

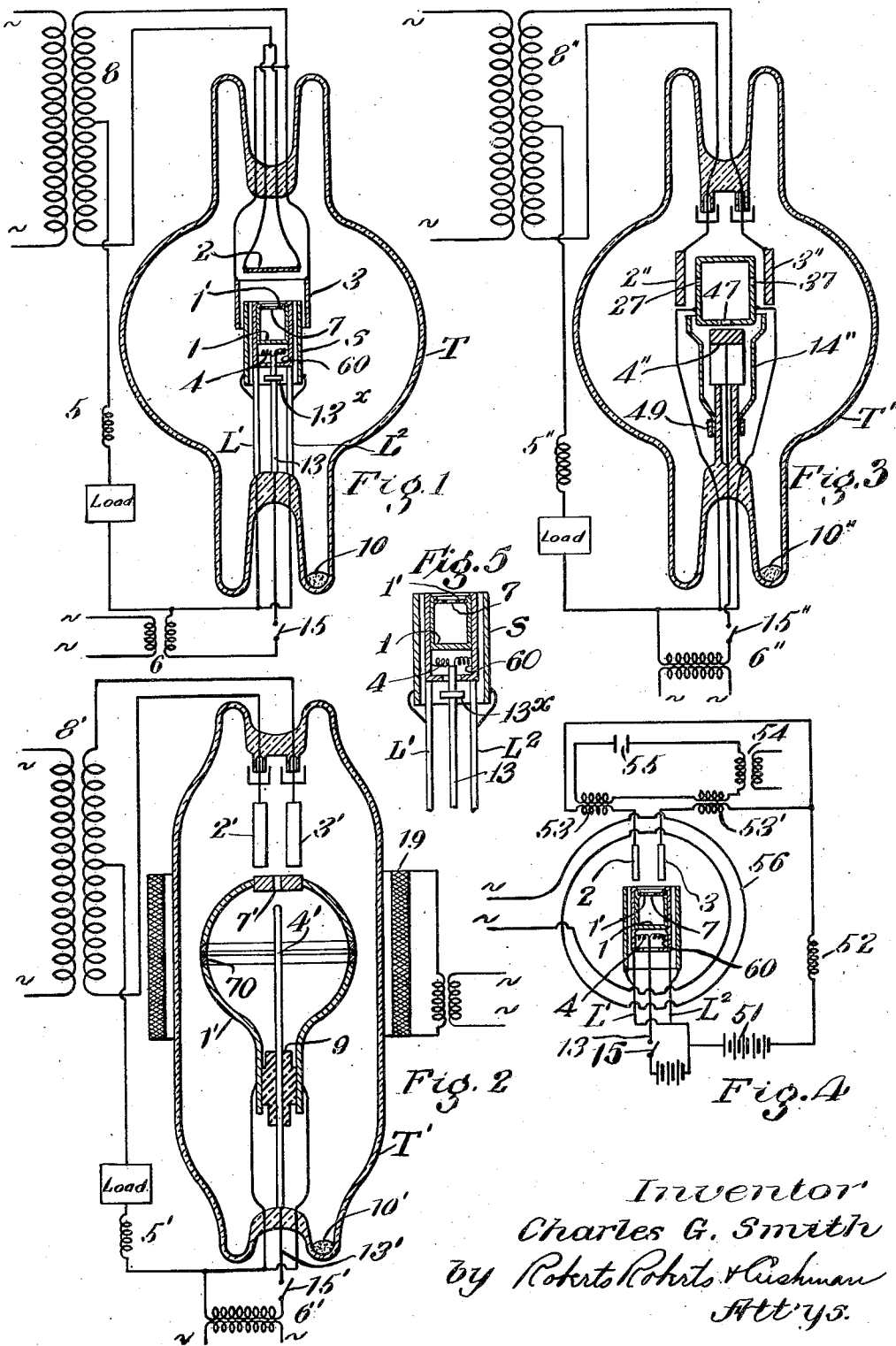
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ELECTRONIC DISCHARGE METHOD AND APPARATUS

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ELECTRONIC DISCHARGE METHOD AND APPARATUS

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This invention relates to electronic space current discharge devices such as rectifiers, amplifiers, oscillators, etc., and more particularly to devices containing a gas or gases at low pressure.

Objects of the invention are to provide gaseous space current devices which operate with low cathode voltage drop when passing relatively large current, the density of which is substantially in excess of that of a glow discharge during normal operation, which have high efficiency and long life, and which may be built for either light or heavy loads. Other objects are to provide a cathode which serves as an abundant source of electrons, to provide conditions between anode and cathode such that the discharge is easily controllable by electric or magnetic means, to secure effective valve action against reverse voltage discharges, and generally to increase the efficiency and performance capacity of such devices.

For the purpose of illustration a few typical embodiments of the invention are shown diagrammatically in the accompanying drawing in which:

Figs. 1, 2 and 3 are diagrammatic showings of three forms of tubes connected for rectification;

Fig. 4 is a circuit diagram showing one way of connecting the tube of Fig. 1 as an oscillator; and

Fig. 5 is an enlarged view of the cathode structure of Fig. 1.

The device shown in Figs. 1 and 5 comprises a sealed tube, envelope, or container T containing electrodes including a tubular thermionic cathode 1, which is connected to the mid-point of a transformer secondary 8 through a load and a choke coil 5, and anodes 2 and 3 connected respectively to the opposite ends of the secondary 8. The cathode comprises a metallic container or enclosure which is cylindrical and contains a chamber or cavity which has its ends closed except for a restricted discharge opening 7 through which the electrons escape and thus through which the electronic discharge passes from the interior of the cathode to the anodes. The size or cross-sectional area of the opening 7 is a small fraction of the area of the inner surface or internal walls of the cavity. The latter area is at least twice as great as the size of said opening. A suitable material for the cathode is nickel. The extended interior discharge surface of the cathode is preferably coated with material capable of enhancing the electron emissivity of said cathode at an elevated tem-

perature. Preferably this material is but slowly volatilizable and remains substantially intact on the walls of the cathode cavity at a temperature of effective electron emissivity. This material should be of higher electron emissivity than the cathode and may be a material such as an alkaline earth oxide which emits electrons in copious or appreciable quantity at a temperature below the corresponding temperature for nickel. A suitable coating comprises barium, strontium, and calcium oxides or some of them. These and similar activating or thermionic materials are substantially solid or non-volatile at the normal operating temperature of the tube envelope T and hence will be termed herein—solid substances or materials. Thus, in general, the interior surface of the cathode has a low work function, and the outside of the cathode has a higher work function. During operation, therefore, the coated interior surface of the cathode has a considerably larger electron emission than the exterior of the cathode so that substantially only said interior surface emits electrons during operation. The discharge which occurs between the cathode and the anodes is limited substantially to said interior cathode surface. The opening 7, whereby the cathode cavity is open to the exterior, may have a relatively small diameter of the order of $\frac{1}{25}$ inch for example, while the cathode cavity may have a large internal surface. A small quantity of mercury or alkali metal 10 is incorporated in the tube to afford a readily ionizable gas as hereinafter described. The gas pressure of the readily ionizable gas (such as mercury vapor) at the operating temperature of the device may be a fraction of a millimeter of mercury, for example within the range of about one to one hundred microns of mercury. When employing caesium vapor instead of mercury vapor the oxide coating on the interior of the cathode may be omitted inasmuch as the condensed layer of caesium at the interior surface of the cathode will provide a low work function inside the cathode.

The cathode in Figs. 1 and 5 is in the form of a cylinder with a closed bottom and an open top closed by the perforated disk 1' which is preferably formed of molybdenum. Disk 1' is held tightly in place by spinning the upper edge of the cylinder 1 over the periphery thereof. The hollow cathode 1 is substantially enclosed by a heavy nickel cup 60 and may be held in position by interior shoulders on the cup 60, the upper shoulder being formed by inwardly spinning the upper edge of the cup after the cathode is posi-

tioned in the cup. The lower end of cup 60 is spaced from the bottom of the cathode to form a chamber in which is mounted resistance means such as a filamentary heater 4 of tungsten or molybdenum segregated from the cathode cavity and serving to heat the cathode to an electron-emitting temperature. Since the filament is substantially enclosed within the cup 60 the heat therefrom is largely imparted to the cathode by direct radiation and by conduction through the cup 60. Thus said filament constitutes a radiation heater whereby the cathode may readily be heated to a temperature of thermionic emission.

