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GASEOUS DISCHARGE DEVICE

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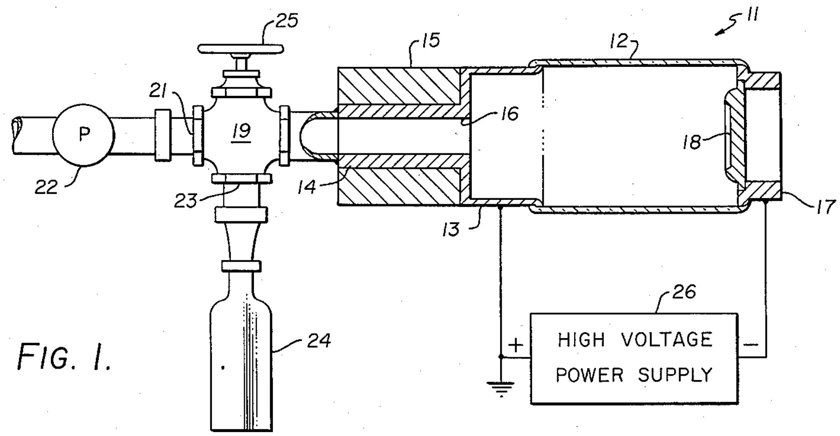

FIG. 1.

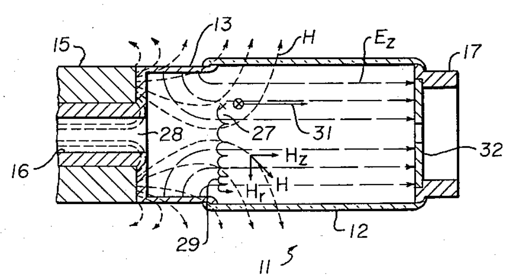

FIG. 2.

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GASEOUS DISCHARGE DEVICE

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8 Claims. (Cl. 250—84.5)

The present invention relates generally to gaseous discharge devices, and more particularly to compact source apparatus for producing and containing energic ions and electrons which may be employed to produce copious quantities of neutrons.

Many gaseous discharge devices are commonplace in the art for producing charged particles which may be employed for a variety of purposes. Prominent among such devices are various neutron sources wherein nuclear reactions productive of neutrons in copious yields may be induced by utilizing accelerated charged particles. Heretofore such devices have generally included a charged particle source, an accelerating region, and a target. More particularly, a linear gaseous discharge column, together with suitable extraction electrode structure, has been generally employed as the source of charged particles and the accelerating region is generally provided by accelerating electrodes disposed between the source and the target. Separate electrical circuits are generally required to establish the discharge, to provide extraction voltage, and accelerating potential respectively. Such conventional devices are, accordingly, not readily adapted to use in applications where size, compactness, and simplicity are requisites. Moreover, in conventional discharge devices, the potential drop across the device is limited, for example, by anode or cathode sheath phenomena or by electron emission induced by positive ion bombardment of the cathode. The electric field gradient available for accelerating particles to increased energies within the device is accordingly relatively low. The ultimate attainable energy of the charged particles within the discharge device, per se, is therefore seriously limited.

The present invention overcomes the above-noted difficulties of prior art discharge devices by providing a crossed electric-magnetic field discharge device for producing relatively energetic ions and/or electrons without entailing the use of auxiliary particle acceleration apparatus which would thereby result in high cost together with a material loss in device compactness. The relatively high energy particles produced by the device are directly extractable from the discharge for a great variety of purposes as, for example, bombarding a target of suitable material to produce copious quantities of neutrons.

It is therefore an object of the present invention to provide a small, compact, economical source for producing accelerated charged particles.

It is another object of the present invention to provide an extremely compact neutron source capable of producing copious quantities of neutrons while requiring but a single auxiliary source of operating potential.

Still another object of the invention contemplates the ionization of a gas with extreme efficiency for either steady state or pulsed modes of operation.

Still another object of the invention is the provision of an improved gaseous discharge tube wherein the potential drop is not determined by anode or cathode sheath phenomena.

Another object of the invention is to provide an improved gaseous discharge device wherein the discharge operates in a stable manner for an extremely wide range of applied control voltages.

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It is also an object of the present invention to provide an improved gaseous discharge device wherein the potential drop is not determined by phenomena related to emission of electrons induced by positive ion bombardment of the cathode.

