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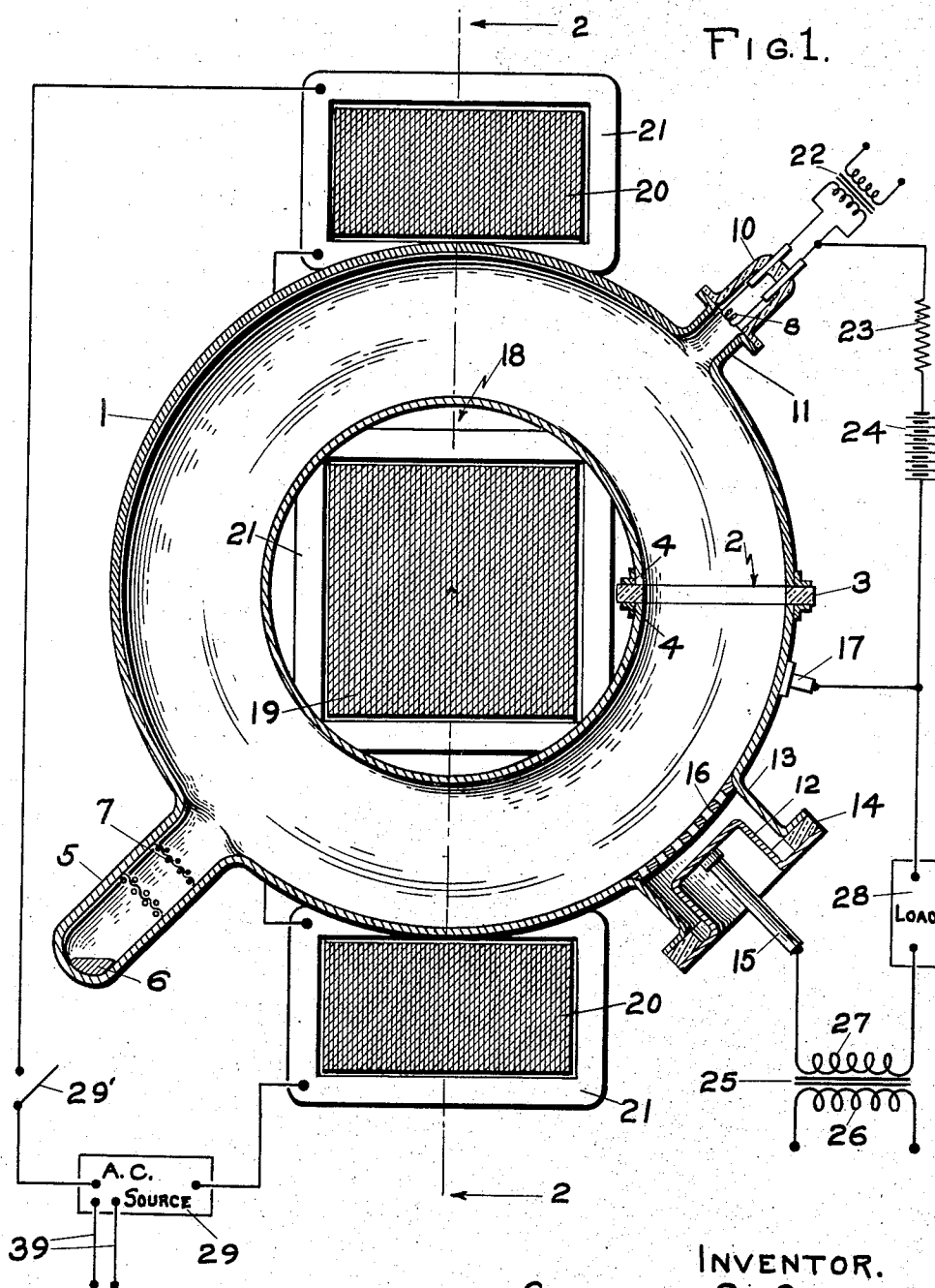
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LOW PRESSURE CONTROLLED DISCHARGE DEVICE