Opposite ends of the filament are connected to the cup 60 and the mid-point to lead 13 extending through a small opening in the bottom of cup 60. However, the filament does not function as a cathode and may be energized by having its opposite ends connected to a heating circuit independently of a discharge between the cathode and the anodes. Indeed, any suitable means may be employed to heat the cathode. A disk 13^a may be mounted on lead 13 below said opening to reflect downward radiation back toward the cathode. A light metallic shield S surrounds the cup 60 in such close juxtaposition that the gas space therebetween is of the order of, and preferably less than, the mean free path of the gas molecules in the space. The cathode is supported on lead wires L₁ and L₂. By making the cathode in hollow form, its walls are in reciprocal heat shielding relation, and by heating it, the interior may be readily maintained at high temperature.

The shield S surrounding the hollow cathode, and spaced therefrom by a gap, serves to suppress or minimize the heat losses from the exterior of the cathode enclosure and to maintain the interior of the cathode enclosure at higher temperature. The heat shield S thus constitutes heat insulating means for reducing the energy required to maintain the cathode at an electron-emitting temperature. Said shield is open at the top to permit the discharge to pass from the interior surface of the cathode to the anodes. This feature of the invention was disclosed by me in my prior copending application Serial No. 13,145, filed March 5, 1925.

The cooperating anodes 2 and 3 are located external to the cathode cavity. Anode 2 is in the form of a disk while anode 3 comprises a cylinder forming a shield around the discharge space, the anodes together shielding the tube substantially completely from electrons emitted from the opening 7. The anodes 2 and 3 as a unit are thus mounted around the opening 7, enclose the discharge space and screen the space bordering the walls of the tube T from the discharge space so as to substantially prevent the extension of the discharge to the said space bordering the tube walls. It will be seen that anode 3 is located out of direct line with the opening 7 and that the cathode 1 is arranged to interpose its wall as a shield between the cathode cavity and said anode. Anode 2 is preferably formed of molybdenum or other refractory material inasmuch as it tends to heat if the gas pressure is too low. Inasmuch as anode 3 does not become very hot even when the gas pressure is abnormally low it may be formed of nickel.

The tube of Fig. 1 is started by first heating the cathode with coil 4 and then applying a suitable potential for starting. During operation the cathode operates at a temperature at

which the space conduction of the relatively large current, or the unidirectional conduction or rectification, where the device is used as a rectifier, is dependent upon thermionic emission. Due to its temperature the cathode provides the desired thermionic emission to maintain the electronic discharge which flows from the interior of the cathode through the opening 7 and thence to the anodes 2 and 3 alternately during alternate half-cycles with ionization of the gas between the cathode and anodes. The material 10 is vaporized to some extent by the heating coil simultaneously with the heating of the cathode and to maximum degree by the heat due to the electronic discharge. As the mercury is vaporized and ionized the voltage drop between cathode and anode decreases until maximum temperature is reached at which time the mercury pressure in the tube may be of the order of a fraction of a millimeter of mercury, e. g., 10 microns (.01 mm.). After maximum temperature is attained the circuit of the heating coil 4 may be opened at switch 15.

One feature of the invention resides in an arrangement between the surfaces of the two electrodes, of an obstruction having a restricted opening therethrough, the electronic discharge passing through this opening. The aforesaid obstruction is preferably made a part of a hollow cathode, the discharge passing from the interior of the cathode through an opening in the obstruction part of the cathode to the anode or anodes located outside the cathode. The opening through which the discharge passes is preferably so restricted that the intensity of the discharge is very high in the opening.

Either a single gas or a mixture of two or more gases may be employed. The single gas or one of the mixed gases, which should be readily ionizable, may comprise mercury vapor or the vapor of an alkali metal (preferably caesium), the vapor being derived from a small quantity of liquid or solid material incorporated in the tube. The quantity of material incorporated in the tube is at least sufficient to afford the desired gas pressure at normal temperature. When employing mixed gases the second gas preferably comprises an inert monatomic gas such as helium, argon, krypton, xenon, or other gas which when not ionized does not greatly hinder the passage of electrons. The second gas should be less easily ionizable and, therefore, should have an ionizing voltage higher than the first gas and preferably higher than the normal operating discharge voltage of the tube, although, in the case of a rectifier, not necessarily as high as the back voltage during reverse half-cycles.

The pressure of the readily ionizable gas (such as mercury vapor) is preferably only sufficient, during normal operation, to prevent the accumulation of excessive space charge near the anode; and in the typical embodiments chosen for illustration it may be only a fraction of a millimeter of mercury (e. g., ten microns). When using a second gas, such as helium, or argon, the pressure of the second gas is preferably high enough for starting purposes and, in the typical embodiments, when using a second gas, its pressure may be a centimeter of mercury more or less (e. g., 15 mm.). The pressure of said second gas may likewise be of the order of that required to minimize space charge near the anode to the desired extent. In the examples given the second gas has a relatively high pressure compared to the easily ionizable gas. Preferably in each

case the gas in the device is attenuated but its pressure, although low, is sufficiently high to permit of substantial ionization for furnishing positive ions to neutralize space charge to the desired extent. In the presence of such positive ions the electrons pass freely through the cathode discharge opening. The range of permissible gas pressures is relatively wide, covering, as indicated above, a range of about 1 micron to at least several millimeters of mercury.

When employing a second gas such as argon or helium with a readily ionizable gas such as mercury vapor, the second gas has the substantial pressure described above even when cold, while the readily ionizable has a lower pressure when cold than during normal operation. When utilizing the embodiment of Fig. 1 under these conditions, an arc-like discharge is started through the argon or helium. The starting discharge vaporizes the mercury contained at 10 and generates a sufficient amount of mercury vapor to maintain the discharge by the ionization of the mercury vapor in the presence of the argon or helium. As described above, the pressure of the mercury vapor during normal operation may be of the order of one to one hundred microns. When utilizing the embodiments of Figs. 2 and 3, under these conditions, a similar action takes place except that a starting glow discharge takes place from the starting electrodes 4' and 4'' through the helium or argon. In each instance after the initial operation of the tube is continued for a very brief interval, the cathode voltage drop may be of the order of the ionization voltage of the mercury vapor or less.

The embodiment shown in Fig. 2 is in general similar to that shown in Fig. 1, corresponding parts being correspondingly designated. However, the starting means comprises an auxiliary electrode consisting of a small rod 4' extending into the cathode through an insulator 9 which closes the lower end of the cathode, and a coil 19 which produces a magnetic field longitudinally of and substantially coaxial with the restricted central opening 7'. Said magnetic field extends in the region of the discharge from the cathode discharge surface within the cathode enclosure 1' to the anodes 2' and 3'. The sides of the opening 7' in the cathode 1' constitute surfaces adjacent the path of electron flow in the space discharge between the inner electron-emitting surfaces of the cathode and the anode. However, the magnetic field of the coil 19 is coaxial with said path of electron flow at the surfaces within the opening 7' and thereby controls the motion of the electrons and causes them to pass by these surfaces and reach the anodes 2' and 3'. In the embodiment shown in Fig. 2, a starting discharge may be produced at exceedingly low pressures (e. g., one micron of mercury and lower) with a voltage drop of 500 volts or less which is materially above the arc-sustaining voltage of the gaseous filling. Under these conditions the characteristics of the auxiliary electrode are such as to produce such a discharge in which the cathode voltage drop is materially higher than the cathode voltage drop normally characteristic of an arc in the gaseous filling. The magnetic field may be in phase or 180° out of phase with the alternating current impressed on the cathode-anode circuit and serves to facilitate the starting current and the ionization resulting therefrom. When using the magnetic field the cathode should be formed of non-magnetic material such as non-magnetic nickel steel