A further object of the invention is the provision of an intense X-ray source.

It is a still further object of the invention to provide crossed electric-magnetic field means for producing accelerated charged particles without conventional auxiliary acceleration structure.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in conjunction with the accompanying drawings, of which:

Figure 1 is a cross sectional plan view of the present invention as embodied in a neutron source; and

Figure 2 is a partial cross sectional plan view of this embodiment as modified to produce accelerated ions and graphically illustrating particle motion in the crossed electric and magnetic field region established therein.

In the specification, the invention will be described, by example only, as embodied in a neutron source utilizing the hydrogen isotope deuterium as both the gaseous filling material and target material. Briefly, therefore, such a neutron source, constructed in accordance with the invention, includes envelope means adapted to provide a housed, low pressure region, i.e., an at least partially evacuated space, containing a gas comprising a hydrogen isotope, e.g., deuterium. Means are disposed at one end of the region to establish a magnetic field diverging radially outward therein. A target of deuterized material is disposed at the opposite end of said region, spaced apart from the magnetic field. An electric field is also established axially of the region extending through the magnetic field at substantially right angles thereto to the target. The crossed electric-magnetic field region thus established is effective in ionizing the gas within the low pressure region and the resulting ions are accelerated by the electric field to impinge upon the target causing nuclear reactions which yield copious quantities of neutrons. It will be appreciated that other appropriate gases may be introduced into said low pressure region and the ions thereof likewise caused to impinge upon a target which may include a material with which such other ions may thereby be caused to react to produce neutrons. Alternatively, the target may be dispensed with and the invention employed directly as a source of accelerated charged particles or for a variety of other purposes, e.g., for producing X-rays, as are subsequently described.

Referring now to the drawing, and Fig. 1 in particular, the low pressure region of previous mention preferably is provided in an enclosure indicated generally at **11** and including a tubular cylindrical member **12** to which a suitable electrode **13** is attached in pressure sealed relationship at one end thereof. Member **12** is preferably circular in cross section and is fabricated from a good electrically insulating material which is suitable for high vacuum service, as for example, borosilicate glass or the like. Pressure sealed attachment of electrode **13** to the cylindrical member may be accomplished by any one of various common methods for facilitating a glass to metal seal, preferably by fusing.

As regards electrode **13**, it will be noted that same is preferably formed as a cylindrical cup with the open end thereof attached to member **12** to provide ion shield as well as electrode structure, and is fabricated from an electrically conducting material which is also pervious to magnetic fields, i.e., a material such as copper. Electrode **13**, in addition, preferably includes an elongated cylindrical arbor **14** which extends axially rearward from the rear closure face of the electrode to accommodate a hollow cylindrical permanent magnet **15** or other suitable magnet means for establishing the above-noted magnetic field within envelope **11**. Arbor **14** is preferably provided with a central axial bore **16** communicating with the interior of envelope **11** to facilitate inlet of gas thereto as subsequently described; however the gas inlet may as well be provided at substantially any other desired portion of the envelope.

Magnet **15** is mounted concentrically about arbor **14** and oriented with a pole face adjacent the rear closure face of electrode **13**. The magnet is retained in position on arbor **14** by any suitable means of attachment such as by a forced fit. With magnet **15** so disposed, magnetic field lines are accordingly, in general, directed longitudinally forward from the pole face thereof through the front face of electrode **13** to then diverge radially outward in the interior of envelope **11**.

At the distal end of envelope **11** relative to electrode **13** there is attached in pressure sealed relationship to member **12** a second electrode **17** which may also serve as a target holder. Electrode **17** is fabricated from an electrically conducting material, e.g., copper, and is preferably annular in form. Such electrode is best outwardly flanged at the inner face thereof to facilitate the above-mentioned pressure sealed attachment to cylinder member **12**, as by fusing. Electrode **17** also is preferably provided with an annular indentation at the inner face thereof for receiving and retaining a central circular target **18** in electrically conducting pressure sealed relationship therewith. Target **18** is fabricated from a suitable target material, such as deuterium occluded in titanium, which is capable of undergoing nuclear reaction with the ions of the particular gas admitted to envelope **11** to thereby produce copious quantities of neutrons. It will be appreciated that in some applications of the present invention other than as a neutron source, e.g., where the discharge device is utilized as a source of accelerated ions, target **18** is replaced by a diaphragm and the outer face of electrode **17** may be adapted for direct flanged attachment to ion utilizing equipment. (See Fig. 2.) In still other embodiments of the invention, as when same is employed as an X-ray source, the annular configuration of electrode **17** is replaced with a circular disc electrode structure to, in addition, facilitate front closure of envelope **11**.

