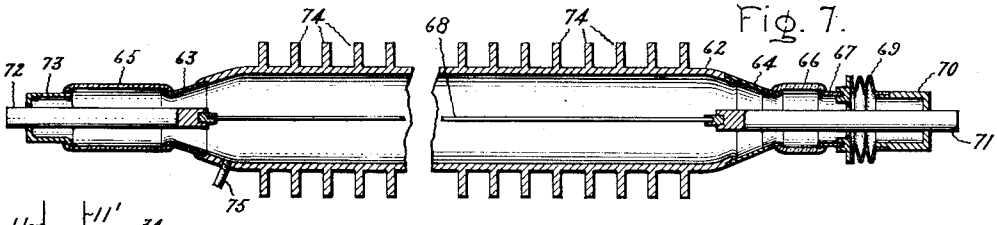
Jan. 27, 1931. A. W. HULL 1,790,152

ELECTRICAL DISCHARGE APPARATUS

Original Filed Oct. 13, 1922 2 Sheets-Sheet 1

Fig. 7.



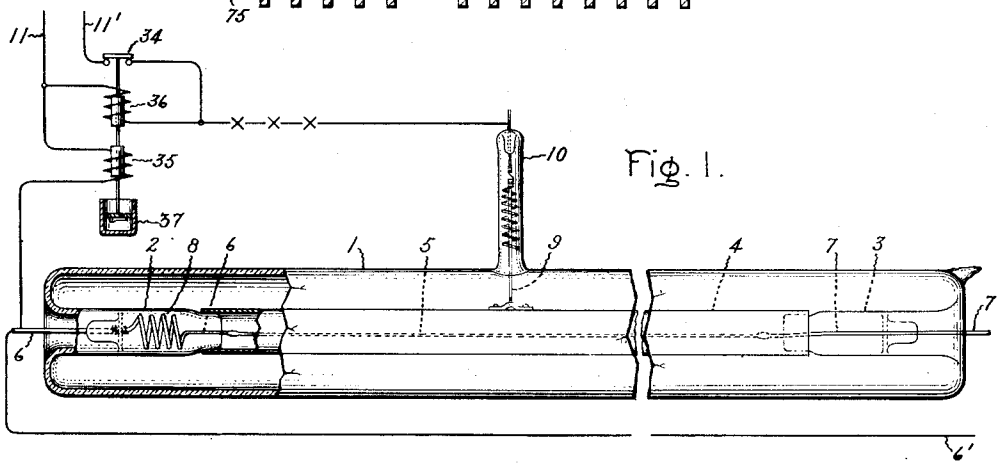
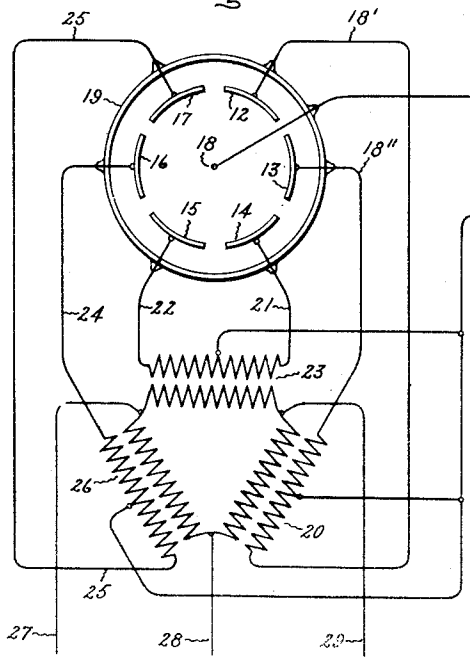


Fig. 1.

Fig. 2.



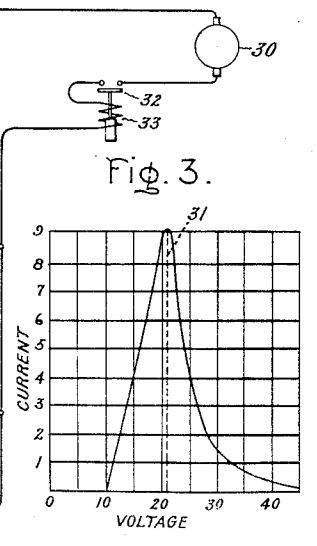


Fig. 3.

