Jan. 5, 1960 J. S. LUCE 2,920,234

DEVICE AND METHOD FOR PRODUCING A HIGH INTENSITY ARC DISCHARGE

Filed May 27, 1958 2 Sheets-Sheet 1

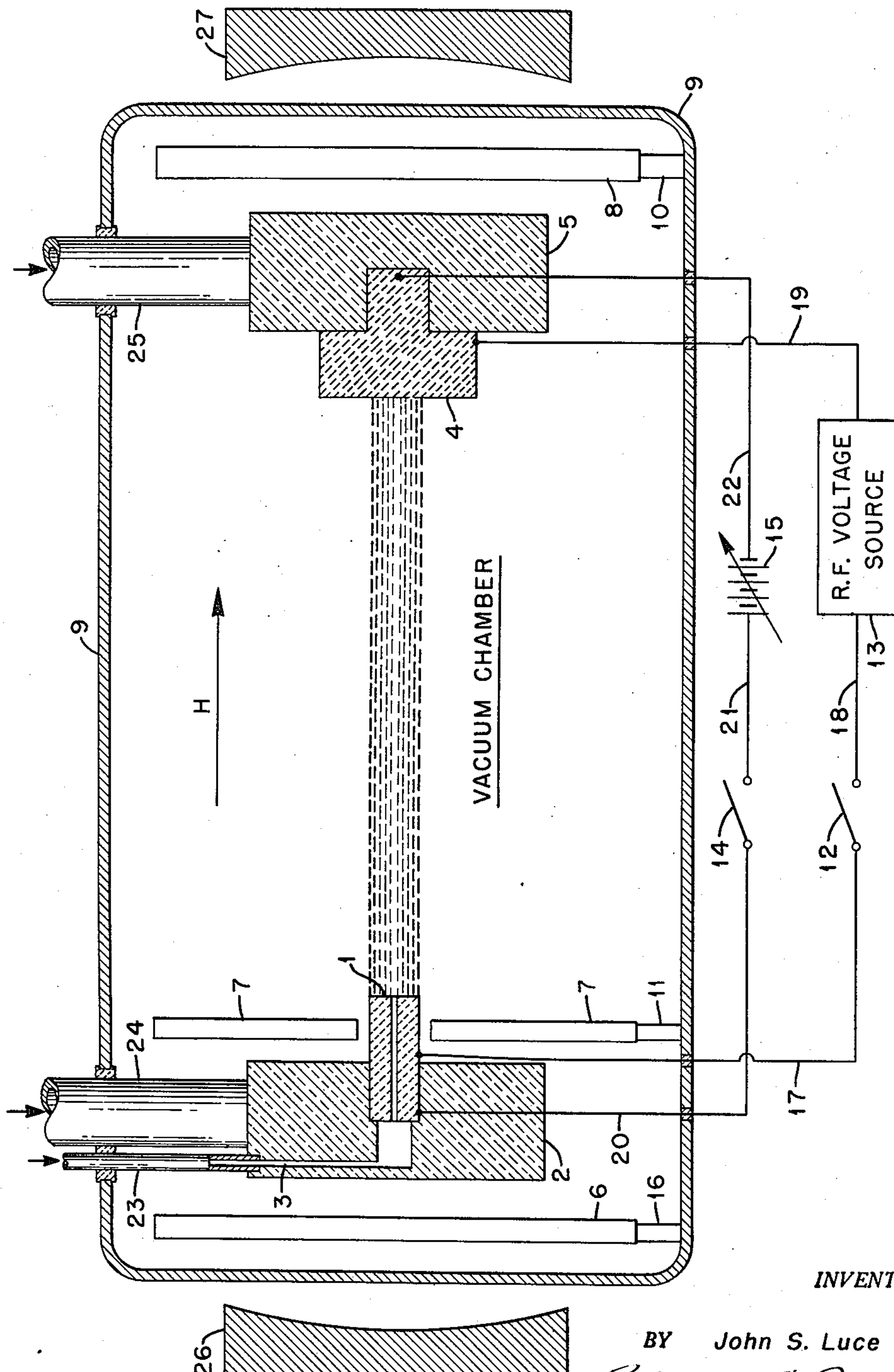

Fig. 1.

