anode **2**. An equipotential surface which is generally circular in cross-section and coincident with the circle defined by the conductors **3** and **4** is formed and may be regarded as a virtual anode transparent in the shield sections **37** to electrons.

The electrons emitted by the cathodes **32** enter the central volume of the anode as indicated by the arrows in FIG. **6**. These electrons are deflected away from the individual conductors **3** and **4** because of the shielding magnetic fields thereabout as explained previously. The electrons that enter the anodic volume pass on through the virtual anode into the interelectrode space and form a negative space charge. As the electrons approach the cathode **1**, they encounter a decelerating negative field which turns them around and directs them back toward and through the anode once again. The net result is the establishment of a negative space charge in the anodic volume which sets up a potential distribution of generally circular configuration as depicted by the graph of FIG. **9**. At the virtual anode as indicated by the numeral **2***a* is FIG. **10**, the potential is near the anode potential. As the center **6** of the anodic space is approached, the potential rapidly diminishes to zero or that of the cathode **1**. Thus, there is established in the central portion of the anodic volume a negative potential well into which ions may fall.

Because of the shielding effect of the magnetic field about the individual conductors **3** and **4**, the electrons traverse the space inside the cathode numerous times before they are lost. The more trips an electron makes, the greater its contribution is to the creation of the necessary negative potential well inside the anode.

Certain electrons impact and are lost to the cathode **1**, but this is not necessarily deleterious inasmuch as relatively little energy is lost and secondary electrons are usually produced.

The gas introduced to the plenum **17** is distributed to the various ion guns **23** which ionize the gas and form beams which are focused toward the cross-over point **6**. This is illustrated more clearly in FIG. **10** wherein the dashed arrows **43** indicate the paths followed by such ion beams. The ends **28** of the ion guns **23** are at a position within the virtual anode **2***a* where the potential is V_i as shown in FIG. **9**, this potential V_i being perhaps 10 kilovolts less than V_a, the virtual anode potential. As shown in FIG. **9**, the ion guns **23** emit "Class I" ions which initially fall toward the center **6** with a velocity dependent upon the potential difference between V_i and that produced by the negative space charge which is the potential of the cathode **1**. Such ions travel onwardly past the center **6** and decelerate as they encounter the increasing positive potential on the opposite side of the volume. Such ions are thereupon reflected back toward the center **6**, repeating these diametral excursions a number of times building a high ion density at the center. The motions of the Class I ions is represented by the double-ended arrow **44** in FIG. **9**. Once the ion concentration in the anodic volume increases to a predetermined value, certain of the ions will be scattered, some downwardly in potential and others upwardly. These are indicated, respectively, in FIG. **9** by the symbols II and III. In any event, by reason of the circular uniformity of the potential distribution inside the anode as well as the fact that the ions are initially focused toward a common cross-over point or axis **6**, the resultant ion motions inside the anodic cavity will be primarily diametral with the ion paths intersecting on the axis **6** where the ion density will be highest. Ions that collide which are moving at fusion-reacting energies will fuse.

Because of the potential of the virtual anode **2***a* (FIGS. **9** and **10**), high energy ions moving along collision courses having a common cross-over point are effectively trapped or contained. These ions can make repeated trips inside the electrostatic cage without being lost, thereby contributing to the probability of ions fusing before being lost to competing reactions.

Electrons, on the other hand, which establish the negative potential well which surrounds the center **6** are preserved and suffer only minimal loss for the reason that the anode conductors are effectively shielded by the magnetic fields thereabout.

Ions are injected into the anodic volume at locations where the ion guns are protected from damage by electron interception. Thus, losses and damage heretofore encountered in prior art devices are effectively overcome by reason of the electron-shielding and guiding effects of the magnetic fields produced in the region of the anode.

While there have been described above the principles of this invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of the invention.