Filed Aug. 27, 1940

3 Sheets-Sheet 1



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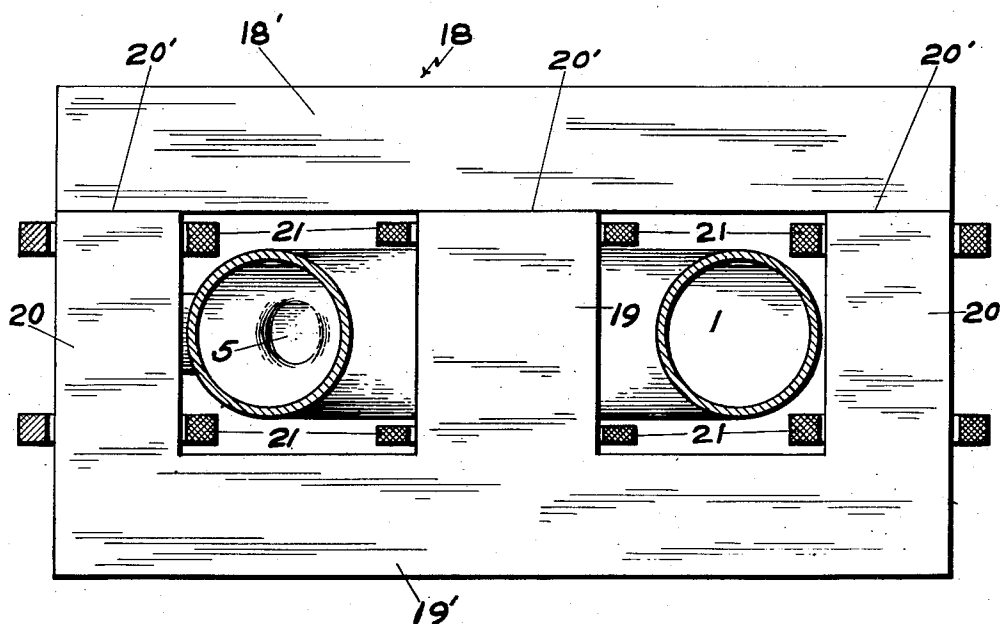
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3 Sheets-Sheet 2

FIG. 2.



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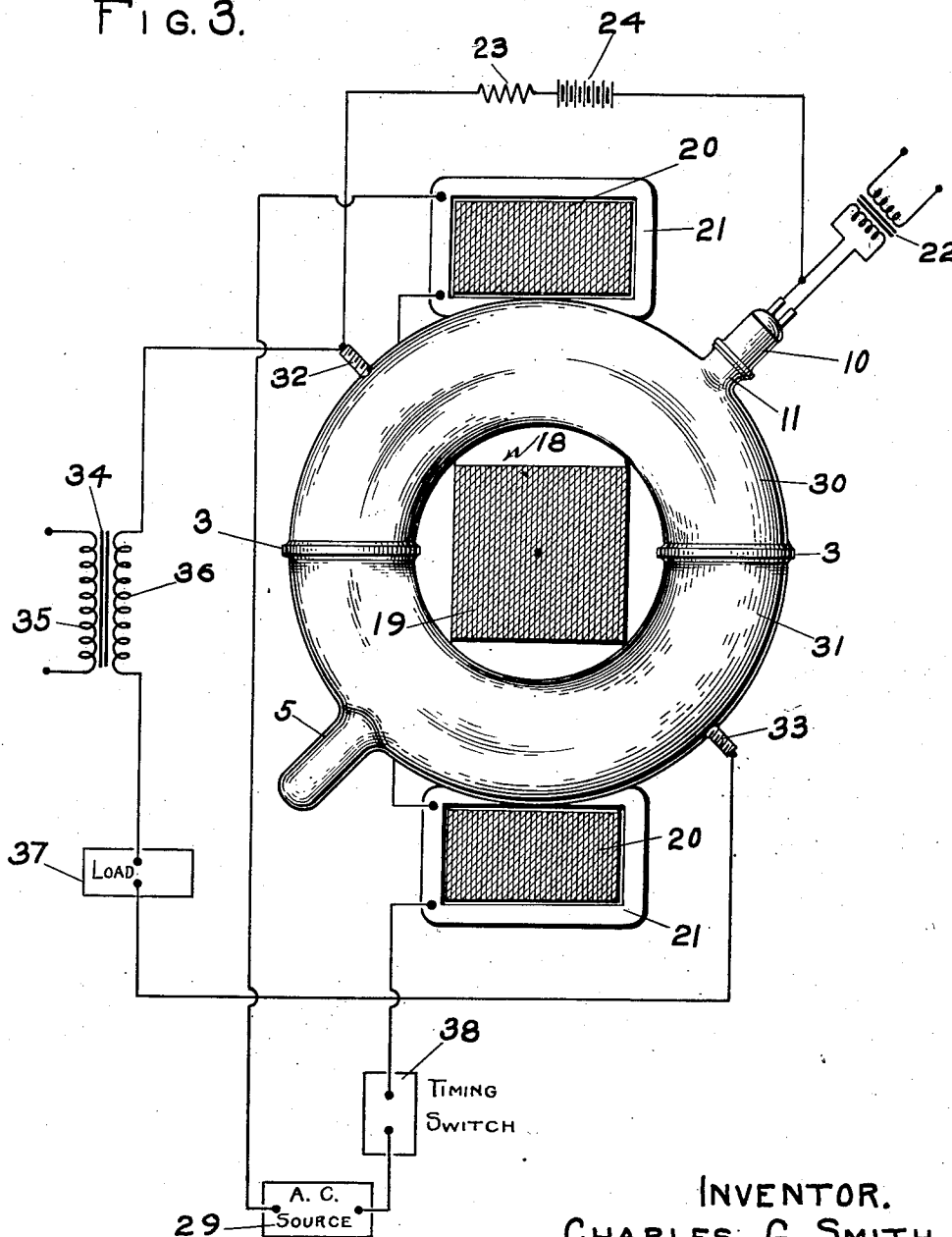
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LOW PRESSURE CONTROLLED DISCHARGE DEVICE