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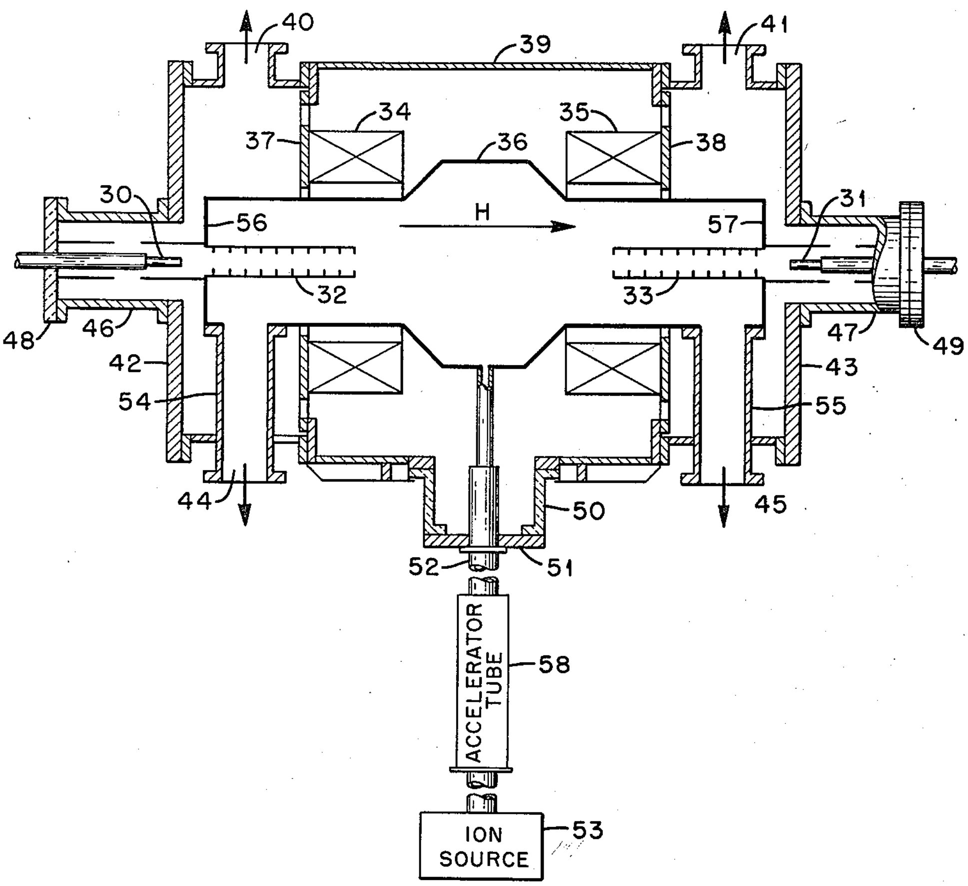

Fig. 2.

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2,920,2[illegible]

Patented Jan. 5, 19[illegible]

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DEVICE AND METHOD FOR PRODUCING A HIGH INTENSITY ARC DISCHARGE

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Application May 27, 1958, Serial No. 738,242

4 Claims. (Cl. 315—111)

This invention relates to a device for providing an energetic direct current discharge between widely-spaced electrodes in a magnetic field under high vacuum, and more especially to means for establishing and maintaining a novel electrical discharge which has certain characteristics distinguishing it from a normal high-current arc. Establishment of such discharges is of fundamental importance in studies of electrical discharge phenomena, and has found further usefulness specifically in dissociation and ionization of high energy (20 to 600 kev.) molecular ion beams.

In most vacuum arcs, a tungsten or tantalum filament is heated to emission temperature by passing a large current through it. Electrons are accelerated from the filament towards the anode by a potential gradient which is applied between the cathode and a defining electrode intermediate the anode and cathode. This electrode defines the shape of the arc as desired. Approximately half the electrons pass through the defining slot into the arc chamber, and an arc is formed. The arc may be stabilized by a magnetic field oriented parallel to the arc. At low arc currents approximately half the electrons pass through the defining slot and half drain to it directly. If the arc current is raised, a critical point is reached when a direct short exists between the filament and defining electrode, and only very few electrons pass through. Other arc geometries have been developed that do not use defining electrodes, but shorts always appear some place to limit the usable current. The limit for stable operation in the conventional arc is about 100 amperes. Moreover arcs could not heretofore be established and operated in intense magnetic fields of about 3000 gausses, for example, at extremely low pressures such as 2×10^{-7} mm. Hg.