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Fig. 4.

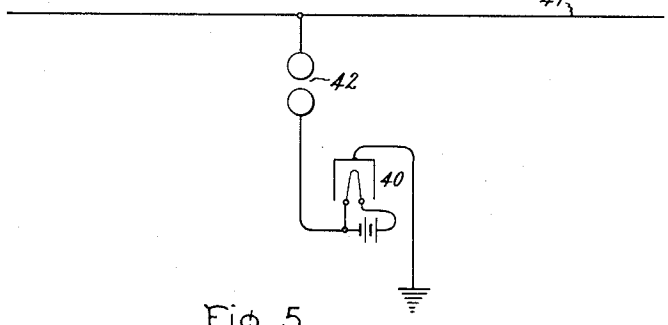


Fig. 5.

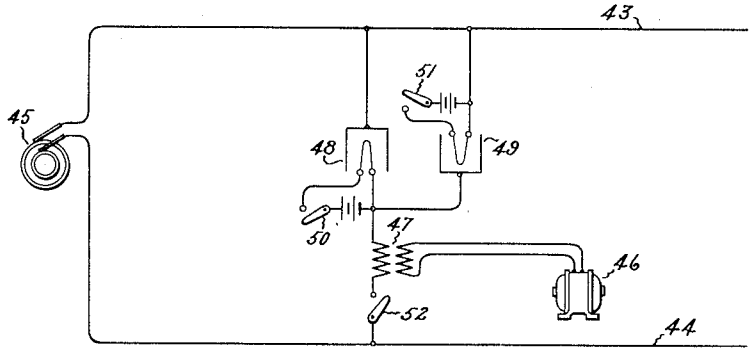
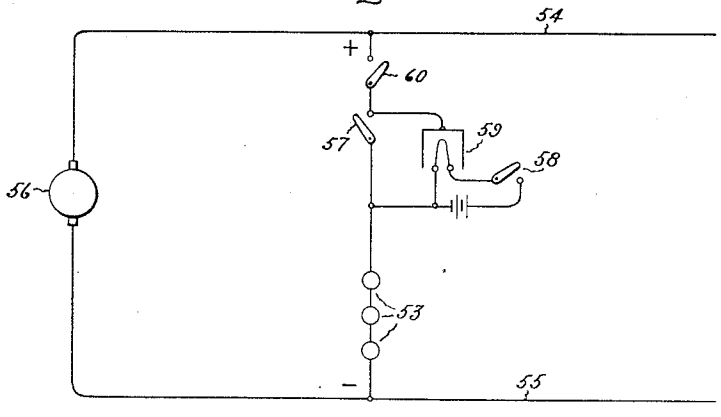


Fig. 6.



Inventor:
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by [signature]
His Attorney

Patented Jan. 27, 1931 1,790,152

UNITED STATES PATENT OFFICE

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK

ELECTRICAL DISCHARGE APPARATUS

Application filed October 13, 1922, Serial No. 594,370. Renewed September 18, 1930.

The present invention comprises an electrical discharge apparatus which is suitable for general technical use and has certain novel characteristics which render the device particularly adaptable for power conversion and control, as for example, the rectification of high potential current, the breaking of high potential electric circuits, the discharge of lightning and like technical purposes.

Heretofore, commercial power devices containing cathodes operating at incandescence have been operated either in a vacuum so high that the ionization of residual gas was negligible, that is, with a pure electron discharge; or, in a gas at a pressure so high that an arc-like, concentrated discharge of negative volt-ampere characteristic has resulted.

In pure electron discharge devices the conduction of current is accompanied by a high voltage drop in the discharge path, caused by the mutual repulsion of the electrons on each other, which is known as the space charge effect. This high space charge has confined power devices operating by pure electron conduction to the field of relatively small currents at high voltage.