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FIG. 3.



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LOW PRESSURE CONTROLLED DISCHARGE
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23 Claims. (Cl. 250—27.5)

This invention relates to a controlled electrical discharge device of the gaseous type which operates at relatively low gas or vapor pressures and conducts current of high power with relatively low losses.

This invention is based upon certain discoveries which I have made concerning the electrodeless ring discharge. I have discovered that a ring discharge can be passed through tubes of relatively large size at pressures of the order of one micron or less as well as at pressures of higher orders of magnitude. I have passed currents of hundreds of amperes through mercury vapor at pressures below one micron. I have also caused such discharges to pass through gaseous atmospheres contained within a ring entirely made of metal, except for one or more insulating sections which prevent the metal from acting as a short circuit. I have further shown that at excessively low pressures of the order of 10^{-4} mm. and even lower pressures, large ring currents can be passed, and the resultant ionization can be used to substantially completely neutralize space charge in the region between a thermionic cathode and an anode exposed in the discharge. I have further observed that cathodes at temperatures below the usual thermionic emission range, when exposed to such a discharge, may be employed as cathodes supplying many amperes of current and having said current under complete control of the discharge.

An object of this invention is to utilize the foregoing discoveries for the purpose of making an efficient, controllable, unidirectionally conducting device.

Another object is to provide such a device capable of rectifying large amperages and voltages.

A further object is to produce such a device in which the conduction of current is under complete control of a relatively small controlling influence.

The foregoing and other objects of my invention will be best understood from the following description of exemplifications thereof, reference being had to the accompanying drawings, wherein:

Fig. 1 is a cross-section of my novel tube together with a diagrammatic representation of a typical circuit with which it may be used;

Fig. 2 is a cross-section taken along line 2—2 of Fig. 1; and

Fig. 3 is a showing similar to Fig. 1 of an additional embodiment of my invention, the tube, however, not being shown in section.