With a knowledge of the difficulties encountered by prior workers in attempting to achieve useful arc currents above 100 amperes, applicant has as a primary object of this invention to provide means for establishing a high intensity direct-current arc, and more particularly a carbon arc discharge which is to be maintained in a magnetic field under high vacuum between widely-spaced electrodes.

It is a further object of this invention to provide an improved apparatus and method of establishing a carbon arc discharge without using a defining electrode and thus overcoming the shorting problem between the filament and defining electrode that existed in prior art devices.

Other objects and advantages of the invention will be apparent from a consideration of the following detailed specifications and the accompanying drawings, wherein:

Fig. 1 is a sectional drawing of one embodiment of components used to provide a discharge, and

Fig. 2 is a schematic diagram of a use for the arc discharge for ionization or dissociation in a thermonuclear device.

The invention described herein has overcome the shorting problem aforementioned so that stable direct-current vacuum arcs have been operated in the heretofore im-

possible range of 100 to 5000 amperes. Another sign[illegible] cant difference between this device and prior arc sour[illegible] is that the cathode is heated, not by an external curre[illegible] but by bombardment of positive ions from the arc its[illegible]

In the embodiment of Fig. 1, a hole is bored throu[illegible] the center of the cathode, and gas is fed directly to [illegible] arc. This method of feeding the discharge allows [illegible] pressure to be relatively high in the discharge its[illegible] without appreciably increasing the pressure in the volum[illegible] thus avoiding shorts due to high pressure. These a[illegible] have been operated with nitrogen, argon, hydrogen, [illegible] and several vaporized solids such as carbon, tungst[illegible] etc. Many different materials can be used for catho[illegible] and anodes, for example, copper, steel, carbon, tantalu[illegible] tungsten, tungsten carbide, etc. In some cases (carb[illegible] for example) it has been found that the flow of gas c[illegible] be stopped, and the discharge will maintain itself [illegible] vaporization of the electrodes.

A discharge characterized by high average electr[illegible] energy is desired. In normal gas arcs, or discharges, [illegible] sheath is formed at the end of the arc adjacent and par[illegible] lel to the face of the cathode. In such an arc, the me[illegible] free path of the electrons is very short as a result [illegible] the pressure in the arc and the resultant multiple co[illegible] sions. Thus, essentially all of the voltage drop of [illegible] arc occurs across the gap between this sheath and [illegible] cathode. The loss of energy, as a result of the ma[illegible] collisions, results in a low average energy of these el[illegible] trons. The electrons that reach the anode are genera[illegible] non-energetic since they are mostly secondary electro[illegible] However, this is not true of the carbon discharge to [illegible] described. In the carbon arc a sheath is formed betwe[illegible] the cathode and the arc, and a potential gradient is ma[illegible] tained between the sheath and cathode. The high[illegible] gradient appears on the outer rim of the cathode wh[illegible] the intensity of the arc is greatest and the gradient is l[illegible] at the central portion of the cathode face where the [illegible] tensity of the arc is not as great. Electrons are acce[illegible] rated away from the cathode by the aforementioned [illegible] tential gradient, and positive ions are accelerated fr[illegible] the arc to the cathode. In the carbon arc, most of [illegible] ions originate at the anode. A large part of the [illegible] tential drop occurs along the arc and many energe[illegible] electrons reach the anode because the arc pressure [illegible] relatively low, and few collisions occur. Thus, [illegible] average energy of the electrons in the discharge is hi[illegible] and the mean free path is long. In addition, the avera[illegible] energy of the ions is higher than usual as can be sho[illegible] by spectrographic analysis, thus further indicating t[illegible] the potential energy distributions are substantially d[illegible] ferent than those of conventional arcs.