To facilitate means for evacuating envelope **11**, as well as to control inlet of suitable gaseous material, e.g., deuterium or other hydrogen isotopes, a suitable two-way pump-out and gas inlet valve **19** is preferably provided at the end extremity of arbor **14** to communicate with the interior of envelope **11** through the central axial bore **16** of electrode **13**. One inlet connection **21** of valve **19** is adapted for connection to the inlet port of a vacuum pump **22**, while the other inlet connection **23** of the valve is adapted for connection to a container **24** of filling gas. Valve control means **25** may consequently be operated to render the bore communicable with inlet **21** and vacuum pump **22** for purposes of evacuating envelope **11**. Alternatively, control means **25** may be operated to close inlet **21** and at the same time communicably connect the bore to inlet **23** and gas container **24** for the purpose of admitting filling gas to the evacuated envelope **11**. Control means **25** may then be operated to close both inlets **21** and **23** to thus seal the gas within the envelope. It will be appreciated that for some applications, it is desirable that the neutron source of the present invention be provided as a sealed unit in which case subsequent to evacuation and filling of envelope **11** with gas the bore is closed by permanent closure means (not shown) familiar to those skilled in the vacuum art and therefore not considered in detail herein.

Energization of the components of the above-described gaseous discharge device is facilitated by connection of a single power supply **26** between electrodes **13**, **17** with the positive and negative terminals of the supply being respectively connected to electrode **13** and electrode **17**. A longitudinal electric field is thereby established within envelope **11** between the electrodes which is negatively increasing in a direction away from electrode **13** toward electrode **17**, and therefore target **18**. Power supply **26** may be either continuous or pulsed, depending upon whether continuous or pulsed operation of the discharge device is desired.

Considering now the operation of the gaseous discharge device of the present invention with same suitably energized as described above, it is to be noted that crossed electric-magnetic fields are established within envelope **11** symmetrically about the axis thereof and having configurations substantially as diagrammatically illustrated in Fig. 2. The electric field, E_z, which is denoted in the figure by dashed lines, is directed axially forward from positive electrode **13** to negative electrode **17**, and therefore target **18** in instances where same is employed. The flux lines of the magnetic field, H, which are shown in the figure as dotted lines, extend axially forward from the front face of magnet **15** through electrode **13** and into envelope **11** with a small degree of convergence and then diverge radially outward from the axis. Magnetic flux lines are also established within the electrode bore **16** converging axially rearward from the front opening thereof. There is thus established in the region of envelope **11** axially inward from electrode **13** a crossed electric-magnetic field region **27** wherein there exists a radial component, H_r, and an axial component, H_z, of magnetic field which are respectively directed radially outward and axially forward, for example, although the sense of the direction is immaterial, together with the axial electric field, E_z, in the direction and sense previously mentioned. There is similarly provided a second and independent crossed electric-magnetic field region **28** within the front opening of the magnetic field established therein due to the distribution of flux lines produced by an annular permanent magnet such as that employed as magnet **15**. The two crossed electric-magnetic field regions **27**, **28** are effective in trapping electrons as will be subsequently described in detail and are accordingly hereinafter referred to as electron trapping zones. It will be appreciated that in the event a solenoid or a solid cylindrical magnet is employed as magnet **15**, the characteristic distribution of the magnetic flux lines therefrom is such as to establish only the principal electron trapping zone **27** within the envelope **11**. The operation of the present invention is not materially altered, however, if the second trapping zone **28** is not established therein.