In the arrangement illustrated in Figs. 1 and 2, the tube consists of a metal torus 1 made of some suitable material, such as stainless or chrome steel or aluminum. The metal of the torus is interrupted at 2, and a ring of insulation 3 sealed to a pair of flanges 4 which are welded to the torus 1 is utilized to complete the torus and to make it hermetically tight. A side tube 5 extends from one side of the torus 1, and contains a small quantity 6 of vaporizable material, such as mercury or caesium. Other vaporizable materials, such as the other alkali metals, may also be used. The use of caesium or potassium may be made particularly effective inasmuch as the walls of the torus 1 can be made to reflect substantially all of the radiations emitted from ionized caesium or potassium vapor, and thus greatly increase the efficiency of the device. The side tube 5 may be maintained at a constant predetermined temperature by immersing it in a constant temperature bath or the like so as to maintain the pressure within the torus 1 at a predetermined value. This pressure is preferably of the order of one micron of mercury or less. For example, in the case of mercury, the temperature of the side tube 5 may be about 5° C. or higher. In the case of caesium, the temperature may be about 90° C., while in the case of potassium, the temperature may be about 140° C. Of course it is to be understood that higher values of temperature, and in some instances even lower values of temperature, may be utilized. One or more grids 7 may be interposed across the side tube 5 in order to prevent the discharge within the torus 1 from extending through to the vaporizable material 6, and producing an excessive vaporization thereof.

I have found that a discharge may be readily started through gases at the low pressures mentioned if a number of ions are introduced into the discharge space. Such ions may be supplied by providing a filament 8 adapted to be heated to a temperature of thermionic emission. The filament 8 may be sealed through a glass stem 10, which in turn is sealed to the outer end of a tubular extension 11 formed on the torus 1. The filament 8 may be located well within the extension formed by the tubular member 11 and the stem 10 and yet cause a sufficient number of ions to pass out into the main body of the torus 1 for the desired purpose.

An anode 12 formed by a reentrant metal cup is insulatingly sealed to a tubular extension 13 by means of an insulating sealing ring 14, preferably of glass. A lead 15 is secured to the outer

side of the anode 12 so as to provide an electrical connection thereto. A grid 16 is preferably provided across the opening to the tubular extension 13, the grid 16 being electrically connected to and supported by the torus 1. The torus 1, which in the present instance is to serve as the cathode, is provided with an electrical connection 17. Although I have described the tube as consisting of a torus, the shape of the closed gaseous path does not have to be circular but can take on various desired forms. The size of the central opening in the torus 1 should be large enough to permit the passage of considerable total magnetic flux through said hole for the purpose of generating an electromotive force around through the closed gaseous path. For example, in certain instances I have used values of from three to seven inches for the diameter of said central opening. In addition the cross-section of the gaseous path determined by the cross-section of the tubular portion of the torus should be relatively large. In certain cases I have utilized values of from one to six inches for the diameter of said cross-section. Of course these dimensions may be departed from considerably.

Electrodeless discharge currents are induced in the torus 1 by means of a suitable transformer 18 comprising a magnetic core preferably made of iron of high magnetic permeability. The core is provided with a central leg 19 of maximum size to conveniently pass through the central opening in the torus 1. The core is also provided with a pair of outer legs 20. The lower ends of the legs 19 and 20 are joined by a lower leg 19'. The upper ends of the legs 19 and 20 provide pole faces 20'. These pole faces are ground off flat so as to provide as smooth a surface as practicable without the presence of projecting portions, such as burrs and the like. In addition it is also preferable to paint the faces of the pole pieces 20' with a thin insulating varnish. A top leg 18' likewise ground flat adjacent the pole pieces 20' is laid across the tops of the legs 19 and 20 so as to complete the magnetic circuit of the transformer. The leg 18' may be retained in place by any suitable fastening means which preserves the slight air gap provided at the pole pieces 20' by the above construction. At the upper and lower ends of each of the legs 19 and 20 is provided an energizing coil 21, resulting in a total of six such coils in the arrangement of Figs. 1 and 2. The coils 21 are adapted to be supplied with energizing currents of frequencies of the order of 1000 to 2000 cycles. In devices of this kind the presence of transverse fields intersecting the gaseous discharge path are undesirable inasmuch as such fields interfere with the free passage of the discharge. The symmetrical arrangement of the transformer 18 and the exciting coils 21 reduce leakage fluxes to a minimum, and substantially prevent the presence of transverse magnetic fields in the gaseous discharge space. The upper coils 21 are placed closely adjacent the air gaps 20', whereby leakage fluxes from these air gaps are likewise minimized.