Studies have been made of the carbon discharge [illegible] determine to what extent it is ionized. For examp[illegible] spectrographic measurements have been made of d[illegible] charges of 170, 270 and 425 amperes. A quartz wind[illegible] was used to permit the study of carbon resonance lin[illegible] at 2478 A. Reasonably strong spectra of C^+ and C[illegible] were observed; the ratio of C^{++} to C^+ increased wi[illegible] increased current. No trace of the resonance line [illegible] neutral carbon was observed, thus indicating that [illegible] discharges were more than 99% ionized. Neutral arg[illegible] gas was then introduced into the discharge at both [illegible] cathode and anode ends, and spectrographic measu[illegible] ments made. The pressure was varied from 2×10[illegible] mm. Hg. to 5×10^{-4} mm. Hg. Essentially comple[illegible] ionization was observed as only A^+, A^{++}, A^{+++} and [illegible] A. lines were detected. The introduction of the g[illegible] substantially reduced the number of C^{++} ions detect[illegible] These results indicate that the introduction of the neut[illegible] gas reduces the average energy of the particles in t[illegible] discharge.

Referring now to Fig. 1, both a cathode 1 and [illegible]

›de 4 are supported in water cooled brackets 2 and respectively, these brackets being supplied with cool- water through conduits 24 and 25, respectively. The ›de 4 is provided with an insulated shield 8 mounted insulated bracket 10 and the cathode 1 is provided h insulated shields 6 and 7 mounted on insulated ckets 16 and 11, respectively. The hole in the cathode connected through a passageway 3 with a gas supply t tube 23. The magnets 26 and 27 provide a strong gnetic field whose direction is indicated by the arrow ." The centers of the anode and cathode are aligned ng the magnetic field, and the corresponding arc dis- rge, when struck, is parallel to the magnetic field. s have been run in magnetic fields in the range from to 10,000 gausses, for example.

The anode 4 is connected by wire 19 to one side of a rce of R.F. voltage 13, such as used in a conventional ding system. The other side of source 13 is connected a wire 18, switch 12 and wire 17 to cathode 1. The de-cathode path is also electrically energized through e 20, switch 14, wire 21, adjustable source of potential battery 15, and wire 22. The source 15 is used both elp initiate an arc discharge between the cathode and de and also to selectively vary the intensity of the discharge. The arc discharge is shown by the broken s between the cathode and anode. The anode, cath- , anode shield, cathode shields, and brackets 2 and 5 mounted within a vacuum chamber 9 which is evacu- d by conventional vacuum pumps, not shown.

n operation of Fig. 1, when the anode and cathode trodes are made of carbon, a carbon discharge may initiated by applying substantially 250 volts D.C. and R.F. voltage of substantially the same magnitude to electrodes, and admitting gas to the cathode passage. size of the hole in the cathode is 1/16 inch, the gas to the cathode is argon, for example, the pressure in chamber 9 is maintained below 1 micron, and the gnetic field H is maintained at approximately 3000 sses. The R.F. arc appears first followed by the main harge. After the arc is struck, the gas feed and . voltage are discontinued. The discharge is sus- ed by carbon ions produced as a result of electron nbardment of the anode and/or other ion-forming ns. The intensity of the discharge may then be varied varying the voltage source 15 between the electrodes. arc is stable at a pressure of 1 micron and at all sures obtainable below 1 micron. When the arc is ck in a magnetic field of 3000 gausses, in a vacuum 3×10^{-5} mm. Hg, with an arc length of 12 inches, a cathode diameter of ½ inch, the said arc will have iameter of ½ inch and the voltage across the arc ld be maintained at approximately 55 volts to pro- an arc current of 300 amperes. When the arc th is increased to 5½ feet to 6 feet, a voltage of at 125 volts is required across the arc to produce an current of 300 amperes with the other parameters g the same as for the 12 inch arc. It can be seen the arc voltage is proportional to the arc length in r to provide an arc current of a predetermined unt. For any configuration there is a critical cur- below which the arc will not continue to run. For inch arc, this current has been made as low as 50 eres for a few seconds.

he type of discharge formed by the device of Fig. 1 ot a true arc in that no stable, homogeneous struc- exists. Rather, the discharge constantly undergoes nentation, each section appearing as a filament of narge. The filaments are in constant motion and ily move across the magnetic field. The life of each nent is limited and new ones are constantly formed. number of filaments vary in direct proportion to amperage of the discharge. Stable segmented dis- ges of up to 2000 amperes, having a current density 5,000 amperes per square inch, are easily attained. addition to the segmentation of the discharge, the

dynamic conditions thereof induce appreciable impacts and/or thermal gradients at the cathode which cause small charged carbon particles to be torn from the cathode and ejected at high speeds in a wide arc toward the anode. Vaporized carbon from both the cathode and anode absorb gas and thus produce a high pumping capacity for neutral particles. The arc will also act as an ion pump if proper baffles are used.