What is claimed is:

1. Improvements in apparatus for generating fusion reactions, comprising cathode means, anode means inside said cathode means, said anode means defining a volume centrally located with respect to both said anode and cathode means, said volume being free of tangible structure, said anode means including impervious conductive portions which define openings through which charged particles may freely pass, means for supplying electrons to the interelectrode space between said anode and cathode means, means for establishing a first magnetic field for inhibiting interception of said electrons by said conductive portions but rendering said openings permeable to the passage of electrons therethrough, means for applying a potential to said anode means which is positive with respect to said cathode means thereby producing an electric field in said interelectrode space which propels said electrons through said openings into said volume, means for introducing fusion reactive ions into said volume at a predetermined potential less than that applied to said anode means and for focusing said ions toward a common cross-over point in said volume, said electrons which penetrate said volume creating in the latter a negative potential, the positive potentials of said anode means and said ions being of a magnitude with respect to said negative potential sufficient to contain said ions in said volume and to impart fusion-reacting energies to said ions such that collisions of said ions produce fusion reactions.

2. The improvements of claim **1** wherein the conductive portions have a plurality of current-conducting paths extending in a common direction, and means for developing unidirectional currents in said conductive portions with the direction of current flow in adjacent paths being opposite.

3. The improvements of claim **1** wherein said conductive portions are elongated current-carrying elements which are spaced apart and parallel, the aforesaid openings being the spaces between said elements, and means for developing unidirectional currents in said elements with the direction of current flow in adjacent elements being opposite.

4. The improvements of claim **3** wherein there are a plurality of said elements circularly arranged about a common axis coincident with said cross-over point, said cathode means including a metallic shell which coaxially surrounds in spaced relation said plurality of elements, said electron-supplying means including an electron emissive electrode mounted in said interelectrode space.

5. The improvements of claim **4** in which said anode means has mirror portions impervious to electron penetration, said mirror portions being defined by parallel spaced-apart extensions of said elements, means developing currents in said extensions which flow in the same direction, and said ion-introducing means including a plurality of circularly arranged ion guns disposed in the spaces between predetermined ones of said extensions, said ion guns having ion-delivering portions located within said volume.

6. The improvements of claim **5** wherein said elements and extensions are metallic bars, an element and its extension being portions of the same bar, said bars extending substantially parallel to each other and to said common axis, said bars being electrically divided into two sets, the first set being alternate ones of said bars, the second set being the remaining ones of said bars, first and second terminal means connected to said first set of bars at longitudinally spaced points thereon, third and fourth terminal means connected to said second set of bars at longitudinally spaced points thereon, said terminal means being longitudinally arranged on said bars in the order of first, third, second and fourth, said first and second terminal means being connected across a direct current power supply, said third and fourth terminal means also being connected across a direct current power supply, whereby the currents in said bars between said first and third and said second and fourth terminal means flow in the same direction and opposite to each other between said second and third terminal means.

7. The improvements of claim **6** wherein said terminal means are, respectively, an even number of annular conductive headers coaxially surrounding said sets of bars, the second and third headers being spaced farther apart than the first and third and the second and fourth, respectively, thereby rendering the electron permeable portion of said anode means larger than the mirror portion thereof.

8. The improvements of claim **7** in which there are a plurality of annular electron-emissive electrodes in said interelectrode space, each said electrode being disposed adjacent to the electron permeable portion of said anode means, a plenum in said interelectrode space supporting said ion guns and surrounding the mirror portion of said anode means, said plenum having a conduit portion leading to the outside of the shell of said cathode means, said shell being hermetically sealed, a source of fusion-reactive gas operatively connected to said conduit for supplying said ion guns, and electrical leads for said ion guns disposed in said plenum and conduit for connection to an ion-gun power source located externally of said cathode shell, and means for evacuating said shell.

9. The improvements of claim **8** wherein said cathode shell is of toroidal shape and said bars are annular and concentrically disposed therewithin, there being a plurality of annular plenums spaced circumferentially about said shell, said plenums concentrically surrounding the anode means as defined by said bars, ion guns mounted on each plenum and projecting through said bars into said volume, and a plurality of said mirror portions on said anode means, there being one mirror portion for each plenum-ion gun assembly and two headers for each mirror portion, said two headers last-mentioned being connected to said two sets of bars, respectively, in such polarity as to provide common direction current flow in the bars of the mirror section.

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