Gaseous conduction devices containing incandescent cathodes on the other hand have been restricted heretofore, by certain inherent characteristics, to a low voltage field and have been used chiefly for the rectification of alternating currents of moderate amperage and voltage. In some low-powered relay devices, such as radio detectors, a gas at low pressure has been provided to increase the sensitivity. In the power field, however, the utilization of gas in electronic devices in amounts sufficient only to reduce or eliminate space charge by positive ionization without producing an arc-like discharge has been excluded for various reasons, such as the irregular disappearance of the gas by an electrical effect, disintegration or sputtering of the cathode, deleterious arcing, and so forth.

As a consequence of my invention these difficulties have been overcome and I have provided a new gas ionization electron discharge device which is radically unlike the arc type of incandescent cathode devices and which is capable of use for power purposes, as for example the control of power currents and the rectification of alternating currents.

One of the new properties characteristic of devices embodying my invention is the high current-carrying capacity which is maintained when the voltage impressed between the electrodes of the device is chosen at a value above the ionization voltage of the gas filling and below a critical value, but which drops substantially to zero when the voltage impressed on the device for any reason rises above this range.

The essential features of my invention comprise a cathode containing a material capable of forming a surface film of high electron emissivity and a gas or gasifiable material which is inert with respect to the cathode film and which is present at a pressure sufficiently high to reduce space charge by being ionized.

The geometric or spatial relation of the electrodes is so chosen that substantially all the positive ions strike the heated cathode, instead of being permitted to discharge themselves upon the container walls, or other cooler parts, which would cause consumption of gas by the disappearance of ions into the body of the glass container or other discharging surface. When these conditions are fulfilled, heavy currents may be conducted at high efficiency without substantial clean up of gas. Sufficient gas or vapor is provided to materially reduce or eliminate space charge, the pressure preferably being materially below the region of pressure at which the discharge becomes arc-like in character, and becomes concentrated or localized upon the cathode. This pressure ordinarily is within the range of about several microns up to as high as several millimeters of mercury, depending on the nature of the gas.

In accordance with another feature of my invention, I have provided a rectifier capable of rectifying currents over a wide range of voltages by so arranging the discharge-carrying electrodes that the maximum distance from anode to cathode in the direction of an

electric field, produced by an applied potential, is less than the mean free path of the electrons in the gas at the given pressure of gas in the device. Preferably the anode entirely and closely surrounds the heated portion of the cathode thereby fulfilling both aforesaid conditions.

I have discovered that various advantages result when the cathode is constituted of a material capable of forming a surface film of high electron emissivity, as for example, a cathode of the thoriated type, one form of which is described in Langmuir Patent 1,244,216. In accordance with my invention the utilization of the thoriated type of cathode has been extended from the field of discharges operating without substantial ionization to the field of devices making use of gas ionization during operation. In this case, the device is capable of conducting substantial currents, say of the order of magnitude of three amperes per sq. c. m. of cathode surface, when the temperature of the cathode is about 1800° C., provided the voltage between the electrodes does not exceed a critical value, which depends on the character of the gas and varies for about 10 to 50 volts in different gases. At materally higher impressed voltages a sudden reduction of electron emissivity occurs, the high conducting condition being restored when the high voltage is removed. The latter unique function of my new devices renders the same applicable to various special purposes, as, for example, as circuit breakers or as lighting arresters.

The accompanying drawing shows in Fig. 1, partly in section, one embodiment of my invention; Figs. 2 and 7 are diagrammatic sectional views of modifications; Fig. 3 is a diagram of a current-voltage characteristic of a device embodying my invention Figs. 4, 5 and 6 are diagrams illustrating technical applications of my invention.

The device shown in Fig. 1 comprises a tubular glass envelope 1, upon the reentrant stems 2, 3 of which is supported an anode 4. The thermionic cathode 5 is supported axially within the cylinder and consists preferably of tungsten containing a small amount of thoria, that is, of the order of one per cent of thoria, together with about one-half per cent of a reducing agent, such, for example, as carbon. In some cases magnesium or calcium may be used in place of or in addition to carbon. As described in Langmuir Patent 1,244,216, a thoriated cathode when in a condition of high electron emissivity, functions with a surface film or coating of thorium, or possibly some compound of thorium, in a lower state of oxidation than thoria.