As regards the mechanism by which electrons within envelope **11** are trapped within the principal trapping zone **27**, it is to be noted that the motion of such electrons no matter what their origin includes motion components in an axial direction and in a direction at right angles to the axial direction and to the radial direction due to the forces exerted by the radial magnetic field component, H_r, and the axial electric field, E_z. More particularly, due to the direction of the electric field, E_z, electrons in the prinicpal trapping zone **27** are attracted towards the positively charged electrode **13**. The motion of an electron of zero initial velocity moving towards electrode **13**, however, is influenced by the radial magnetic field component, H_r. Such component, H_r, bends the electron azimuthally such that the electron describes a **U**-shaped orbit on a cylindrical surface disposed concentrically about the axis of envelope **11**. Accordingly, when the electron returns to the same transverse plane of constant electric field potential as its starting point, the electron has completed one reflection in the radial magnetic field and its velocity again becomes zero. The process then repeats itself, thus forming a succession of such U-shaped orbits whereby electrons within zone **27** follow paths as designated generally at **29**. It is to be noted, however, that an electron in traversing path **29** is also acted upon by the axial component of magnetic field, H_z. This component acts on the azimuthal component of velocity of the electron, thus producing a force directed radially inward towards the axis of envelope **11** and causing the electrons to circulate about the axis in substantially cardioid fashion. The electron trapping zone **27** extends outward from the axis within envelope **11** (electrons on the axis are not trapped) to the point where the axial component of magnetic fields, H_z, reverses direction. In the direction of electrode **13**, the zone extends to where the radial component of magnetic field, H_r, becomes zero, and in the direction of electrode **17** to where the field weakens to the extent that the electron orbits intersect the walls of envelope **11**.

The energy transmitted to an electron undergoing the above-described motion is characterized only by the ratio of the strengths of the electric and magnetic fields, provided the initial energy of an electron in zone **27** is considered as being inappreciable. The average electron velocity under the foregoing conditions is given approximately by the following expression:

$$v=10^8\frac{E_z}{H_r}$$

where v is the electron velocity in centimeters per second, E_z is the electric field strength in volts per centimeter, and H_r is the radial component of the magnetic field strength in oersteds. In the event an electron within envelope **11** has some small initial energy, the resulting motion and average electron velocity are not appreciably different from that described above. Consequently, electrons of relatively low initial energy within trapping zone **27** undergo a rapid and complicated motion which is generally typified by path **29** and gain an appreciable average energy in accordance with the above-noted expression. Moreover, such electrons are constrained to the zone for many oscillations or reflections. Electrons are similarly trapped within the second trapping zone **28** and gain energy therein in a manner generally similar to that described above.

A small quantity of stray electrons which exist naturally at all times within envelope **11** are consequently trapped as previously described within the trapping zones **27**, **28** upon the establishment thereof by energization of electrodes **13**, **17** with power supply **26**. The stray electrons are thus accumulated and gain appreciable energy within the trapping zones and thereby comprise a highly efficient means for ionizing gas entering envelope **11** through the electrode bore **16**, or otherwise contained within the envelope. Such trapped energetic stray electrons collide with and ionize atoms of the gas within the trapping zones **27**, **28** and thereby release a new electron and an ion from each atom. Each new electron commences a cycloidal motion of the type hereinbefore described while the ions, as a result of their relatively large ionic mass and consequent low velocity, have a relatively large radius of curvature in the crossed field trapping zones **27**, **28** and are, therefore, strongly attracted axially in the direction of decreasing potential toward electrode **17** as depicted by the typical ion path shown generally at **31**. As each new electron is released and trapped within the trapping zones, more and more gas atoms are ionized thereby and the ionization process becomes cumulative resulting in the establishment of an ionized gaseous discharge within the trapping zones **27**, **28**. The ionization per unit of time increases and the discharge increases in intensity until the mechanisms which are responsible for the escape of electrons from the crossed field trapping zones **27**, **28**, i.e., space charge effects, scattering, and the like, come to equilibrium with the electron production rate by collision with the gas atoms.

It will be appreciated that in order for the stabilized gaseous discharge in accordance with the present invention to be maintained, a suitable pressure of the filling gas must be established within envelope **11**. The filling gas pressure must be within a pressure range the lower limit of which is determined by there being sufficient gas present for electron multiplication effects due to ionizing collisions to be appreciable. The upper limit of the pressure range is determined such that the density of gas molecules not be so high as to cause runaway ionization processes leading to an arc discharge. The foregoing pressure range is influenced by the geometry of the system and by the particular filling gas employed. For a small device in accordance with the present invention wherein the filling gas is deuterium, suitable gas pressure is of the order of 15 microns.

