Jan. 27, 1931. A. W. HULL 1,790,153

ELECTRICAL DISCHARGE DEVICE AND METHOD OF OPERATION

Filed Oct. 15, 1927 2 Sheets-Sheet 1

Fig. 1.

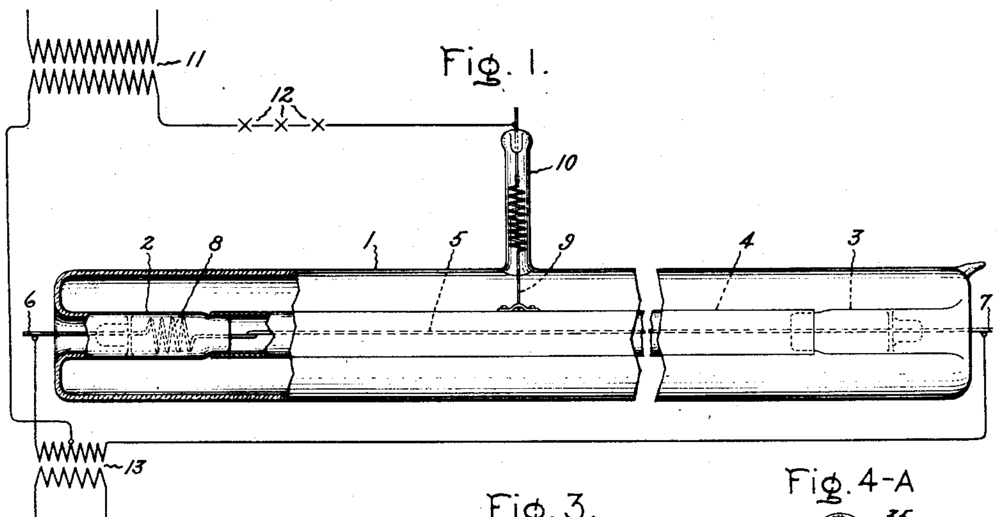


Fig. 2.

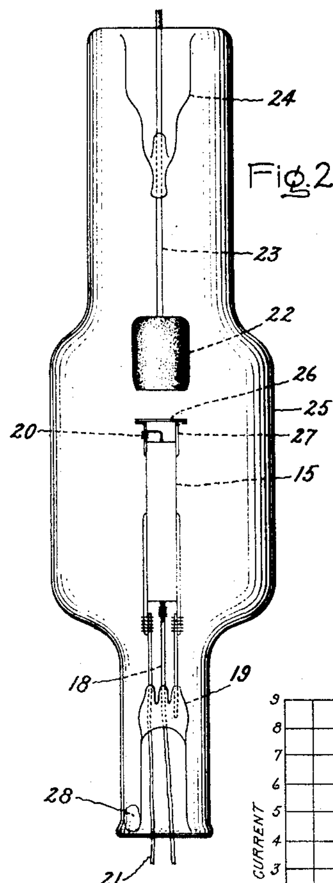


Fig. 3.

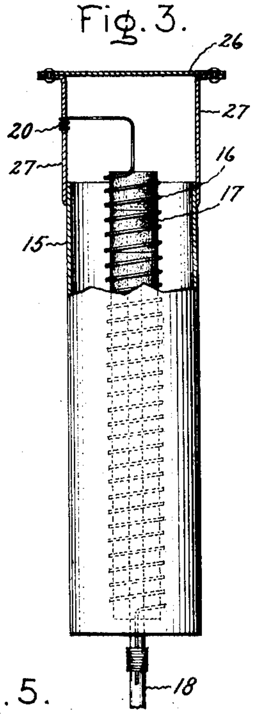


Fig. 4-A

Fig. 4.

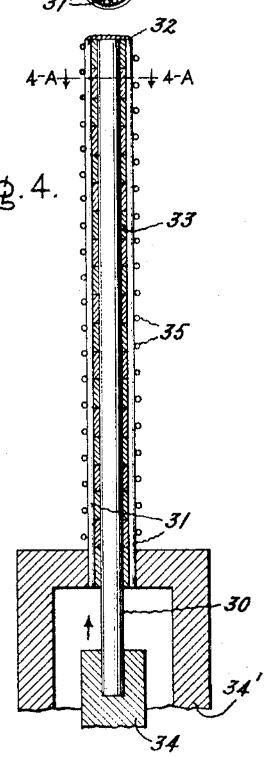
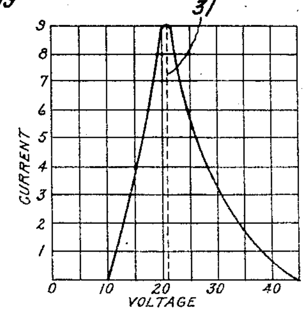


Fig. 5.