or at least be divided by a belt 70 of such material at its equator. After the parts are heated by the starting discharge, the operating discharge passes from the cathode 1' and the starting circuit may be opened at 15', all as above described. The discharge, which during normal operation occurs between the auxiliary electrode 4' and the cathode 1', may be termed an auxiliary discharge. Due to the fact that the auxiliary electrode 4' extends centrally along the cathode 1', the discharge region separating these two electrodes comprises an annular region. The magnetic field of the coil 19 extends through this annular region transverse to the normal direction of the electron travel. This produces a reaction between the electron flow and the magnetic field which causes a discharge to whirl around the auxiliary electrode 4'. In this whirling discharge the electrons passing between the cathode 1' and the auxiliary electrode 4' rotate around the auxiliary electrode making the discharge path between said two electrodes longer than the direct distance between them. The disk in the top of cathode 1' which has the opening 7' therein separates the anodes 2' and 3' from the region of the auxiliary discharge and gives access to said anodes only through the restricted aperture 7'. The auxiliary electrode 4' is located adjacent the space between the main electrodes and the auxiliary discharge when in operation functions as a source of electrons and ions for a main discharge from the cathode 1' to the main anodes 2' and 3'. This main discharge is maintained with the cathode along a discharge path through the opening 7' which is a discharge path different from that between the cathode 1' and the auxiliary electrode 4' in which the auxiliary discharge is produced. During normal operation the circuit of coil 19 may be open although this field may be continued for the purpose described below.

In Fig. 3 where parts corresponding to those in Figs. 1 and 2 are correspondingly designated, the anodes 2'' and 3'' are presented to the interior of the cathode through openings 27 and 37 respectively and a starting anode 4'' is presented to the interior of the cathode through opening 47. A tubular shield 14'' mounted on the tube T'' at 49 extends around the anode 4'' and the lower end of the cathode in such close proximity that electronic discharge between the exterior of the cathode and the anode 4'' can not take place for the reason that ionization cannot be effected in such a short gap, the distance being comparable to the mean free path of electrons in the space. After starting a discharge between the cathode and anode 4'', with a relatively high potential impressed on transformer 6'', the main operating discharge may be initiated between the cathode and anodes 2'' and 3'' with a comparatively low voltage, e. g. of the order of twenty-five volts or less. The anodes 2'' and 3'' cover extended areas of the cathode and are placed so close to the cathode that electrons flow only through the openings 27 and 37, the spacing being comparable to the mean free path of electrons in the space.

As described in connection with Fig. 1, the cathodes of Figs. 2 and 3 are preferably coated on the inside with material which emits thermionically in appreciable quantity at a temperature below the corresponding temperature of nickel of which the cathode is preferably composed.

In Fig. 4, where the tube of Fig. 1 is connected

as an amplifier, the D—C, source 51 is connected to the cathode and the primaries of transformers 53 and 53'. The load transformer 54 is connected to the secondaries of the transformers 53 and 53' through the medium of a closed circuit containing a condenser 55. A control coil 56, having its axis parallel to the faces of the anodes and perpendicular to the axis of the discharge, serves to flip the discharge from one anode to the other during alternate half-cycles of current in the coil. This arrangement may be employed as an oscillator by interconnecting the output and input circuits as by connecting the secondary of transformer 54 to the coil 56.

According to my present understanding of the theory of operation of my invention, a higher static pressure or density of ionizable gas is maintained in the region of the electron source than at the terminus of the discharge. This static pressure is sharply distinguished from a kinetic pressure such as, for example, a pressure resulting from a continuous flow, at a substantial velocity, of gas against a surface whose shape is such (e. g., plane) as to permit the gas to spread and continuously flow away or a pressure at the surface of boiling liquid from which the vapor flows away.

When employing a hollow cathode with a restricted opening therein the principle of operation when employing only a single readily ionizable gas such as mercury is believed to be as follows: The hollow cathode confines the space in the region of its electron-emitting surface, which constitutes a source of electron emission and likewise the source of discharge from which the relatively small opening leads. The hollow cathode with its discharge opening likewise comprises a perforate obstruction between said discharge source and the anode or anodes. The electronic discharge flowing out of the cathode is accompanied by a positive ion current flowing into the cathode (through opening 7, 7' or 27 and 37). These positive ions are atoms of mercury minus one or more electrons. Thus there is a flow of material, or a pumping of the easily ionizable gas, into the cathode. This flow of material builds up a gas pressure inside the cathode and for the conditions existing in a practical case the pressure is many times as great as that outside the cathode. Thus, for example, in Fig. 1, the disk 1' together with the opening 7 therein cooperates with the discharge to cause the pumping and to maintain this higher density or pressure of easily ionizable gas inside the hollow cathode structure while the device is operating at normal capacity. This pumping action is probably most pronounced at high current density and low gas pressure outside the cathode (e. g., 0.01 mm. of mercury pressure). That is, the pumping effect is greatest when the intensity of the discharge and the ionization in the opening (7, 7', or 27 and 37) is so great that neutral molecules are in the minority.

In addition to the foregoing pumping action in Fig. 2, when the field due to the coil 19 is continued as described above, said field, which extends axially along the cathode chamber 1', operates on the discharge between the cathode 1' and the auxiliary electrode 4 to give to the electrons of the discharge current a rotating movement as described above whereby said electrons impart to the gas molecules within the cathode chamber a similar gas movement, thereby rotating the gas inside the cathode. This rotation

of the gas results in centrifugal compression of the gas, moves the gas particles toward the cathode and produces a higher pressure adjacent the inner periphery of the cathode, thereby affording a higher state of ionization at the active discharge surface of the cathode and facilitating electronic emission therefrom. Thus, a low voltage discharge may be maintained between said cathode surface and the anodes. By extending the rod 4' through the center of the cathode to a point adjacent the opening 7', the gas inside the cathode is more effectively trapped and prevented from flowing out of the cathode along the axis thereof. Indeed, this construction results in gas flow into the cathode through openings 7', which is in the nature of a continuous pumping action, thereby maintaining a higher average pressure inside the cathode than outside. This type of pumping as exemplified by the embodiment illustrated in Fig. 2 affords another way of creating a difference in pressure in predetermined localized regions in the tube.

It has been observed that electrons can slip through certain gases without being substantially retarded if the electron velocities are below a critical velocity; and apparently the field of positive ions in the region of openings 7, 7', 27 and 37 displays a similar phenomenon at voltages which impel the electrons through the openings. That is, the outflowing electrons apparently slip through the field of ions without tending to push them out of the cathode. The momentum of the electrons results in a pressure upon the anode where the electrons are absorbed, whereas the momentum of the positive ions results in a pressure inside the cathode since the ions approach the active surface of the cathode but can not be absorbed for the reason that they are of a material nature and the electrode material is not permeable to the vapor.

While the bounding surface of the discharge opening in the cathode absorbs some of the momentum of the positive ions flowing into the cathode, thereby tending to retard the ion flow, this effect is more than counteracted by an opposite effect, resulting from the density of the current being greatest at the centre of the opening and much less dense adjacent the boundary.

After the initial operation of the tube is continued for a very brief interval the gas is at sufficient pressure and ionization and in sufficiently excited condition so that the voltage drop may be as low as the ionization voltage of the gas (10.4 volts for mercury vapor) and even considerably lower, probably due to the heat and light radiations inside the cathode and also the losses are relatively smaller. Under these conditions the cathode voltage drop is likewise of the order of the ionization voltage of the gas or less. In the specification and claims the term—arc-like discharge—and equivalent phrases mean, a discharge in which the cathode voltage drop is of the order of the ionization voltage of the gas in the device or less.