The cathode conductors 6, 7 are sealed into the stems 2, 3 in the usual manner. The helical spring 8 maintains the filament 5 taut during operation of the device. The anode conductor and support 9 has been sealed into a side arm 10, but of course can be otherwise supported. The envelope contains a gas which is inert with respect to the cathode under operating conditions, and which is stable when ionized, a gas of the rare or monatomic group being preferred. For example, the envelope may contain argon or neon at a pressure of about 20 to 100 microns of mercury. In some cases, especially using a thoriated filament as cathode, sodium or potassium in the gaseous state may constitute the ionizable medium, the temperature of the device being so chosen that a suitable gaseous pressure of vaporized alkali metal prevails in the tube. The cathode is heated during operation by a suitable current supply (not shown), connected to the conductors 6, 7.

It will be noted that in the structure illustrated, the anode 4 entirely encloses the cathode 5 so that the positive ions formed by the ionization by collision of the electrons with gas molecules are restricted to the space between the electrodes and therefore are prevented from discharging on the glass container or any part of the device itself other than the cathode, which, being negatively charged, attracts the positive ions. I have found that this discharge of the ions upon an incandescent surface does not "clean up" or fix gas, therefore, the gas pressure within the device is maintained substantially constant during use.

When the device is to be used as a rectifier of alternating currents, the geometric relations of the electrodes and the pressure of the gaseous filling should be so chosen that the number of collisions between electrons passing from cathode to anode and gas molecules produces sufficient ionization of gas to eliminate, or at least to substantially reduce, space charge, but the electrons also should be prevented from taking such a long path from anode to cathode in the direction of an electric field produced by the applied potential as to permit a discharge during the half cycle intervals when the anode is negative. In other words, with the gas pressures here involved the longer the path an electron may take in its passage from one electrode to another, the lower the voltage required to produce a reverse discharge from the unheated electrode to the heated electrode. It is not only necessary that the cathode be located close to the anode but it is also necessary that the electrons from the electrode which is normally anode should be prevented from taking a round about path from the outside of the anode to the cathode travelling in the direction of the electric field.

With a pressure of 30 microns of argon a tube having a dimension between the anode and cathode of about 1.25 c. m., and being constructed as shown in Fig. 1 so that the

heated part of the cathode does not project beyond the anode and the mouth of the anode is closed, will rectify currents at 8000 volts or higher, without an inverse discharge from anode to cathode.

During the rectification of current at this high voltage, most of the voltage is consumed in an external load which is indicated by crosses in Fig. 1, and during the passage of current the voltage drop in the tube itself must be less than a critical voltage which depends on the nature of the gas. In argon gas at about 30 microns pressure, the critical voltage is about 20 volts which is but slightly above the ionization voltage of argon. Increasing the potential between the electrodes 4 and 5 above the critical voltage, for example, by short-circuiting the load wholly or in part, results in a decrease of electron emission to a low value due to the removal of the active film of thorium from the cathode surface by positive ion bombardment.

Fig. 3 is a curve showing the current-voltage characteristic of a device embodying my invention when different voltages are steadily applied until an equilibrium condition is attained. The current rapidly increases with the applied voltage up to a maximum value indicated by the dotted line 31. The voltage corresponding to this current value herein has been called the "critical voltage". When the applied voltage rises above this critical value, the current rapidly decreases and, at a value several times the critical voltage the current falls substantially to zero.

My device, therefore, is an ideal circuit breaker and may perform this function at the same time that it acts as a rectifier. When the conductors 11, 11′ (Fig. 1) are connected to a source of alternating current, the impedance of the load should be so chosen with respect to the electrical characteristics of the tube, that the voltage across the electrodes 4, 5 during normal operation does not exceed the critical voltage.