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ELECTRICAL DISCHARGE DEVICE AND METHOD OF OPERATION

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Fig. 6.

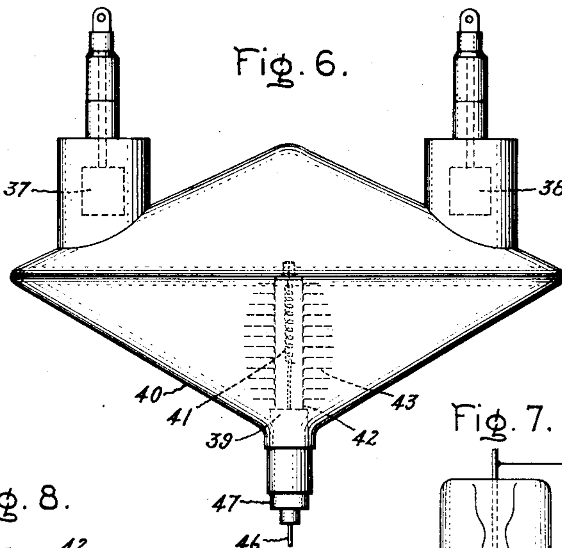


Fig. 7.

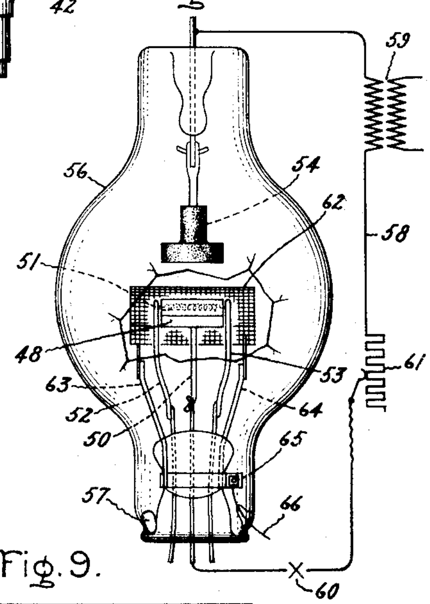


Fig. 8.

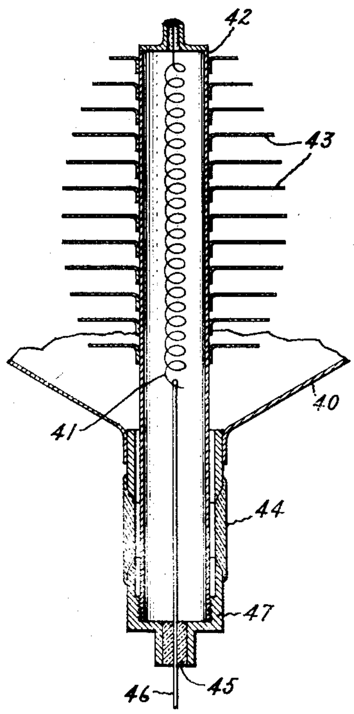


Fig. 9.

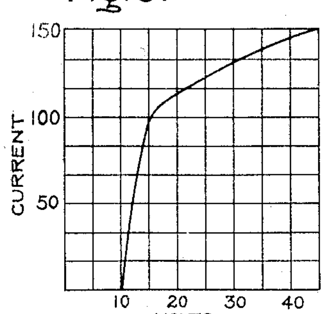
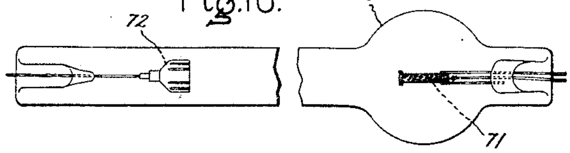


Fig. 10.



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Patented Jan. 27, 1931 1,790,153

UNITED STATES PATENT OFFICE

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ELECTRICAL DISCHARGE DEVICE AND METHOD OF OPERATION

Application filed October 15, 1927. Serial No. 226,376.