The arrangement described above may be connected in any suitable circuit, such as shown, for example, in Fig. 1. In this circuit the filament 8 is provided with heating current from a heating transformer 22. The filament 8 is connected through a current-limiting resistance 23 and a source of potential, such as a battery 24, to the connection 17 of the torus 1. In this way an ionizing discharge may be maintained be-

tween the torus 1 and the filament 8 for the purpose of generating ions to facilitate starting of the main discharge. A relatively small number of positive ions is needed for this purpose, and therefore only a few milliamperes passing between the filament 8 and the torus 1 are usually sufficient for starting said main discharge. The current to be rectified is applied to the tube from a power transformer 25 having a primary winding 26 adapted to be connected to a suitable source of alternating current, and a secondary winding 27 connected in series with the load 28 between the cathode 1 and the anode 12. A suitable source 29 of alternating current of the desired frequency, for example 1000 to 2000 cycles, is connected to the energizing coils 21 in series with the control switch 29'. The current output of the source 29 may be modulated from a pair of leads 30 energized from a source of alternating current of the same frequency and bearing a definite phase relationship with respect to the alternating current energizing the primary winding 26 of the transformer 25. The modulation and phase relationship are preferably such that current is supplied to the coils 21 when the anode 12 is positive with respect to the cathode 1, and such energizing currents are stopped during the time that the anode 12 is negative with respect to the cathode 1. The electromotive force around the closed gaseous discharge loop may be relatively small, of the order of 15 volts more or less.

When the system is energized, electrons from the filament 8 cause ionization throughout the interior of the torus. When the switch 29' is closed, an intense ring discharge is initiated around the closed gaseous discharge loop. In absence of an auxiliary supply of ions as described above, the starting of such a discharge at the low pressures described would be extremely difficult. Under the conditions of the intense electrodeless discharge, a large amount of current may be passed between the torus 1 acting as a cathode and the anode 12 representing a large emission of current carriers from the cathode 1. A large part of this emission is probably caused by large numbers of positive ions arriving at the walls of the torus 1 where they recombine with electrons. Some of the emission is undoubtedly due to causes in addition to such positive ion collection. The current emission from the interior walls of the torus 1 can readily be made 10 milliamperes per square centimeter and even greater in accordance with observations made on such tubes. In order that the current passing between the cathode 1 and the anode 12 be 200 amperes, the internal area of the torus 1 need only be about 2×10^4 square centimeters.

Under the above conditions, whenever the voltage of the secondary winding 27 makes the anode 12 positive with respect to the cathode 1, substantially 200 amperes of current may be drawn to said anode. When, however, the voltage becomes negative, the inducing currents to the coils 21 are cut off, and therefore substantially no current can be drawn between the anode 12 and cathode 1. This is true even if high voltages are impressed between the electrodes. Such voltages may be of the order of 10,000 volts, for example. The conduction of current is thus under complete control of the source 29. If, for example, it is desired to stop all flow of current to the load 28, it is merely necessary to open the switch 29'. The tube, therefore, acts as a very

effective rectifier for supplying direct current to the load 28.

The voltage drop during the period of current flow between the anode 12 and the cathode 1 is relatively small, being of the order of five volts more or less in the case of mercury vapor. The rectifier illustrated, therefore, is very efficient, due to the low drop which it is thus possible to secure. As previously indicated in the case of the alkali metals, by making the interior surfaces of the torus 1 reflecting to the radiations generated in said vapors, the drop through the tube may be made relatively smaller than in the case of mercury, and therefore the efficiency may be relatively greater.

Although the arrangement has been described in connection with a magnetic core transformer, in some instances with the proper selection of frequency and other constants, the iron core can be eliminated and merely an air core coupling made between the exciting coils and the torus 1.

Since the conduction of current between the cathode 1 and the anode 12 is under complete control of the excitation source 29, the tube may be made for other purposes than rectification. For example, if a direct current power source is connected between the cathode 1 and the anode 12 in a direction so as to make the anode 12 positive, conduction of direct current through the tube will be under complete control of the switch 29' so that by closing said switch, direct current is permitted to flow, while opening of the switch will cut off flow of direct current. In this way by closing and opening the switch 29' at a predetermined frequency, the direct current can be periodically interrupted, thus causing the tube to function as an inverter.