It is not only desirable to have high pressure or density in the region of the cathode but also to have low pressure near the anode. In the case of rectifiers low pressure near the anode restrains reverse discharge from anode to cathode during alternate half-cycles when the anode is negative, and in the case of oscillators this low pressure permits a quick and free shifting of the discharge from one anode to the other in contradistinction to the slow and feeble control in ordinary gaseous discharge oscillators.

By using a second gas such as helium as above described, the discharge is started through said second gas, and in accordance with my theory of the operation of the device as given above, the discharge maintains a higher static pressure of the readily ionizable gas near the source of the discharge than at the anode which constitutes the electron-receiving area or terminus of the discharge. As described above, the second gas has a substantial pressure when cold while the readily ionizable gas, which is usually a metallic vapor, has a lower pressure when cold. The second gas probably also assists in maintaining the higher pressure in the cathode, particularly in the case of rectifiers having a single anode for utilizing only alternate half-cycles of current in which case the second gas effectually retards the escape of gas from the cathode during the half-cycle when electronic discharge is not flowing out of the cathode. The pressure of the second gas should be high enough to impede the escape of the first gas from the region of higher pressure, but not high enough to retard the passage of electrons in marked degree. In a typical embodiment, the pressure of the second gas may be a centimeter of mercury or less. The restraint is apparently due to the fact that in the presence of the second gas the first gas can only diffuse out of the cathode whereas in the absence of the second gas the first gas could escape by mass flow during intervals of no discharge. Thus, by using a second gas the cathode may have a plurality of openings as in Fig. 3.

When employing two gases such as mercury vapor and helium, the pressure of mercury vapor inside the cathode is probably much greater than the pressure of mercury vapor outside the cathode, notwithstanding the total pressure may be substantially equal inside and outside in which case the helium pressure would be correspondingly lower inside than outside the cathode.

By using a second gas whose ionization voltage is above the operating voltage, as in the case of helium in the example referred to, the helium is not absorbed by the electrodes or other parts of the tube and therefore its pressure does not diminish during operation. Any absorption of the mercury vapor is automatically compensated for by further vaporization of the drop in the tube.

Moreover, according to this invention disintegration of the active surface of the cathode does not result in loss of cathode material since the atoms of cathode material can not fly out of the cathode and little if any material, such as the activating coating within the cathode cavity, escapes through the opening especially when using a second gas. The walls of the cathode enclosure, in each instance, are sufficiently closely adjacent so that particles of cathode material volatilizing from different points of the internal surface of said enclosure are largely intercepted by the walls of said enclosure before reaching an opening. Thus the cathode, due to its configuration, restrains escape of said material from the cathode cavity by volatilization through the opening. Since the walls of said cavity are positioned in shielding relation to one another, they not only conserve cathode material but also shield the interior of the cathode against loss of heat and radiation.

From the foregoing I believe that the invention affords among others the following advantages. Increased pressure at the active surface of the cathode tends to maintain a condensed layer of

gas on the surface, which tendency counteracts the tendency of elevated temperatures to dislodge such layer. When using caesium instead of mercury vapor the layer of condensed gas is even more pronounced, the layer of dense gas being due to bombarding molecules sticking at or near the surface momentarily. The condensed layer functions to facilitate thermionic emission and also to minimize disintegration. The increased pressure also affords arcing conditions inside the cathode by serving as a radiation trap, that is the high pressure serves to increase all ionizing factors such as electronic flow, radiation, etc. The intensity of radiation from the denser gas is greater than that possible from the rarer gas in the neck of the cathode. Thus radiation from this dense gas is an important ionizing agent for the molecules at the cathode opening. By producing high enough current density in the restricted opening to produce the aforesaid pumping action it is unnecessary to heat the cathode by an auxiliary source (except possibly for starting) and it is unnecessary to employ auxiliary pumping agencies although such auxiliary factors may be employed if desired.

When the hollow cathode is coated on the inside with oxides of the alkaline earths, its interior surface will emit thermionically when heated to a temperature of the order of 800° C. whether by the main cathode-anode current or by a separate heat source as in Fig. 1 and the work function of the interior surface is low compared to that of the outer surface.

Many modifications of the invention will suggest themselves to those skilled in the art and I desire, therefore, that the appended claims be given a broad construction commensurate with the scope of the invention in the art.

I claim:

1. An electrical discharge device comprising an envelope provided with electrodes including an anode and a cathode, said cathode containing a cavity having an opening for the escape of electrons, the size of which is a small fraction of the area of the inner surface of the cavity, a solid activating material in said cavity, and a material contained within said envelope which at the operating temperature of said device has a gas pressure within the range of about one to one hundred microns of mercury, said cathode and anode being spaced apart to permit ionization therebetween and said cathode operating at a temperature at which rectification is dependent upon thermionic emission and providing thermionic emission to maintain the discharge between cathode and anode.

2. An electric discharge device comprising a sealed container, a thermionic cathode having a cavity open to the exterior, the area of internal walls of said cavity being at least twice as great as the cross-sectional area of its opening, a solid material of higher electron emissivity than said cathode located in said cavity, resistance means for heating said cathode to an electron-emitting temperature, an anode located out of direct line with the opening of said cavity, and a gaseous material in said container having at the operating temperature of the device a pressure within the range of about 1 to 100 microns of mercury.

3. An electrical discharge device comprising the combination of an envelope, electrodes therein including a cathode, an attenuated gas therein at a pressure sufficiently high to permit of substantial ionization, said cathode compris-

ing an enclosure with one or more openings, a solid thermionic material in said enclosure, means for suppressing heat loss from the exterior of said enclosure, and a radiation heater for heating said enclosure to an electron-emitting temperature.

4. An electrical discharge device comprising an envelope, an anode, a cathode which is provided with a cavity having an opening for the escape of electrons to said anode, a solid material therein of higher electron emissivity than the body of said cavity, the area of said opening being a small fraction of the internal area of said cavity, thereby restraining escape of said material from said cavity by volatilization through the opening, means for maintaining said cathode at a temperature of thermionic emission independently of a discharge between said anode and cathode, and gas at low pressure in said envelope for furnishing positive ions.

5. An electrical discharge device comprising a sealed envelope containing electrodes including an anode and a thermionic electrode having a cavity of large internal surface provided with a relatively small opening for the passage of electrons from the interior of said cathode to said anode to maintain the discharge between said cathode and anode, and an alkaline earth oxide coated on the interior walls of said cavity, said walls being positioned in shielding relation to one another, a filamentary heater for said cavity and an attenuated gas in said envelope at a pressure sufficiently high to neutralize space charge.

6. An electrical discharge device comprising an envelope, a plurality of electrodes mounted therein, one of said electrodes having an open cavity, the area of the interior walls of said cavity being at least twice as great as the cross-sectional area of said opening, a solid material coated on the walls of said electrode within said cavity which is capable of enhancing the electron emissivity of said electrode and remaining substantially intact on said walls at a temperature of effective electron emissivity, resistance means for heating the coated walls of said cavity to an electron emitting temperature, said heated walls being positioned in shielding relation to one another, and a gas in said envelope at sufficiently high pressure to neutralize space charge.

7. An electrical discharge device comprising a sealed envelope, an anode and a cathode therein, said cathode being a metallic enclosure having an opening, the interior surface of said enclosure being at least twice as great as the cross-sectional area of said opening, a material of higher electron emissivity than said enclosure on the interior walls of said enclosure, a radiation heater for said enclosure and a quantity of mercury within said envelope.

8. An electrical discharge device comprising a metallic electrode having a cavity provided with an opening, a solid material coated on the walls of said electrode within said cavity, which is capable of enhancing the electron emissivity of said electrode and being but slowly volatilizable at a temperature of effective electron emissivity, the coated walls of said electrode having an area at least twice as great as the cross-sectional area of said opening, resistance means for heating the coated walls of said cavity to an electron-emitting temperature, and a cooperating electrode external to said cavity.