As a result of the foregoing, there is established an intense axial ion beam directed axially of envelope **11** toward electrode **17**. With the target **18** mounted transversely within electrode **17**, the ions impinge upon the target with an energy which is substantially equal to the difference in electrical potential between electrodes **13**, **17**. With envelope **11** containing deuterium, for example, whereby the ions are deuterons, and target **18** fabricated, for example, from deuterium occluded in titanium, the deuterons in striking the target produce copious quantities of neutrons by nuclear reactions between the deuterons and deuterium. It will be appreciated that the discharge device of the present invention may also be operated to produce nuclear reactions between other elements using one element as the filling gas and the same or another element as the target material.

In order to operate the discharge device of the present invention as an ion source, it will be appreciated that it is merely necessary to remove target **18** and substitute a diaphragm **32** (see Fig. 2) to provide a transverse termination to the axial electric field, E_z, which is pervious to ions. The energetic ions extracted from the discharge established in trapping zones **27**, **28** are thus accelerated by the electric field, E_z, and pass unobstructed through the central opening of the diaphragm constituting electrode **17**. The intense energetic ion beam so produced may consequently be used directly in a variety of ion utilizing equipment, such as particle accelerators, by suitable communicable flanged attachment of electrode **17** to the vacuum enclosure of such equipment.

It will be appreciated that the gaseous discharge device of the present invention may be used for a wide variety of additional purposes. For example, the discharge device may be utilized as an X-ray source merely by replacing the annular electrode **17** by a circular electrically conducting front closure disc. The electrons circulating in trapping zones **27**, **28** in the above-described manner generate intense X-rays in colliding with the gas molecules due to Bremsstrahlung phenomena. In addition, low energy electrons are produced at the front closure disc in copious quantities by secondary emission due to bombardment by the ion beam. Such low energy secondary electrons are accelerated toward electrode **13** by the longitudinal electric field and are partially focused axially by the magnetic field. As a result of electron impact at high velocity with electrode **13**, additional X-rays are generated due to Bremsstrahlung phenomena.

While the invention has been disclosed with respect to but several preferred embodiments, it will be apparent to those skilled in the art that numerous variations and modifications may be made within the spirit and scope of the invention, and thus it is not intended to limit the invention except as defined in the following claims.

What I claim is:

1. A gaseous discharge device comprising envelope means for establishing an evacuated region, electrode means disposed within said region for establishing a uni-

form potential gradient electric field therein, magnet means carried by said envelope for establishing a magnetic field in axial symmetry with the electric field, said magnetic field having a parallel portion directed in the direction of decreasing potential gradient of the electric field and a diverging portion diverging radially outward therefrom to thereby establish a crossed electric-magnetic field region within said evacuated region, said crossed field region trapping and accumulating stray electrons existing within said evacuated region and imparting energy thereto, and inlet means communicating with said envelope means for admitting ionizable gas into said evacuated region, said gas being ionized in said crossed field region by the energetic stray electrons therein to establish an intense ionized gaseous discharge.

2. A gaseous discharge device comprising means for establishing an evacuated region, positive and negative electrodes disposed in axially aligned spaced-apart relationship within said region, power supply means connected between said electrodes to establish an axial electric field within said region, a magnet disposed axially outward from said positive electrode to establish an axially symmetric magnetic field within said evacuated region diverging radially outward through said electric field and substantially at right angles thereto, said electric and magnetic fields thereby establishing in combination a crossed electric-magnetic field electron trapping zone within said evacuated region to trap and increase the energy of stray electrons existing naturally therein, and gas source means communicably connected to said evacuated region for introducing ionzable gas thereto, said gas being ionized by said stray electrons in said trapping region to establish an intense ionized gaseous discharge therein.

3. A gaseous discharge device comprising a vacuum envelope containing an ionizable gas together with stray electrons existing naturally therein, a positive electrode disposed at one end of said envelope, a negative electrode disposed at the other end of said envelope in axial alignment with said positive electrode, a permanent magnet disposed axially outward from said positive electrode with a pole face thereof adjacent the outer face of the electrode, said magnet thereby producing magnetic field lines directed axially inward from the pole face of said magnet through the face of said positive electrode to then diverge radially outward within said envelope, and power supply means connected between said positive and negative electrodes to establish an axial electric field through said envelope and at substantially right angles to the diverging portion of said magnetic field lines to establish a crossed electric-magnetic field region within said envelope, said stray electrons being trapped and increased in energy within said trapping region and ionizing said gas to establish an intense ionized gaseous discharge therein.