The invention can also be employed to control alternating current instead of direct current. Such an arrangement is illustrated in Fig. 3 wherein identical reference numerals are applied where the elements are identical with those of Figs. 1 and 2. In Fig. 3 the tube, instead of having a single interruption in the torus, is provided with two such interruptions at diametrically opposite points, dividing the torus into two halves 30 and 31. These halves are provided with external electrical connections 32 and 33, respectively. The side tube 5 and the extension 11 containing the ionizing filament are employed. However, the anode of Fig. 1 is omitted. The tube of Fig. 3 is supplied with power from a power transformer 34 having a primary winding 35 adapted to be connected to a suitable source of alternating current, and a secondary winding 36. One end of said secondary winding is connected to the half 30, while the other end is connected through a suitable load 37 to the other half 31. The switch 29' of Fig. 1 may be replaced by a timing switch 38 which may be operated in accordance with a predetermined time sequence. When the switch 38 is in its closed position, alternating current will pass between the two halves 30 and 31, while in the open position of said switch, flow of current between said halves will be stopped. In this way alternating current will be supplied to the load 37 in accordance with the time sequence of operation of the switch 38. The load 37 may be, for example, a resistance welding load in which case the timing switch 38 is preferably operated in synchronism with the alternating current supply so as to furnish a predetermined number of cycles to the load 37 for each operation of the switch 38.

Of course it is to be understood that this invention is not limited to the particular details as described above as many equivalents will suggest themselves to those skilled in the art. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. An electrical discharge device comprising an envelope containing an ionizable gaseous atmosphere, means for producing an electrodeless discharge in said atmosphere, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, said cathode surface substantially surrounding said discharge, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said electrodeless discharge.
2. An electrical discharge device comprising an envelope containing an ionizable gaseous atmosphere, means for producing an electrodeless discharge in said atmosphere, means for introducing ions for facilitating starting of said electrodeless discharge, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said electrodeless discharge.
3. An electrical discharge device comprising an envelope containing an ionizable gaseous atmosphere at a pressure of the order of one micron or less, means for producing an electrodeless discharge in said atmosphere, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said electrodeless discharge.
4. An electrical discharge device comprising an envelope containing an ionizable gaseous atmosphere at a pressure of the order of one micron or less, means for producing an electrodeless discharge in said atmosphere, means for introducing ions for facilitating starting of said electrodeless discharge, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said electrodeless discharge.
5. An electrical discharge device comprising a ring-shaped envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere, means for producing a ring discharge in said atmosphere, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said ring discharge.
6. An electrical discharge device comprising an envelope containing an ionizable gaseous atmosphere, electromagnetic means for inducing an

electrodeless discharge in said atmosphere, means for introducing ions for facilitating starting of said electrodeless discharge, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said electrodeless discharge.

7. An electrical discharge device comprising a ring-shaped envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere at a pressure of the order of one micron or less, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, electromagnetic means for inducing a ring discharge in said atmosphere, and means for introducing ions for facilitating starting of said ring discharge.

8. An electrical discharge device comprising a ring-shaped envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere at a pressure of the order of one micron or less, and electromagnetic means producing flux interlinking said ring for inducing a ring discharge in said atmosphere, said electromagnetic means being arranged to substantially prevent magnetic fields transverse to the path of said discharge.

9. An electrical discharge device comprising a ring-shaped envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere at a pressure of the order of one micron or less, electromagnetic means producing flux interlinking said ring for inducing a ring discharge in said atmosphere, said electromagnetic means being arranged to substantially prevent magnetic fields transverse to the path of said discharge, and means for introducing ions for facilitating starting of said electrodeless discharge.

10. An electrical discharge device comprising a metal ring-shaped envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere, the interior surface of said envelope being adapted to function as a cathode, and an electrode surface adapted to operate as an anode for said cathode surface, additional means for producing an ionizing discharge in said atmosphere, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said discharge.