The present application is a continuation in part of my application for electrical discharge apparatus, Serial No. 594,370, filed October 13, 1922.

The present invention relates to electrical discharge devices of the thermionic type. It is the object of my invention to provide an improved device of this type which is capable of a greater current carrying capacity, higher efficiency and a longer life than has been characteristic heretofore of devices of this character.

My invention is particularly applicable to electric power devices, and from the description which follows it will be understood that it is distinct from the class of thermionic devices which are used as radio detectors or amplifiers in which the currents are so small and the operating voltages so low that certain fundamental phenomena which are of importance in a power device, for example, cathode disintegration, do not appreciably come into play. By the term "power devices" I mean to designate devices in which the output current has an energy value of at least one watt and which may and ordinarily does have an energy value of many hundreds or thousands of watts.

In its electrical characteristics my new device may be termed "arc device", in a broad sense of the term. Over the operating range the current is nearly independent of voltage. In its preferred form it differs, however, from ordinary arc devices, such as the mercury arc rectifier or the high pressure hot cathode rectifier (such as the "Tungar" rectifier) by the fact that its voltampere characteristic is positive over the usual operating range, that is, with increasing current through the device the difference of voltage, or drop of voltage, between the electrodes increases. Such a device with a positive characteristic will operate stably without series resistance from a source of constant potential.

Under special conditions when high efficiency for low voltage operation is desired it may be preferable to so construct the present device, particularly with reference to the pressure of the gas filling, that the operating characteristic is negative.

While the benefits of my invention may be obtained with various forms of thermionic cathodes, its greatest advantages are obtained with thermionic cathodes which are provided with a surface coating of an activating material which has a higher electron emissivity than the main body, or foundation, of the cathode.

Two distinct types of thermionic power devices have been in use heretofore. One type or class is constituted by thermionic devices operating with a pure electron discharge having a positive volt-ampere characteristic, the pressure of residual gas being reduced therein to a value so low that gas ionization during operation is negligible. Such devices are operable at high voltages but their current carrying capacity is quite limited due to the space charge condition which accompanies the substantial absence of ionization. As the voltage required to overcome space charge is an energy loss, low efficiency is obtained unless this loss represents a small fraction of the operating voltage. For this reason, such power devices in commercial practice have been limited to high voltage uses. The energy loss at the anode even at an operating potential of 15,000 volts in such devices is generally about one-third of the transmitted energy. The current output is seldom more than a few amperes and usually is less than one ampere.

A second type is constituted by thermionic devices in which a gas is present at relatively high pressures, that is, pressures materially above one millimeter of mercury, and usually as high as about five centimeters of mercury, although even higher pressures may be utilized. Known devices of this class are characterized by a negative volt-ampere characteristic over their whole operating range. The function of the gas is to furnish positive ions, as a result of collision between the electrons and the molecules of the gas. These ions neutralize the space charge of the electrons, and allow large currents to pass from cathode to anode when the potential difference between them is only slightly greater than, or even less than, the ionizing potential of the gas. The potential difference between the cathode and the space immediately around it in the direction of current flow is, therefore, not materially greater than the ionizing potential of the gas. The maximum velocity of the positive ions, therefore, cannot be materially greater than the value corresponding to the ionizing potential of the gas. This velocity is further reduced by collisions between the ions and the molecules of the gas as the mean free path of ions at these pressures is only a few thousandths of a millimeter. Thus under the operating conditions the ions arrive at the cathode with very small energy, and their impact upon it causes no material disintegration.

Thermionic rectifiers containing argon, or other suitable gas, at pressures of several centimeters and having operating characteristics placing them in this second class are very efficient for rectifying moderate currents, up to about fifteen amperes, and for potentials up to about 200 volts. With larger currents the discharge tends to injure the cathode and at higher voltages inverse discharges occur, that is, the valve action, or rectification, begins to break down. As the discharge in devices of this second class is a concentrated band, or flame, these devices will be referred to herein as concentrated arc devices.

Between these two ranges of pressure, namely, the very low pressure of the pure electron discharge devices on the one hand and the relatively high pressures of the concentrated arc devices on the other hand, there is a range of pressures from about one micron to about one millimeter (1,000 microns) of mercury pressure which has never been considered practical for use in any thermionic devices of the power type. All attempts to use pressures within this range have resulted in excessive disintegration of the cathode. In fact, it has generally been observed in the concentrated arc discharge range of pressures, that the lower the pressure the shorter has been the life of the cathode. When the pressure has been reduced to a millimeter or less, the cathode has lasted only a few hours.