Should the critical voltage be exceeded, for example by a short circuit in the load, a device is provided for automatically opening the circuit, thus removing the voltage impressed on the electrodes, so as to enable the electron emissivity of the cathode to be restored. This device may assume the form of a circuit breaker 34 having a series or current winding 35 and a high resistance voltage winding 36. During normal operation these two windings pull in opposite directions, the contact 34 remaining closed. Should the current fall to a low value by reason of the loss of emissivity of the cathode, the coil 35 becomes ineffective and the circuit breaker opens the circuit by the action of the coil 36. The opening of the circuit deenergizes the coil 36 and gravity closes the circuit. During the interval of open circuit the cathode regains its high emissivity by the formation of a sensitive film. Preferably the closing of the circuit breaker is delayed by a dashpot 37, or other suitable device, to give sufficient time for the cathode to regain its high emissivity. In case the short circuit still exists, the operation will be repeated without harmful effect.

I have shown somewhat diagrammatically in Fig. 2 a modified discharge tube embodying my invention operating as a rectifier from a polyphase source. As shown in a section taken at right angles to the main axis of the device, there are provided a plurality ot anodes 12, 13, 14, 15, 16 and 17, spaced about a central cathode 18 in an envelope 19. The cathode consists of an axial filament, such as shown in Fig. 1, and the anodes consist of plates extending the length of the cathode and grouped about the same as indicated in Fig. 2. The envelope contains a suitable gas at a pressure high enough to remove space charge, but below the pressure at which concentration of the discharge occurs upon the cathode surface.

The anodes 12 and 13 are connected by the conductors 18′ and 18″ to the secondary of a transformer 20; the anodes 14, 15 are connected by the conductors 21, 22 to the secondary of a transformer 23; and the anodes 16, 17 are connected by the conductors 24, 25 to the secondary of a transformer 26. The primaries of these transformers 20, 23 and 26 are connected in delta and are supplied with three phase alternating current by the conductors 27, 28 and 29. A direct current motor 30 has been shown for illustrative purposes as a load device.

In case of a short-circuit of the load 30, the rectifier tube acts as a circuit breaker by the removal of the active film on the cathode, as described above. During normal operation, the contactor 32 is held closed by a series coil 33. When a short-circuit occurs and the current transmitted by the tube falls to a low value, the series coil is deenergized and the contactor opens. This removes the voltage from the rectified tube and the cathode again becomes coated with a sensitive layer of high electron emissivity ready for operation. For the sake of simplicity the contactor in this case has been shown in a simple form which may be closed by hand.

I have shown in Figs. 4, 5 and 6 several technical applications of my invention. The discharge tube is diagrammatically indicated in these figures by a hair-pin shaped cathode, surrounded by a U-shaped anode. Although for lightning arrester purposes the discharge device may be of the type shown in Fig. 1, it is not necessary for this purpose to employ this particular structure for the electrodes.

Fig. 4 illustrates my invention used as a lightning arrester, meaning by the term "lightning" to include surges or other high voltage disturbances of short duration. The discharge tube itself has been symbolized at

40. The filament located within the anode is indicated as being heated by a battery, the enclosing envelope not being shown. The device 40 is shown as connected between a line 41 and ground in series with a sphere gap 42. High voltage discharges of short duration will pass to earth through the tube without raising the voltage across the terminals above the critical voltage, but the line current is prevented from following as the passage of a considerable current will raise the voltage across the tube above the critical value and will render insensitive the cathode, or, in other words, cause it to lose its condition of high electron emissivity, thereby interrupting the current. Hence, as soon as the lightning discharge has passed the sphere gap again insulates the line from ground, and the film quickly reforms on the cathode.

Fig. 5 shows an application of my new device to the interruption of alternating current. The conductors 43, 44 are fed by an alternating current generator 45. The load represented by a motor 46 is connected to the secondary of a transformer 47, the primary of which is connected across the supply lines 43, 44, in series with the devices 48, 49 oppositely connected; that is, the anode of the device 48 and the cathode of the device 49 are connected to the conductor 43, the cathode of the device 48 and the anode of the device 49 are connected to the primary of the transformer 47. The circuit conditions are so chosen that the electron tubes normally operate below their critical voltages.