There is shown in Fig. 2, one use for an energetic direct-current arc. One method of growing a plasma of high energy ions in a thermonuclear machine is that of trapping atomic ions as a result of the dissociation of molecular ions within the machine. This dissociation may be accomplished in several different ways, one of which is passing the molecular ion beam through an arc, such as shown in Fig. 2. Such a method is the subject matter of my co-pending application Serial No. 728,754, entitled "Method and Apparatus for Trapping Ions in a Magnetic Field," by John S. Luce, filed April 15, 1958.

In the device described in that application, high-energy molecular ions are injected into a confining magnetic field perpendicular to the lines of magnetic force. At some point in the orbit of these ions in the magnetic field, a portion of them are caused to dissociate and/or ionize to form atomic ions. These resultant atomic ions have one-half the momentum of the original molecular ions and hence have one-half the radius of curvature in the field. If the center of the orbits of these atomic ions coincides with the axis of the magnetic field, the ions will circulate in a ring. If the center of the orbits and the axis of the machine do not coincide, the atomic ion orbit will precess about the point of origin of the atomic ion. The ions will circulate until a charge exchange reaction occurs with one of the neutral gas atoms in the system.

The device of Fig. 2 comprises an outer cylindrical shell 39 with joining end walls 42 and 43. End wall 42 has a circular opening to which a tubular member 46 is affixed. Member 46 has an end closure member 48 in which the cathode 30 is fixedly mounted. End wall 43 has a circular opening to which is affixed a tubular member 47. Member 47 has an end closure 49 in which the anode 31 is fixedly mounted. Outer shell 39 is provided with a circular opening to which is attached a tubular member 50 which in turn has affixed thereto an end closure member 51. Fixedly mounted in said member 51 is a tubular member 52 provided with a reduced portion which connects with an aperture in liner 36. A conventional ion accelerator tube 58 communicates with member 52, and serves to accelerate molecular ions from an external ion source 53 to relatively high energies. The accelerator tube may be energized by a conventional high voltage generator. A suitable high current source of molecular ions may be provided by apparatus such as set forth on page 18 of Nucleonics, vol. 9 (3), 1951; Rev. Sci. Instr., vol. 24, p. 394, 1953, for example, or that described by Von Ardenne, "Tabellen der Elektronenphysik, Ionenphysik and Ubermikroskopie," VEB Deutscher Verlog der Wissenschaften, Berlin, 1956 (Duo-Plasmatron). The molecular ions then pass through the aperture in liner 36 and into the path of an arc formed between the cathode and anode electrodes 30, 31. This arc is a high intensity direct current arc such as produced by the device of Fig. 1. The arc formed between said electrodes is substantially enclosed in an inner chamber formed by liner 36 and end walls 56, 57. The walls 56 and 57 have circular openings in axial alignment with the anode and cathode. Surrounding the cathode 30 and anode 31 are suitable tubular baffles 32 and 33, respectively, which extend through the openings in said walls 56 and 57, respectively. Liner 36 has a pair of circular openings in alignment with a pair of circular openings in outer shell

39. The aligned openings are joined by insulated bushings 54 and 55, respectively. The inner chamber, formed by liner 36 and walls 56 and 57, is connected to a vacuum through openings 44 and 45 of bushings 54 and 55, respectively. Outer liner 39 also has a pair of additional openings 40 and 41 connected to a vacuum, said openings being connected to an outer chamber located between the shell 39 and inner chamber referred to above. A circular magnetic mirror coil 34 is mounted on apertured wall 37 and is disposed around the outside of inner liner 36 between the ion source tube 52 and bushing 54. Another circular magnetic mirror coil 35 is mounted on apertured wall 38 and is disposed around the outside of inner liner 36 between ion source tube 52 and bushing 55. These mirror coils provide a containing magnetic field whose direction is shown by the arrow H. The magnets 26 and 27 of Fig. 1 are not required when the arc striking and maintaining means of Fig. 1 are used in the device of Fig. 2 since the magnetic mirror coils 34 and 35 take the place of magnets 26 and 27.