9. An electrical discharge device comprising the combination of an envelope, electrodes therein including a cathode structure, a gas therein at a

pressure sufficiently high to permit of substantial ionization, said cathode structure comprising an enclosure with an opening, said opening being small in comparison with the internal area of said enclosure, a thermionic material in said enclosure, means located in said envelope for heating said enclosure, and means forming part of said cathode structure for heat insulating said cathode structure.

10. A thermionic electrode having a cavity, the walls of which are in reciprocal heat-shielding relation, a material within said cavity for enhancing the electron-emissivity of said electrode, resistance means for heating said electrode to an electron-emitting temperature, and heat-insulating means surrounding said electrode for reducing the energy required to maintain said electrode at an electron-emitting temperature.

11. In the art of electronic discharge through gas, the method which comprises confining the space in the region of the source of discharge, providing a small opening leading therefrom, pumping an easily ionizable gas into said space by an intense discharge through said opening, and employing a gas having a higher ionizing voltage to retard the escape of said gas from said space.

12. In the art of electronic discharge, the method which comprises starting the discharge through a gas having a substantial pressure when cold and by the discharge maintaining another gas having a lower pressure when cold at a higher static pressure near the source of the discharge than at its terminus.

13. In the art of electronic discharge, the method which comprises starting an arc-like discharge through a gas having a substantial pressure when cold, generating by the starting discharge a gas having a lower pressure when cold and a pressure of the order of one to one hundred microns during normal operation, and maintaining the discharge by the ionization of the latter gas.

14. In the art of electronic discharge, the method which comprises starting a glow discharge through a gas of relatively high ionizing voltage by ionizing said gas, utilizing said discharge to supply a vapor of lower ionizing potential than said gas, and ionizing said vapor to produce a discharge having a cathode voltage drop of the order of the ionizing voltage of said vapor or less.

15. An electronic device comprising a gas, a source of electron emission and an electron-receiving area separated by a gas gap and means including a perforate obstruction between said source and area for maintaining, by the discharge, higher gas pressure in the region of the source than in the region of said area.

16. An electronic device comprising a tube containing a hollow cathode structure with an opening therein and an anode presented to the interior of said cathode structure through said opening, said tube also containing an inert gas at a pressure of the order of that required to minimize space charge near the anode, and a more easily ionizable gas at a lower pressure, and means, including part of said cathode structure, for maintaining a higher pressure of the latter gas inside the hollow cathode structure than outside thereof while operating the device at normal capacity.

17. An electric discharge tube containing a gas, spaced electrodes within said tube, one of said electrodes constituting a cathode structure, 75

said cathode structure containing a hollow chamber having a restricted discharge opening, the other of said electrodes being adjacent the opening, said hollow chamber having an interior surface having a low work function, and a heater adjacent said chamber and segregated therefrom.

18. A rectifier comprising a container having a quantity of gas therein, an anode and cathode structure in spaced relation to each other, said cathode structure comprising a hollow member having an inner electron-emitting surface and another member substantially enclosing said hollow member, and a member substantially surrounding said hollow member and its enclosing member.

19. An electrical space discharge device comprising a vessel having therein an anode and a hollow thermionic cathode having an extended interior electron-emitting surface, said cathode having a discharge opening for passing a space discharge between said surface and said anode, and an ionizable gas in said vessel at a pressure sufficient to supply the requisite number of ions necessary to neutralize the space charge of the discharge between said cathode and anode, said cathode embodying means cooperating with the discharge to cause pumping of gas from the vessel into the interior of said cathode enclosure and maintenance of a higher pressure therein during the discharge.

20. A gaseous discharge device in which during the normal operation thereof the current density is substantially in excess of that of a glow discharge, said device comprising a tube containing gases having different ionization voltages, a hollow cathode structure adapted to emit electrons from an interior surface and provided with a discharge opening therein, an anode spaced from said cathode, and means, including part of said cathode structure, for maintaining a higher density of the gas having the lower ionization potential on the cathode side of said opening than on the anode side.

21. An electrical discharge device comprising the combination of an envelope, electrodes therein including a cathode structure, a gas therein at a pressure sufficiently high to permit of substantial ionization, said cathode structure comprising an enclosure with an opening, said opening being small in comparison with the internal area of said enclosure, a thermionic material in said enclosure, means located in said envelope for heating said enclosure, and a heat shield constituting an enclosure surrounding said enclosure to prevent loss of heat therefrom.

22. A gaseous discharge device comprising an envelope containing gas, an anode in said envelope, a structure having an extended cathode discharge surface for producing an electron discharge to the anode during operation, said structure constituting an enclosure confining a body of gas adjacent said discharge surface, said enclosure having a restricted opening for passing the discharge between said discharge surface and said anode, and means for producing a magnetic field in the region of the discharge from said cathode surface to said opening to impart a gas movement in said envelope for producing a higher pressure in the region adjacent said cathode surface than in the region of said anode.

23. A gaseous discharge device comprising an envelope containing gas, an anode in said envelope, means constituting a hollow chamber having a restricted central opening, said means having an electron-emitting cathode surface dis-

posed adjacent the periphery of said chamber for producing an electron discharge to the anode during operation, and means for producing a magnetic field in the region of the electron flow from said electron-emitting surface to said restricted opening to give said electrons a movement at which they impart to the gas molecules within said chamber a rotary motion resulting in centrifugal compression of the gas in said chamber adjacent said emitting surface.

24. A gaseous discharge device comprising a tube containing an anode, a cathode, and means for rotating said discharge adjacent said cathode surface to maintain by centrifugal action a high pressure adjacent said cathode surface, whereby a low voltage discharge may be maintained between said cathode surface and said anode.

25. A unidirectional gaseous discharge device comprising an evacuated envelope containing gas, an anode, a cathode having an extended discharge surface producing an electron discharge to said anode during operation, and means for producing a magnetic field in the discharge space between said cathode surface and said anode to impart a gas movement in said envelope for producing a high pressure in the region adjacent said cathode surface, whereby a low voltage discharge may be maintained between said cathode surface and said anode.

26. An electrical space discharge device comprising a vessel having therein an anode and a hollow thermionic cathode structure containing therein a thermionic electron-emitting surface, said cathode structure having a relatively small discharge opening for passing a space discharge between said surface and said anode, and means for producing a magnetic field substantially coaxial with said opening.

27. An electrical space discharge device comprising a vessel having therein an anode and a hollow cathode structure containing therein an electron-emitting surface, said cathode structure having a relatively small discharge opening for passing a space discharge between said electron-emitting surface therein and said anode, and means for producing a magnetic field substantially coaxial with said opening.

28. An electrical space discharge device comprising a vessel having therein an anode, a thermionic hollow cathode structure constituting a chamber containing therein an electron-emitting surface, said chamber having at one end a space discharge opening for passing a discharge to said anode, an ionizable gas in said vessel, and means for producing a magnetic field axially along said cathode chamber.

29. An electrical space discharge device including a plurality of elements comprising an anode and a thermionic cathode, said anode and cathode being adapted to support a space discharge between them, an ionizable gas in said device, one of said elements having a surface adjacent the path of the electron flow to said anode in said discharge, and means for producing a magnetic field coaxial with said path of electron flow at said surface.

30. An electrical space discharge device including a plurality of elements comprising an anode and a thermionic cathode, said anode and cathode being adapted to support a space discharge between them, an ionizable gas in said vessel, one of said elements having a surface adjacent the path of the electron flow in said discharge, and means for producing a magnetic field for controlling the motion of the electrons and causing

the same to pass by said surface and to reach the anode.

31. A gaseous discharge device comprising a cathode and an auxiliary electrode between which in a normal operation of the device an auxiliary discharge occurs, said cathode surrounding the region of discharge, means for making the discharge path substantially longer than the direct distance between said cathode and auxiliary electrode, and an anode, said auxiliary discharge when in operation functioning as a source of electrons and ions for a main discharge to said anode.