4. A neutron source comprising an envelope containing an ionizable gas, a magnet disposed at one end of said envelope to produce an axially symmetric magnetic field diverging radially outward from the axis of said envelope, an electrode disposed within said envelope transverse to the axis thereof and within said magnetic field, a target disposed within said envelope and axially spaced apart from said electrode, and a power supply connected between said electrode and said target to establish a negative potential at said target relative to the potential established at said electrode whereby an intense ionized gaseous discharge is established within said envelope and the ions thereof are attracted towards said target to impinge thereon and produce copious quantities of neutrons by nuclear reactions between the ions and target material.

5. A neutron source comprising a tubular cylindrical insulating member, a first cup shaped electrode hermetically attached to one end of said member, said electrode having a central rearwardly extending arbor and a central axial bore extending therethrough, a second annular electrode hermetically attached in closing relationship to the other end of said member, a target centrally attached in closing relationship to said second electrode, an annular magnet concentrically engaging said arbor and an intimate engagement with the rear face of said first electrode, said magnet producing a magnetic field extending axially through said first electrode and then diverging radially outward in the region enclosed by said insulating member and also converging rearwardly through said bore, a high voltage power supply having its positive terminal connected to said first electrode and its negative terminal connected to said second electrode to establish an axial electric field between said first electrode and said target, said electric field producing a negatively increasing potential in the direction of said target and establishing with said magnetic field crossed electric-magnetic field regions axially forward of said first electrode and in the throat of the bore thereof, said crossed field regions trapping and increasing the energy of stray electrons existing naturally within the region enclosed by said insulating member, and gas supply means communicably connected with the bore through said first electrode to introduce ionizable gas thereto, said gas being ionized by the stray electrons of increased energy trapped within said crossed field regions to establish an intense ionized gaseous discharge therein, the ions produced within said discharge being attracted towards said target to impinge thereon and produce copious quantities of neutrons by nuclear reactions with the target material.

6. A neutron source as claimed in claim 5 and further defined by said target being fabricated from a hydrogen isotope occluded in titanium and said ionizable gas being at hydrogen isotope.

7. An ion source comprising a hollow elongated tubular insulating member, a first cup shaped electrode hermetically attached to one end of said insulating member and having a central arbor extending axially outward therefrom, said electrode having a central axial bore, a second annular electrode hermetically attached to the other end of said insulating member to form a vacuum enclosure therewith, evacuation means communicating with said vacuum enclosure through the bore of said first electrode to evacuate said enclosure and establish a low pressure atmosphere therein, said atmosphere containing naturally existing stray electrons, an annular permanent magnet concentrically engaging said arbor to establish an axially symmetric magnetic field extending axially forward of said first electrode into said enclosure with a portion of the field lines diverging radially outward from the axis thereof and the remaining field lines converging axially rearward through said bore, a high voltage power supply having its positive terminal connected to said first electrode and its negative treminal connected to said second electrode to establish an axial electric field within said enclosure producing a negatively increasing potential in a direction from said first electrode to said second electrode, said electric field forming with said magnetic field crossed electric-magnetic field electron trapping regions within said enclosure axially forward of said first electrode and in the throat of said bore, said crossed field regions trapping said stray electrons and increasing the energy thereof, and gas supply means communicably connected to the bore of said first electrode to admit ionizable gas to said enclosure, said gas being ionized by the stray electrons within said crossed field trapping regions to establish an intense ionized gaseous discharge therein, the ions of said discharge being accelerated axially by said electric field through said second annular electrode.

8. A gaseous discharge device comprising envelope means for establishing an evacuated region, electrode means disposed within said region for establishing a uniform potential gradient electric field therein, magnetic field generating means carried by said envelope means for establishing an axially symmetric magnetic field within said region, said magnetic field having an axial component in the direction of decreasing potential gradient of said electric field and a radial component at right angles

therewith to establish a crossed electric-magnetic field region within said evacuated region, said crossed field region trapping and accumulating stray electrons existing within said evacuated region and imparting energy thereto, and inlet means communicating with said envelope means for admitting ionizable gas into said evacuated region, said gas being ionized in said crossed field region by the energetic stray electrons accumulated therein to establish an intense ionized gaseous discharge.

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