In accordance with the present invention which includes both a new apparatus and a new method of operating a thermionic discharge, I have provided thermionic discharge devices containing gas ranging in pressure between about one micron and about one millimeter. I have discovered that thermionic tubes containing gas at a pressure in this range when suitably constructed and exhausted, may be operated with power currents for long periods without appreciable disintegration of the cathode. These tubes, which operate with a diffuse discharge, or a glow, are markedly superior for power purposes to tubes of the types previously described, having the low internal resistance and high efficiency of the concentrated arc type, but without its limitations as to voltage and current carrying capacity, I have operated tubes of this low-pressure diffuse discharge type as rectifiers for more than 4,000 hours at an efficiency equal to that of the concentrated arc type and at a voltage higher than that used with this type without any material change in the appearance of the cathode or in its electron emissivity. I have operated other similar tubes through shorter periods with currents of several hundred amperes and with voltages as high as 30,000 volts without any deleterious effects on the cathode or any other part of the tube.

The successful operation of these devices depends upon conditions or requirements which I have discovered and which are explained and illustrated herein. The principal requirement is that positive ions which strike the cathode should have an energy less than a value represented by a critical or limiting voltage (referred to hereafter as the disintegration voltage) which varies with the atomic weight of the gas filling. The disintegration voltage is always greater than the ionization voltage of the gas. The disintegration voltage for mercury vapor is about 22 volts, for argon about 25 volts and for helium about 50 volts (the ionization voltages of these gases being 10, 15 and 25 respectively).

The construction of successful devices of this type requires a combination of several features. The most important of these is that the cathode should be so proportioned with respect to the load or space current which the tube is designed to carry, that its electron emission in the absence of positive ion bombardment shall be equal to or greater than the maximum instantaneous value of the current through the tube. In the devices of this type which have been made heretofore, the electron emission of the cathode has been so inadequate that the tubes would have been inoperable, except for the positive ion bombardment which occurred as an incident to the inadequate electron thermionic emission and increased the electron emission of the cathode but in so doing also disintegrated it. In accordance with my invention the cathode emission is obtained at an operating temperature at which thermal vaporization is inappreciable and since disintegration by positive ion bombardment is avoided the cathode has a commercially long life.

A second requirement is that the electrodes and all other parts of the tube should be so thoroughly freed from gas, that they will not evolve during operation gases which will attack the electrodes or poison the surface of the cathode and the gas filling used should likewise not attack the electrodes nor poison the surface of the cathode, that is, it should be inert or chemically harmless with respect to the cathode, nor should gases of any kind be present at a pressure sufficient to allow a glow discharge between cold electrodes or to increase materially the arc drop.

A third requirement is that the cathode shall be capable of being maintained at the operating temperature with a current that will not produce a magnetic field sufficient to raise the potential between the cathode and the space immediately around it above the disintegrating value, and that the maximum potential difference between parts of the cathode shall be small compared with the disintegrating potential.

A fourth requirement is that the spacing between the electrodes and in general the geometry of the device shall be properly related to the pressure of the gas or vapor content. The electrodes must be spaced apart far enough and the volume of the space available for ionization must be sufficiently great so that the number of ions formed will be sufficient to eliminate space charge. On the other hand, the product of gas pressure and distance between the remotest parts of the electrodes must not be sufficient to permit a glow discharge to pass between the electrodes in the absence of thermionic emission. For example, in the case of a device (such as shown in Fig. 7) containing mercury vapor and having a bulb diameter of about three inches, and a length of about five inches, the operating range of pressure of mercury vapor is between about one micron and about 40 microns for operating voltages materially above 100 volts.

In one form of device embodying my invention, I provide a cathode which is constructed and proportioned to permit heat interchange to occur between its parts at a sufficiently high rate to substantially prevent the formation of localized hot spots, or, in other words, I provide a cathode operating at such equable temperature that no deleterious concentration of the space current will occur upon the cathode. This feature is of particular utility in devices provided with cathodes coated with an alkaline earth oxide or other activating material.

The features of novelty of my invention will be pointed out with greater particularity in the appended claims, the invention being described in greater detail hereinafter with reference to the accompanying drawings.