When the load is taking current, the switches 50, 51 in the cathode heating circuit are closed, heating the cathodes to incandescence. When these switches are opened, the cathodes become deenergized and begin to cool, hence diminishing their electron emissivity. This decreases the voltage drop in the load, and consequently increases the voltage drop in the electron tubes. As the voltage in the tubes rises above the critical voltage, the cathodes rapidly lose emissivity by the destruction of the surface film, thereby still further reducing the current until the circuit is open. By the rapid decrease in cathode emissivity, the liberation of large amounts of energy in the electron tubes, as the current falls, is avoided and the current is interrupted smoothly without surges. If desired, a switch 52 may be provided to finally cut all of the devices out of circuit.

Fig. 6 is a direct current circuit illustrating the employment of my new device as a switch or circuit breaker only at the time the circuit is to be opened.

The load 53 is connected across the lines 54, 55 fed by a direct current generator 56. When the load 53 is taking current the switch 57 is closed and the switch 58 is open. When the circuit is to be opened, the switch 58 is closed, energizing the cathode of the device 59. The switch 57 thereupon is opened, inserting the device 59 into circuit. The switch 58 is then opened, deenergizing the cathode and interrupting the circuit as already explained above. A switch 60 may be provided to permanently open the circuit after it has been deenergized.

In the device shown in Fig. 7 the enclosing envelope is constituted in part by the cylindrical anode 62 which is sealed at opposite ends to somewhat tapered sleeves 63, 64 consisting of copper-coated, nickel-iron alloy adapted to make a gas-tight seal with glass. The sleeves 63, 64 in turn are joined to tubes 65, 66 consisting of suitable refractory glass. The glass tube 66 is sealed by fusion to a nickel-iron sleeve 67. The sleeve 67 is joined by brazing, or other convenient way, to a resilient diaphragm 69 of sylphon metal or other suitable extensible material. This diaphragm is joined to the cap 70 through which projects a cathode conductor 71 making a gas-tight seal. This diaphragm provides means for linear displacement between the anode 62 and the cathode conductor 71. The opposite cathode conductor 72 is suitably sealed into another cap 73 which in turn is joined to the glass tube 65. The cathode 68 consists of thoriated tungsten, or other suitable material of high electron emissivity. The anode 62 preferably is cooled artificially, for example, by a blast of air, fins 74 preferably being provided to increase heat dissipation. The tube may be evacuated and supplied with a suitable gas filling by a tube 75.

The construction of the vacuum discharge device shown in Fig. 1 of this application is also shown in applicant's copending application, Serial No. 226,276, filed October 15, 1927, as a continuation in part of the present application. In said continuation application other examples of low pressure electron discharge devices are also disclosed embodying the fundamental feature of operation above the ionization voltage and below the disintegration voltage and applicant has chosen to put the broad claims in said continuation case, the claims of the present application being drawn to the form of discharge tube disclosed in the present case and to the circuit breaking features of the device.

What I claim as new, and desire to secure by Letters Patent of the United States, is:—

1. An electrical discharge device comprising an envelope, a thermionic cathode therein, means for heating said cathode, an anode, and a gas in said envelope which is inert with respect to said cathode and has a pressure sufficiently high to permit substantial ionization but being below the pressure at which the discharge becomes localized upon the cathode, the parts of said device being geometrically so con-

structed that positive ions produced during operation can strike substantially only the heated part of the cathode.

2. An electrical discharge device comprising a thermionic cathode, an anode surrounding said cathode, and a material in the discharge space between said electrodes which is gaseous at the operating temperature of said device and which will have a pressure, sufficiently high to neutralize space charge but insufficient to produce a concentrated or arc-like discharge at the operating temperature, the distance between said electrodes in the direction of an electric field therebetween being of the order of magnitude of the mean free path of electrons in said gas.