In operation of the device set forth in Fig. 2, a high intensity arc discharge is initiated between the cathode and anode electrodes by means such as set forth in Fig. 1. The inside and outside chambers are evacuated and the pressure of the inside chamber is maintained at approximately 10^{-7} mm. Hg, while the outside chamber pressure is maintained at approximately 10^{-6} mm. Hg, for example. The mirror coils 34 and 35 have an inside diameter of 17 inches and a spacing between the inner faces of the coils of 18½ inches. With these dimensions, a cylinder can be inscribed whose rims just touch the inner edge of the coils and the volume of such a cylinder is then equal to 6.9×10^4 cm.^{3}. The plasma which is ignited by dissociation of the high energy molecular ions as they pass through the high intensity arc is confined and trapped within the said inscribed volume by the magnetic field H. The gas used for the ion source input is deuterium, for example, and the injection voltage of the molecular ions D_2^+ is approximately 600 kev., for example, which results in atomic ions D^+ of substantially 300 kev. energy. The resultant ring of atomic ions is at least 3 inches wide with a radius of 5.3 inches and a circumference of 33.3 inches. The magnetic field strength at the center of said ring of atomic ions is 6880 gausses and at the outer edge of the ring the field strength is 6000 gausses. The current supplied to the magnetic mirror coils is 4250 amperes.

It has been determined that for an arc voltage of 150 volts and an arc current of 300 amperes, there is a 25% breakup of the molecular ions into atomic ions. This percentage increases linearly as the arc current is increased. It has also been determined that dissociation is inversely proportional to the distance from the anode that the 600 kev. molecular ions are injected into the device.

The use of the carbon arc to create circulating ion beams has certain applications in the particle accelerator art also. For example, the breakup of D_2^+ ions and trapping of protons from a point 180° from the point of dissociation may be utilized as a method of injecting protons into a proton synchrotron. Moreover, it has been demonstrated that fifty percent of the power is dissipated in the form of radiation of I ultraviolet light. The arc is a very powerful ioni agent and reduces charge exchange between trap energetic atomic ions and low energy neutrals by io ing many of the neutrals in the volume. Studies of vacuum properties of the arc indicate not only tha will be useful as an ion pump, but also that the de ited carbon absorbs gases and thereby provides a tional pumping action. This action is strong eno to make it possible to valve off the diffusion pu of a facility in which the arc is operating. Probe m urements and arc current studies have shown that operation of the arc is accompanied by consider amounts of R.F. oscillation with frequencies at l up to tens of megacycles. When used for dissocia of molecular ions the high energy arc can also be u for producing large well defined neutral beams. Si the cross section for dissociation decreases slowly the energy increases, this process can be used at desired energy. These neutral particles could be injec into accelerators and then converted into ions.

This invention has been described by way of illus tion rather than limitation, and it should be appa that the invention is equally applicable in fields ot than those described.

What is claimed is:

1. A device for establishing a high-intensity dir current carbon arc having a current in excess of amperes which comprises a high vacuum enclos widely spaced carbon anode and cathode electro mounted within said enclosure, means for establish a magnetic field within said enclosure, said magn field having a direction parallel to the axis of the charge, means for temporarily assisting in the ini tion of an undefined arc discharge directly between s electrodes, and a variable voltage source connected tween said electrodes for also assisting in the initiat and for varying the intensity of said arc discharge, s discharge being sustained by the variable voltage sou and the carbon ions and electrons which are relea from the electrodes.

2. A device as set forth in claim 1 in which the me for assisting in the initiation of an arc includes a sou of gas which is fed to the face of the cathode, an source of R.F. voltage connected between the electro until an arc is struck.

3. A device as set forth in claim 2 in which the is argon and is fed through a conduit within the catho

4. A device as set forth in claim 3 in which the v uum in the enclosure is maintained at approximat 10^{-6} mm. Hg, the spacing between the electrodes is least 6 feet, and the strength of the magnetic field the center of the enclosure is maintained at a selec value in the range from 500 to 10,000 gausses.

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