Fig. 1 of the drawings is a side view, partly in section of one embodiment of my invention; Fig. 2 is a side elevation of a modification; Fig. 3 is an enlarged view of the cathode of the device of Fig. 2; Fig. 4 is an enlarged side view of a magnetically compensated cathode; Fig. 4A is a sectional view of this cathode taken on the plane marked 4—A in Fig. 4; Fig. 5 is a graph showing the relation of current to impressed voltage of the device shown in Fig. 1; Figs. 6 and 7 are side elevations illustrating other modifications of my invention; Fig. 8 an enlarged sectional view of a cathode which is constructed to provide cavities for retaining active material; Fig. 9 is a graph of the volt-ampere characteristic of an arc discharge from an oxide-coated cathode, and Fig. 10 is a condensed view of a lamp embodying 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 filamentary 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 present in the tube. 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.

The cathode conductors 6, 7 are sealed into the stems 2, 3 in the usual manner. The helical spring 8 maintains the cathode 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 supported otherwise. The electrodes 4, 5 are connected to a source of energy represented by the secondary of the transformer 11, in series with a load 12. The cathode 5 is heated by an auxiliary transformer 13.

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 when 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.

It will be noted that in the structure illustrated the anode 4 entirely encloses the cathode 5 so that the positive ions formed 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 the gas, so that 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 at high voltage, the geometric relations of the electrodes and the pressure of the gaseous filling preferably should be chosen as indicated above to cause the number of collisions of electrons with gas molecules to produce sufficient ionization to eliminate, or at least to substantially reduce space charge, but the electrons also should be prevented from taking such a long path between the electrodes, in the direction of an electric field produced by the applied potential, as to permit a discharge to occur during the half cycle intervals when the electrode functioning as anode is negative. In other words, with the gas pressures here involved the longer the path an electron may take in the passage from one electrode to another, the lower the voltage required to produce an undesired reverse discharge from the unheated electrode to the heated electrode. It is not only desirable that the cathode be located close to the anode but it is also desirable that the electrons from the 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 ends of the anode are closed, will rectify currents at 8,000 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 disintegration voltage which depends on the nature of the gas, as stated above. In mercury vapor the preferred operating pressure is about 5 microns, corresponding to a tube temperature of about 40° C. Increasing the potential between the electrodes 4 and 5 above the disintegrating voltage, (for example by short-circuiting the load wholly or in part), results in a decrease of electron emission to a low value by the removal of the active film of thorium from the cathode surface by positive ion bombardment.

Fig. 5 is a curve showing the current-voltage characteristic of a device having a thoriated cathode embodying my invention when different voltages are steadily applied until an equilibrium condition is attained. The current increases with the applied voltage up to a maximum value indicated by the dotted line 31. The voltage values indicated in this figure are the applied voltages. The actual maximum voltages are slightly higher because of the voltage drop in the filament. The voltage corresponding to the maximum current value is the "disintegration voltage." When the applied voltage rises above this critical value the current rapidly decreases and at a value several times the disintegration 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. The impedance of the load should be so chosen with respect to the electrical characteristics of the tube, and the impressed voltage, that the voltage across the electrodes 4, 5, during normal operation does not exceed the disintegration voltage. In the event of a short-circuit of a substantial part of the load, the voltage between the electrodes will exceed this value causing the current to be reduced to a low value.

In the device shown in Fig. 2, the cathode 15 consists of a sheet metal cylinder, which as shown in Fig. 3 is provided with an internal heater. The cylinder 15 is consists of nickel, iron, molybdenum, their alloys, or other material which is capable of being heated to about 1250° C. without appreciable thermal vaporization.

The cylinder 15 is coated either internally or externally, or both, with a suitable activating material such as barium carbonate, preferably using a suitable binder such as a cellulose compound in solution. The cathode is "formed" by heating in a vacuum to about 1250° C. or to a higher temperature. When the cylinder 15 consists of nickel, the forming temperature should be carried as close as practicable to the melting point of nickel. The heater 16 may be wound upon a support 17 consisting of a refractory material, such as magnesia. One end of the heater is connected to a conductor 18 sealed into the stem 19 and the opposite end is connected electrically to the cylinder 15, as indicated at 20, the electric circuit being completed by a conductor 21 which is also sealed into the stem 19.