32. A gaseous conduction device comprising a cathode and an auxiliary electrode between which an auxiliary discharge occurs in a normal operation of the device, the discharge region comprising an annular region separating said two electrodes, means for establishing a magnetic field in said annular region and transverse to the normal direction of electron travel, and an anode, said auxiliary discharge when in operation functioning as a source of electrons and ions for a main discharge to said anode.

33. A gaseous conduction device comprising a cathode and an auxiliary electrode, said cathode surrounding said auxiliary electrode and between which an auxiliary discharge occurs in a normal operation of the device, means for causing said discharge to whirl around said auxiliary electrode, an anode, means separating said anode from said region of auxiliary discharge, said means giving access to said anode only through a restricted aperture, whereby said region of auxiliary discharge when in operation serves as a source of electrons and ions for the main discharge to said anode, and is maintained at a higher pressure than said anode region.

34. A space current device comprising an envelope having a gas filling, a cathode in said envelope, a main anode in said envelope to maintain a discharge with said cathode along a discharge path, an auxiliary electrode in said envelope to produce a discharge with said cathode along another discharge path, and means for operating on the discharge between said auxiliary electrode and said cathode for moving gas particles toward the cathode to build up a higher pressure in the region adjacent the cathode than in the region adjacent the anode.

25. A space current device comprising an envelope having a gas filling, a cathode in said envelope, an anode in said envelope to produce a discharge with said cathode along a discharge path, and magnetic means for operating on the discharge between said anode and said cathode in such a way as to create a difference in pressure between predetermined localized regions in said envelope.

36. A space current device comprising an envelope having a gas filling, a cathode in said envelope, an anode in said envelope to maintain a discharge with said cathode along a discharge path, an auxiliary electrode in said envelope to produce a discharge with said cathode along another discharge path, and magnetic means for operating on the discharge between said auxiliary electrode and said cathode in such a way as to create a difference in pressure between predetermined localized regions in said envelope.

37. A space current device comprising an envelope having a gas filling, a cathode structure in said envelope, a main anode in said envelope to maintain a discharge with the active surface of said cathode along a discharge path, an auxiliary electrode in said envelope to produce a dis-

charge with said cathode surface along another discharge path, said cathode structure comprising means for separating the region adjacent said cathode surface from the region adjacent the main anode and having a discharge opening for allowing the discharge to pass, and means for operating on the discharge between said auxiliary electrode and said cathode surface for moving gas particles toward the cathode surface to build up a higher pressure in the region adjacent the cathode surface than in the region adjacent the anode.

38. A space current device comprising an envelope having a gas filling, a thermionic cathode structure in said envelope, a main anode in said envelope to maintain a discharge with the active surface of said cathode along a discharge path, an auxiliary electrode in said envelope to produce a discharge with said surface along another discharge path, said cathode structure comprising means for separating the region adjacent said cathode surface from the region adjacent the main anode and having a discharge opening for allowing the discharge to pass, and magnetic means for operating on the discharge between said auxiliary electrode and said cathode surface for moving gas particles toward the cathode surface to build up a higher pressure in the region adjacent the cathode surface than in the region adjacent the anode.

39. A space current discharge device comprising an envelope, a hollow cathode structure in said envelope having an interior surface, an anode in said envelope outside said hollow cathode structure, an easy-to-ionize gas in said envelope, means including a heater element inside said hollow cathode structure to be independently heated to maintain said surface at a temperature of copious electron emission to produce a discharge between said surface and said anode at a relatively low cathode voltage drop, and a second gas having an ionizing voltage higher than the discharge voltage within said envelope, said second gas having a relatively high pressure compared to said easy-to-ionize gas.

40. A space current discharge device comprising an envelope, a hollow cathode structure in said envelope having an interior surface, an anode in said envelope outside said hollow cathode structure, an alkali metal vapor in said envelope, means including a heater element inside said hollow cathode structure to be independently heated to maintain said surface at a temperature of copious electron emission to produce a discharge between said surface and said anode at a relatively low cathode voltage drop, and a monatomic gas having an ionizing voltage higher than the discharge voltage within said envelope, said monatomic gas having a relatively high pressure compared to said vapor.

41. A space current device comprising an envelope, a hollow cathode structure in said envelope having an interior surface, an anode in said envelope outside said hollow cathode structure, caesium vapor and argon in said envelope, and means including a heater element inside said hollow cathode structure to be heated to maintain said surface at a temperature of copious electron emission to produce a discharge between said surface and said anode at a cathode voltage drop lower than the ionizing voltage of argon, the pressure of the vapor being less than the pressure of the argon.

42. A space current discharge device comprising an envelope containing a hollow cathode structure having an interior surface, an anode

and a gas, said surface having a coating adapted to emit electrons at a relatively low temperature, and a heater element inside said hollow cathode structure to be independently heated to maintain said coating on said surface at a temperature of electron emission to sustain an arc-like discharge between said hollow cathode structure and said anode.

43. An electronic discharge device containing a gas having a substantial pressure when cold and a gas having a lower pressure when cold, means for starting a discharge through said first-named gas and for maintaining the discharge by the ionization of the latter gas, said latter gas having a pressure of the order of one to one hundred microns during normal operation.

44. An electrical discharge device comprising an envelope, main electrodes including a solid thermionic cathode mounted therein, said cathode having a surface coated with an electron-emissive material, a gas in said envelope at a pressure at which an electrical discharge between said electrodes may be operated with a drop of voltage at the cathode normally characteristic of an arc in such gas, and electrode means operable to produce an auxiliary discharge in said gas with a materially higher cathode voltage drop, said means being located adjacent the space between said main electrodes.

45. An electrical discharge device comprising the combination of an envelope, main electrodes therein including a solid thermionic cathode, said cathode having a surface coated with an electron-emissive material, a gaseous filling therefor at a pressure within the range of about one micron to several millimeters of mercury, and auxiliary electrode means located adjacent the space between said main electrodes and operable to produce an ionizing discharge in said gaseous filling at a voltage above the normal arc-sustaining voltage.

46. An electrical discharge device comprising the combination of an envelope, cooperating main electrodes including a solid thermionic electrode which contains a cavity, said cathode having a surface within said cavity coated with an electron-emissive material, a gaseous filling at a pressure high enough to give to a discharge between said electrodes the characteristics of an arc, an auxiliary electrode which is located in said cavity, the characteristics of said auxiliary electrode being such as to produce a discharge in which the fall of voltage is materially above the arc-sustaining voltage of said gaseous filling.

47. A gaseous discharge device comprising a tube containing gas, an anode, and a hollow cathode having a surface portion through which there is an opening, said opening being smaller than the surface portion and located in the central region thereof, and means for rotating the discharge about an axis extending through said opening, thereby to maintain by centrifugal action a pressure inside the cathode higher than outside the cathode.

48. A thermionic cathode structure comprising an enclosure of conducting material, a material of high electron emissivity therein, said material being solid at the operating temperature of the envelope, at least one opening in said enclosure for permitting the free passage of electrons in the presence of positive ions, said enclosure having closely adjacent walls providing a space whereby particles volatilizing from different points of the internal surface of said enclosure are largely intercepted by the walls of

said enclosure before reaching an opening, and means forming part of the cathode structure for suppressing heat loss from said enclosure.

49. An electrical space discharge device comprising a vessel containing an anode and a cathode structure having an extended surface to be heated to thermionic emission during operation, said cathode structure constituting an enclosure around a part of the space in front of said surface but permitting space current flow between said surface and said anode, an independently energizable heater segregated from said enclosure to heat said surface to thermionic emission, and an ionizable gas in said vessel to be maintained at sufficient pressure and in sufficiently excited condition within said vessel during operation of said device to secure an arc-like space discharge between said surface and said anode.

50. An electrical space discharge device comprising a vessel containing an anode and a hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior surface provided with a coating of a substance having low work function, said enclosure having a discharge opening for passing a space discharge between said cathode structure and said anode, an independently energizable heater segregated from said discharge space to heat said surface to temperature of thermionic emission, and an ionizable gas in said vessel to be maintained at sufficient pressure and in sufficiently excited condition during operation of said device to secure a space discharge between said cathode structure and said anode at a cathode voltage drop of the order of the ionization voltage of said gas or less.