3. The combination of an electrical discharge device having a thermionic cathode, means for forming on said cathode during operation a film having higher electron emissivity than said cathode but being sensitive positive ion bombardment at voltages above a critical voltage, and a mechanical circuit breaker having an operating coil connected across the terminals of said device and having a make and break switch connected in series with said device.

4. An electron discharge device comprising an electrode which is capable of emitting electrons when heated, means for providing in the path of said electrons at operating temperatures of said device a gas at a pressure sufficiently high to eliminate space charge by ionization and a second electrode enclosing said cathode end spatially so related thereto that the positive ions formed by the ionization of said gas strike the cathode only, the maximum distance between said electrodes in the direction of an electric field, when potential is applied between said electrodes, being less than the mean free path of electrons in said gas.

5. An electron discharge device comprising a container, a filamentary thermionic cathode therein adapted to form during operation a surface layer capable of a higher order of electron emissivity than the main body of said cathode, a material in said container chemically inert with respect to said layer and having during operation a gaseous pressure sufficiently high to permit substantial ionization materially to increase the current-carrying capacity of said device but not so high as to cause concentration of the discharge locally on the cathode and an anode substantially completely enclosing said cathode and being geometrically so constructed that positive ions produced during operation can strike substantially only the said filamentary cathode and are substantially prevented from striking the walls of said container.

6. An electrical discharge device comprising an envelope, electrodes therein including a thermionic cathode and an anode, means for heating said cathode, and a gas in said envelope which is inert with respect to said cathode and has a pressure within the limits of about one micron and one millimeter of mercury to permit substantial ionization to reduce space charge, and operation with a discharge which is not localized upon the cathode, the parts of said device being geometrically so constructed that positive ions produced during operation can strike substantially only heated electrode parts.

7. An electron discharge device comprising an incandescible cathode capable of forming a surface film of thorium, an anode substantially enclosing said cathode and a gas in said container chemically inert with respect to said cathode at a pressure sufficiently high to neutralize space charge in said device when said gas is ionized but not so high as to cause concentration of the discharge on the cathode surface.

8. An electric high voltage rectifier comprising a sealed container, a thermionic cathode adapted to form during operation a surface film capable of a higher order of electron emission than the body of said cathode, means for heating said cathode, an anode substantially enclosing said cathode and conductive parts connected to said cathode so that positive ions produced during operation of the rectifier can strike substantially only the heated part of said cathode and a gas in said container at a pressure sufficiently high to permit substantial ionization to increase the current carrying capacity of said rectifier when said gas is ionized but below the pressure at which an arc-like discharge becomes localized on the cathode.

9. The method of operating an electric discharge through a gas between an anode and an incandescible cathode coated with a surface layer of high electron emissivity, said anode and cathode being included in an external circuit, which consists in maintaining during running conditions the voltage difference between said electrodes above the ionization voltage of said gas and below a critical value depending on the nature of the gas at which a decrease of electron emission occurs by removal of said coating, and raising the voltage difference when said circuit is to be opened to a value materially above said critical value.

10. The method of operating an electric discharge with an impressed voltage materially in excess of fifty volts in a gas having a pressure within the range of several microns to several millimeters of mercury pressure between cooperating electrodes including a thermionic cathode which consists in consuming sufficient voltage external to said cathode during normal operation to maintain the ion bombardment voltage to which said cathode is subjected below a critical voltage not exceeding fifty volts at which deleterious sputtering of said cathode would occur, and when

interruption of the circuit is desired causing the voltage drop at the cathode to increase materially above said critical voltage.

11. An electrical discharge device comprising an envelope, a thermionic cathode therein, means for heating said cathode to a temperature of electron emissivity, a gas in said envelope which is inert with respect to said cathode and has a pressure sufficiently high to permit substantial ionization but not sufficient to cause the discharge to become localized upon the cathode, and an anode so constructed and spaced from the cathode that the maximum distance from anode to cathode in the direction of an electric field produced by an applied potential is less than the mean free path of electrons in the gaseous filling.

In witness whereof, I have hereunto set my hand this 12th day of October, 1922.

ALBERT W. HULL.