The anode 22 consisting of graphite, or of a suitable metal, for example, iron or molybdenum, is supported by its conductor 23 which is sealed into the glass stem 24 located at the opposite end of the elongated envelope 25. The anode should have a sufficiently high heat dissipating capacity to operate at a temperature at which its electron emission is negligible even when coated with active material. A shield 26 connected to the cathode cylinder 15 by rod-like supports 27, preferably but not necessarily is interposed between the anode and the cathode.

The glass envelope 25 and the parts contained therein are deprived of water vapor, and the gas contents are evacuated by the most approved methods used in the preparation of pure electron discharge devices. A globule of mercury 28 finally is introduced before sealing the envelope. As during operation the pressure of the mercury vapor is determined by the temperature of the coolest part of the envelope, the latter should be constructed to operate with some part at a temperature not substantially above 70° C.; for example, the necks of the container adjacent the stems. At this temperature mercury vapor has a pressure of about 40 microns. In place of mercury vapor a filling of rare or monatomic gas, such as argon or helium, may be introduced into the container 25, at a pressure of about 200 microns, or less depending on the voltage to be rectified. Mercury vapor, however, is preferred for the ionizing medium, as the unvaporized excess material will maintain a constant vapor pressure. In a device such as shown in Fig. 2 a fixed gas, such as argon or helium tends to "clean up" during the use.

Arcs in the vapors of alkali metals have an extraordinarily low voltage consumption and hence a high efficiency of operation. Such metals may be employed as a source of vapor in special cases. I prefer ordinarily, however, to employ mercury, or a rare gas, as the ionizing medium, particularly in a rectifier, or a device in which the starting of the arc is controlled by a grid; for example, in a device such as shown in Fig. 7. Alkali metals as ionizing media have a much lower resistance to reverse arcing than the non-alkali media. The alkali metals have the property of becoming ionized by contact with a hot negatively charged electrode. These ions prevent proper functioning of the grid. Devices embodying my invention and charged with mercury vapor have been used for rectifying currents of 15,000 volts.

The cathode shown in Fig. 4 is heated directly by passage of current therethrough, the electrodes being essentially concentric cylinders so that their magnetic fields neutralize one another to prevent a reduction of effective electron emission by the magnetic field of the heating current. The cathode here illustrated comprises a central core 30, consisting of tungsten, for example, surrounded by a group of wires 31, also of tungsten or oxide-coated nickel, parallel to one another and to the central core. The core 30 and the wires 31 are connected electrically in series as by welding at 32 and are separated by an insulating layer 33 of magnesia. Electric terminals are shown somewhat diagrammatically at 34 and 34′. An external high resistance binding wire 35 of tungsten, for example, may be used to hold the parts in proper relation. With this construction there is little or no magnetic field at the surface of the cathode. For devices in which the cathode heating current is as high as ten amperes and, for greater currents, I prefer to use such a magnetically compensated cathode instead of the cathode shown in Fig. 1.

For rectifiers of very high power such as the metal container rectifier shown in Fig. 6 which comprises anodes 37 and 38 and a thermionic cathode 39 contained within a metal receptacle 40, I prefer to use a cathode structure which is heated by radiation from an internal heater 41 and comprises a tube 42 upon which are mounted a plurality of vanes or discs 43 the surface of which is coated with activating material, such as alkaline earth oxides or rare metals having a high electron emission. For example, the metal mixture known as "mischmetal" may be used as a coating for the cathode. The external surface of such a cathode and particularly the surface of the vanes 43 may be coated with a solution of barium carbonate and upon drying the structure is heated in a vacuum to a temperature of about 1250° C. or higher, gases being removed during the heat treatment. The cathode as shown in Fig. 8 may be sealed into the metal container by vitreous sealing members 44 and 45, an electrical current being supplied to the heater 41 through the conductor 46 and to the shell 47 which is mechanically and electrically attached to the tubular cathode member 42.

Non-filamentary thermionic cathodes such as shown in Figs. 2 to 4 and 6 to 8 possess advantages over the filamentary cathode such as shown in Fig. 1. Among the advantages are that an equable temperature may be more readily maintained throughout the electron emitting surface of the cathode and the maximum potential difference between parts of the cathode may be maintained small compared with the disintegration voltage as heretofore mentioned. Where the cathode is indirectly heated as, for example, by radiation it is apparent that the cathode may be maintained at a uniform potential.

In my copending application, Serial No. 156,713, filed December 23, 1926, I have disclosed several constructions of thermionic cathodes of the hollow or cavity type having an internal coating and have presented claims to such construction in that application.