51. An electrical space discharge device comprising a vessel containing electrodes including an anode and a hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior surface, said enclosure having a discharge opening for passing a space discharge between said surface and said anode, ionizable gas inert with respect to said electrodes in said vessel, means for heating the interior surface of said cathode to temperature of electron emission during operation of the device and simultaneously maintaining said gas within said vessel at a sufficient pressure and ionization to secure a discharge between said cathode and anode at a cathode voltage drop of the order of the ionization voltage of said gas or less, and a heat shield surrounding said enclosure to prevent loss of heat therefrom, said shield having an opening for passing the discharge from said surface to said anode and being spaced from said enclosure cathode.

52. An electrical space discharge device comprising a vessel containing electrodes including an anode and a hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior surface, said enclosure having a discharge opening for passing a space discharge between said surface and said anode, an ionizable gas inert with respect to said electrodes in said vessel, means for heating said surface to temperature of electron emission during operation of the device and simultaneously maintaining said gas within said vessel at a sufficient pressure and ionization to secure a discharge between said cathode and anode at a cathode voltage drop of the order of the ionization voltage of said gas or less, and a shield for said enclosure to reduce

loss of heat therefrom, said shield being spaced from said enclosure a distance of the order of the mean free path of the surrounding gas or less.

53. An electrical space discharge device comprising a vessel containing an anode and a hollow structure constituting an enclosure around a part of the space in said vessel and having an extended interior surface, said enclosure having a discharge opening for passing a space discharge between said surface and said anode, an independently energizable heater segregated from said discharge space to heat said surface to temperature of thermionic emission, an ionizable gas in said vessel to be maintained during operation at sufficient pressure and in sufficiently excited condition to secure a space discharge between said surface and said anode at a cathode voltage drop of the order of the ionization voltage of said gas or less, and a heat shield surrounding said enclosure and said heater to prevent loss of heat therefrom, said shield having an opening for passing the discharge from said surface to said anode and being spaced from the exterior of said enclosure.

54. An electric discharge tube containing a gas, a hollow cathode having an electron emissive substance on its inner surface, an anode, said cathode having a discharge opening for passing a stream of electrons to said anode, a heater for heating said cathode to thermionic emitting temperature, and shield disposed about the cathode and spaced therefrom.

55. An electrical space discharge device comprising a vessel containing electrodes including anode means and a hollow thermionic cathode constituting an enclosure around a part of the space in said vessel and having an extended interior surface, said enclosure having a discharge opening for passing a space discharge between said surface and said anode means, said anode means disposed outside said cathode, an ionizable gas inert with respect to said electrodes in said vessel, and means for heating said interior surface of said cathode to temperature of electron emission during operation of the device and simultaneously maintaining said gas within said vessel at sufficient pressure and sufficiently ionized to secure a discharge between said cathode and said anode means at a cathode voltage drop of the order of the ionization voltage of said gas or less, said anode means being mounted around said enclosure opening and enclosing the discharge space and screening the space bordering the walls of said vessel from the discharge space.

56. An electrical space discharge device comprising a vessel containing a hollow cathode structure having an extended interior electron-emitting surface, an anode disposed outside said cathode structure, and an ionizable gas, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface, to cause a discharge between the anode and said emitting surface, and shielding the interior of said enclosure against loss of heat and radiation, and means including independently energizable heating means for maintaining said ionizable gas in the interior of said enclosure at sufficient pressure and sufficiently excited to secure a discharge between said anode and said emitting surface at a cathode voltage drop of the order of the ionization voltage of the gas or less, while maintaining substantially lower pressure in the space outside said en-

closure adjacent said anode, said heating means being segregated from said enclosure.

57. An electrical space discharge device comprising a vessel containing a hollow cathode structure having an extended interior surface, an anode disposed outside said cathode structure, and an ionizable gas, said cathode structure constituting a partially open enclosure confining a part of the space in front of said surface to cause a discharge between the anode and the inside of said enclosure, and shielding the interior of said enclosure against loss of heat and radiation, and means for maintaining ionizable gas at sufficient pressure and sufficiently excited in said vessel to secure a space discharge between said anode and the interior of said enclosure at a cathode voltage drop of the order of the ionization voltage of the gas or less, said enclosure having therein contained a substance of low work function to be heated during operation to copious thermionic emission and having during operation larger electron emission than the exterior of said cathode structure.

58. An electrical space discharge device comprising a vessel containing a hollow cathode structure having an extended interior surface, an anode disposed outside said cathode structure, and an ionizable gas, said cathode structure constituting a partially open enclosure confining a part of the space in front of said surface to limit the discharge with the anode only to said surface, and means including heating means for heating said surface to copious thermionic emission and for maintaining said ionizable vapor at sufficient pressure and sufficiently heated and excited in said enclosure to secure a space discharge between said anode and said emitting surface at a cathode voltage drop of the order of the ionization voltage of said gas or less, while maintaining substantially lower pressure of said gas in the space outside said enclosure adjacent said anode, said surface having thereon maintained a coating of a substance of low work function having during operation larger electron emission than the exterior of said cathode structure.

59. An electrical space discharge device comprising a vessel containing a hollow cathode structure having an extended interior surface, an anode disposed outside said cathode structure, and an ionizable gas, said cathode structure constituting an enclosure confining a part of the space in front of said surface and shielding the interior of said enclosure against loss of heat and radiation, but having a discharge opening for permitting space current to flow between said surface and said anode, means for heating said surface to copious thermionic emission during operation and for maintaining said ionizable gas at sufficient pressure and sufficiently heated and excited in said enclosure to secure a space discharge between said anode and said surface at a cathode voltage drop of the order of the ionization voltage of the gas or less, while maintaining substantially lower pressure of said gas in the space outside said enclosure adjacent said anode, and a shield surrounding said enclosure to prevent loss of heat therefrom, said shield having an opening for passing the discharge from said surface to said anode and being spaced from said enclosure.

60. A gaseous discharge device in which during the normal operation thereof the current density is substantially in excess of that of a glow discharge, comprising a tube containing gases having different ionization voltages, a hollow cathode

adapted to emit electrons from its interior surface only and provided with a discharge opening, an anode spaced from said cathode and means for maintaining a higher density of the gas having the lower ionization voltage on the cathode side of said opening than on the anode side.

61. A gaseous discharge device comprising a vessel containing an anode, a partially open hollow cathode structure having an extended interior surface to be heated to thermionic emission during operation, an easily ionizable gas sufficient in amount to constitute during operation a gaseous filling maintained in ionized and excited condition within said vessel at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure a discharge between said anode and said surface, and additional gas in said vessel having an ionizing voltage higher than the ionizing voltage of said first gas.

62. A gaseous discharge device comprising a vessel containing an anode, a partially open hollow cathode structure having therein a material to be heated to thermionic emission during operation, an easily ionizable gas, means for heating said material to temperature of electron emission during operation of the device and simultaneously maintaining said gas ionized in said enclosure, said gas being sufficient in amount to constitute during operation a gaseous filling maintained in ionized and excited condition within said vessel at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure a discharge between said anode and the interior of said cathode structure, and an additional gas in said vessel having an ionizing voltage higher than the ionizing voltage of said first gas.

63. A gaseous discharge device comprising a vessel containing an anode, a partially open hollow cathode structure having therein a material to be heated to thermionic emission during operation, an ionizable gas in said vessel, means for heating said material to temperature of electron emission during operation of the device and simultaneously maintaining said gas ionized in said enclosure, and sufficient in amount to constitute during operation a gaseous filling maintained in ionized condition within said vessel at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure a discharge between said anode and the interior of said cathode structure, and an additional gas in said vessel having a higher ionizing voltage and higher pressure than said gas.