11. An electrical discharge device comprising a metal ring-shaped envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere, said metal ring having an insulating interruption for preventing short-circuit of said gaseous atmosphere, the interior surface of said envelope being adapted to function as a cathode, and an electrode surface adapted to operate as an anode for said cathode surface, additional means for producing an ionizing discharge in said atmosphere, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said discharge.

12. An electrical discharge device comprising a metal ring-shaped envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere, said metal ring being divided into two parts insulated from each other, the interior surfaces of said parts being adapted to function as cathode surfaces, additional means for producing an ionizing discharge in said atmosphere, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surfaces to substantially cease upon stoppage of said discharge.

phere being sufficiently low to cause emission from said cathode surfaces to substantially cease upon stoppage of said discharge.

13. An electrical discharge device comprising an envelope containing alkali metal vapor, the interior walls of said envelope having a surface which reflects most of the radiations emitted from said vapor during operation, means for producing an electrodeless discharge in said atmosphere, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said electrodeless discharge.

14. An electrical discharge device comprising a metal envelope containing an ionizable gaseous atmosphere, the interior surface of said envelope being adapted to function as a cathode, and an electrode surface adapted to operate as an anode for said cathode surface, additional means for producing an ionizing discharge in said atmosphere, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said discharge.

15. An electrical discharge device comprising a metal envelope containing an ionizable gaseous atmosphere, said metal envelope having an insulating interruption for preventing short-circuit of said gaseous atmosphere, the interior surface of said envelope being adapted to function as a cathode, and an electrode surface adapted to operate as an anode for said cathode surface, additional means for producing an ionizing discharge in said atmosphere, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said discharge.

16. An electrical discharge device comprising a metal envelope containing an ionizable gaseous atmosphere, said metal envelope being divided into two parts insulated from each other, the interior surfaces of said parts being adapted to function as cathode surfaces, additional means for producing an ionizing discharge in said atmosphere, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surfaces to substantially cease upon stoppage of said discharge.

17. An electrical discharge device comprising an envelope having a conductive interior wall surface and containing an ionizable gaseous atmosphere, said conductive interior wall surface being adapted to function as a cathode, and an electrode surface adapted to operate as an anode for said cathode surface, additional means for producing an ionizing discharge in said atmosphere, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said discharge.

18. An electrical discharge device comprising a ring-shaped envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere, and electromagnetic means producing flux interlinking said ring for inducing a ring discharge in said atmosphere, said electromagnetic means being arranged to substantially prevent magnetic fields transverse to the path of said discharge.

19. An electrical discharge device comprising an envelope containing an ionizable gaseous atmosphere being sufficiently low to cause emission from said cathode surfaces to substantially cease upon stoppage of said discharge.

mosphere, means for producing a discharge in said atmosphere, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, said cathode surface substantially surrounding said discharge, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said discharge.

20. An electrical discharge device comprising an envelope containing an ionizable gaseous atmosphere, means for producing an electrodeless discharge in said atmosphere, a cathode surface of the type from which emission is dependent on the presence of an ionizing discharge, said cathode surface being in non-shielding relation to said means, whereby said electrodeless discharge occurs immediately adjacent said cathode surface, and an electrode surface adapted to operate as an anode for said cathode surface, the pressure of said atmosphere being sufficiently low to cause emission from said cathode surface to substantially cease upon stoppage of said electrodeless discharge.

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21. An electrical discharge device comprising an ionizable atmosphere, means for producing a discharge in said atmosphere, and means surrounding said discharge, said last-named means having an internal surface which reflects most of the radiations emitted from said atmosphere during operation.

22. An electrical discharge device comprising an alkali vapor, means for producing a discharge in said vapor, and means surrounding said discharge, said last-named means having an internal surface which reflects most of the radiations emitted from said vapor during operation.

23. An electrical discharge device comprising an envelope providing a closed ring-shaped discharge path and containing an ionizable gaseous atmosphere, and electromagnetic means producing flux interlinking said ring for inducing a ring discharge in said atmosphere, said electromagnetic means being arranged to substantially prevent magnetic fields transverse to the path of said discharge.

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