64. An electrical discharge device comprising an envelope provided with electrodes including an anode and a cathode, said cathode containing a cavity having a relatively small opening for the escape of electrons, the walls of said cavity being in shielding relation to one another, an activating material in said cavity, said material being solid at the operating temperature of said envelope and gaseous material in said envelope to neutralize space charge, said cathode and anode being spaced apart to permit ionization therebetween and said cathode operating at a temperature at which space conduction is dependent upon thermionic emission and providing thermionic emission to maintain the discharge between cathode and anode.

65. An electrical discharge device comprising a container, an anode therein, a tubular thermi-

onic cathode also located therein and having a cavity provided with a relatively small opening and having a wall as a shield between said cavity and said anode, the walls of said cavity being positioned in shielding relation to one another, a material in said cavity which is capable of increasing the electron emissivity of said cathode at an elevated temperature, said material being solid at the operating temperature of said container and a heater for maintaining said cathode at a temperature of thermionic emissivity.

66. An electrical space discharge device comprising a vessel containing anode means and a cathode structure having an extended surface to be heated to thermionic emission during operation, said cathode structure constituting an enclosure around a part of the space in front of said surface and having a discharge opening for passing a space discharge between said surface and said anode means, an ionizable gas in said vessel maintained during operation within said vessel at a sufficient pressure and sufficiently ionized to secure a discharge between said surface and said anode means at a cathode voltage drop of the order of the ionization voltage of said gas or less, said anode means being mounted around said enclosure opening to enclose the discharge space and screen the space bordering the walls of said vessel from the discharge space.

67. An electrical discharge device comprising an envelope containing an ionizable gas, an anode and a cathode structure adapted to support a discharge between them, said cathode structure having an extended surface to be heated to thermionic emission during operation independently of said discharge, an activating material coated on said surface, said activating material being solid at the operating temperature of said envelope and enclosing walls constituting part of said cathode structure and interposed between said surface and said anode, said walls having an opening for permitting the discharge to pass between said surface and said anode, said opening being out of line with a straight line path between said surface and said anode.

68. An electrical discharge device comprising an envelope containing two anodes and a cathode structure, said cathode structure having an extended surface to be heated to thermionic emission during operation, said surface being coated with an activating material, said activating material being solid at the operating temperature of said envelope, said cathode structure also comprising an enclosure around a part of the space in front of said emitting surface, said enclosure having an opening for the escape of electrons, the size of which is small with respect to said coated surface, and a material contained within said envelope which at the operating temperature of said device has a gas pressure sufficient to supply the requisite number of positive ions to neutralize space charge.

69. An electrical discharge device comprising an envelope containing two anodes and a cathode structure, said cathode structure having an extended surface to be heated to thermionic emission during operation, said surface being coated with an activating material, said cathode structure also comprising an enclosure around a part of the space in front of said emitting surface, said enclosure having two openings for the escape of electrons, the size of said openings being small with respect to said coated surfaces, said anodes being disposed adjacent said openings respectively, and a material contained within said envelope

which at the operating temperature of said device has a gas pressure sufficient to supply the requisite number of positive ions to neutralize space charge.

- 5 70. An electrical space discharge device comprising a vessel containing a plurality of elements comprising an anode and a thermionic cathode, said anode and said cathode being adapted to support a space discharge between them, an
10 ionizable gas in said vessel, one of said elements having a surface adjacent the path of the electron flow in said discharge, and means for producing a magnetic field for controlling the motion of the electrons and causing the same to pass
15 by said surface and to reach the anode.

71. An electrical discharge device comprising a gas of relatively high ionizing voltage and a vaporizable material, the vapor of which has a lower ionizing voltage than said gas, means for
20 starting a flow discharge through said gas for vaporizing by said discharge some of said vaporizable material to generate said vapor, and for ionizing said paper to produce a discharge having a cathode voltage drop of the order of the ionizing
25 voltage of said vapor or less.

72. An electrical discharge device comprising a gas having a substantial pressure when cold, and a gas having a lower pressure when cold, means including a thermionic cathode for starting
30 a discharge through said first-named gas and for maintaining the discharge by ionization of the latter gas, said latter gas having a pressure of the order of one to one hundred microns during normal operation.

73. An electrical discharge device comprising a gas having a substantial pressure when cold and a gas having a lower pressure when cold, means including a thermionic cathode having thereon an emissive oxide coating to be heated to a temperature of thermionic emission during operation for starting a discharge through said first-named gas, and for maintaining the discharge by the ionization of said latter gas, said latter gas having a pressure of the order of one to
45 one hundred microns during normal operation.

74. An electrical discharge device comprising a gas having a substantial pressure when cold, vapor, and means including a thermionic cathode for starting a discharge through said gas and for maintaining the discharge by the ionization of said vapor, said vapor having a pressure of the order of a fraction of a millimeter of mercury during normal operation.

75. An electrical discharge device comprising a gas having a substantial pressure when cold, a gas having a lower pressure when cold, means including a thermionic cathode for starting a discharge through said first-named gas and for maintaining the discharge by the ionization of said latter gas, and a shield in shielding relation to said cathode, the latter gas having a pressure of the order of a fraction of a millimeter of mercury during normal operation.

76. An electrical discharge device comprising

argon having a substantial pressure when cold, mercury vapor, means including a thermionic cathode for starting a discharge through said argon and for maintaining the discharge by the ionization of said mercury vapor, and a shield in shielding relation to said cathode, said mercury vapor having a pressure of the order of a fraction of a millimeter of mercury during normal operation.

77. An electrical discharge device comprising 10 an envelope containing main electrodes including a thermionic cathode having thereon a coating of an activating material, argon at a pressure of the order of a centimeter of mercury or less, a quantity of mercury, and an auxiliary electrode 15 means adjacent said thermionic cathode to produce an ionizing discharge through said argon for initiating the main discharge through mercury vapor generated from said quantity of mercury, said mercury vapor having a pressure of 20 the order of a fraction of a millimeter of mercury during normal operation.

78. An electrical discharge device comprising an envelope containing main electrodes including a thermionic cathode having thereon a coating of 25 an activating material, an inert gas at a pressure of the order of a centimeter of mercury or less, a quantity of a vaporizable material, and an auxiliary electrode means adjacent said thermionic cathode to produce an ionizing discharge through 30 said inert gas for initiating the main discharge through vapor generated from said quantity of vaporizable material, said vapor having a pressure of the order of a fraction of a millimeter of mercury during normal operation.

79. An electrical space discharge device comprising a vessel having therein an anode, and a thermionic cathode spaced therefrom and having an electron-emitting surface, an ionizable gas inert with respect to said electrodes in said vessel 40 at a pressure sufficient to supply the requisite number of ions necessary to neutralize the space charge of the electron current between said cathode and anode, a shield around the discharge space between said anode and cathode for substantially preventing extension of the discharge from said space to the space bordering the walls of said vessel, and heating means for heating said cathode to temperature of electron emission during operation of the device and simultaneously 50 maintaining said ionizable gas in said space in a state of excitation at which the confined gas secures a space discharge between said anode and cathode at low cathode voltage drop.

80. An electrical discharge device comprising 55 argon having a pressure of the order of a centimeter of mercury or less, mercury vapor, and means including a thermionic cathode for starting a discharge through said argon and for maintaining the discharge by the ionization of said 60 vapor, said vapor having a pressure of the order of ten microns during normal operation.

CHARLES G. SMITH.

CERTIFICATE OF CORRECTION.

Patent No. 2,201,817.

May 21, 1940.

CHARLES G. SMITH.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 5, first column, line 65, for the word "is" read --its--; and second column, line 71, claim 3, for "An" read --In an--; same line and claim, strike out the word "comprising"; page 8, first column, line 50, for the claim number "25" read --35--; and second column, line 1, claim 37, strike out "cathode"; page 10, first column, line 7, claim 53, before "structure" insert --cathode--; line 32, claim 54, before "shield" insert --a--; page 12, first column, line 20, claim 71, for "flow" read --glow--; line 23, same claim, for "paper" read --vapor--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 2nd day of July, A. D. 1940.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.