In my copending application Serial No. 487,533, filed October 9, 1930, I have disclosed and claimed specifically the construction of thermionic cathode shown in Fig. 8 of this application.

For rectifiers of moderate power capacity, I prefer to use a structure such as shown in Fig. 7 in which the cathode having a surface coating of suitable activating material comprises a generally cylindrical member 48 formed by bending upon itself a thin sheet of nickel or nickel-iron-chromium alloy, and welding together the edges. It is supported upon a wire 50 and is heated to an electron emitting temperature by an internally located heater 51 which is supplied with current by the sealed-in conductors 52 and 53. The sealed bulb 56 may be highly evacuated as above described and provided with a globule of mercury 57, or may be charged with argon or other suitable gas at a pressure of about 50 to 200 microns. The drawing also indicates an external circuit 58 containing an electrical supply source, such as a secondary of the transformer 59, and containing a load 60 connected in series with the supply source through an adjustable resistor 61.

The combined resistance of the load 60 and the resistor 61 should be so adjusted with respect to the area of the surface and the thermionic emissivity of the cathode 48 and the voltage drop between the cathode 48 and the anode 54 is below the disintegration voltage. In most cases the resistor 61 may be entirely omitted, the resistance of the load being utilized to control the current. In fact, any means may be used for maintaining the current below the limiting value at which the potential drop at the cathode rises above the disintegration voltage.

In Fig. 7 a grid 62, supported by the conductors 63, 64 from the band or collar 65 surrounding the glass press, also has been shown. This grid, which surrounds the cathode and consists of wire mesh with about $\frac{1}{16}''$ spacing, may be omitted when rectification only is desired. When it is present the current through the device may be controlled by impressing suitable potentials on the grid which is connected to a sealed-in conductor 66.

Fig. 9 shows the volt-ampere characteristic of a device embodying my invention which has an activated cathode, the coating of which is not removed by positive ions, and which contains mercury vapor at a pressure of about 1.5 microns. The discharge begins to assume an operating current value when about ten volts are consumed in the discharge. Very little change of voltage occurs with increasing current until a limiting current value is reached depending on the size and nature of the cathode and the geometry of the device. For higher current values the voltage drop increases and the temperature of the cathode is increased due to positive ion bombardment. The current should be restricted to a value which corresponds to a voltage drop below the disintegration voltage.

In my application Serial No. 226,275, filed concurrently herewith, I have made claims on a lamp embodying some of the broad features of my present invention.

Fig. 10 shows one form of such a lamp on a reduced scale, the elongated envelope 70 being shown broken as its length may be varied with the length of illuminating column desired. The cathode 71 and the anode 72 are spaced apart such distance ordinarily that the total voltage drop is several times the ionization voltage of the gaseous filling which may be neon, mercury vapor, or other gas having a desired luminosity. In a direct current lamp, such as shown in Fig. 10, the permissible gas pressure may be materially higher than in a rectifier. In the case of neon in such a lamp, a pressure of about two to five m. m. may be employed. Such a lamp about 50 to 60 c. m. in length, and about 2.5 c. m. in diameter may be operated at 110–120 volts with a luminous over-all efficiency of about 10 lumens per watt. In the case of a lamp, such as shown in Fig. 10, in which the length of the positive column is considerable, starting will be facilitated by applying high frequency in the known manner.

So far as concerns the inventions herein claimed, it is not material whether the cathode, as for example the cathode 15 shown in Fig. 3, be coated internally or externally, or both. With the coating applied in any of these ways the inventions herein claimed may be utilized in accordance with the disclosure hereof. It is, however, possible to obtain additional important benefits, including increased life and higher efficiency of the cathode, where the active material is internal to such cathode; but such construction, while well adapted for use in particular embodiments of the present invention, forms no part of the present invention, and is claimed in my copending application Serial No. 156,713, filed December 22, 1926, heretofore referred to.

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

1. In combination an electrical discharge device comprising a sealed envelope, cooperating electrodes therein, one of which is adapted to operate as a thermionic cathode and one of which is adapted to operate as an anode, a gas in said envelope which is inert with respect to said cathode at its operating temperature and having a pressure within a range of about several microns to several millimeters of mercury said cathode having a thermionic electron emission sufficient to supply the maximum current the device is designed to carry at a temperature at which thermal evaporation in vacuum is inappreciable and with a voltage drop in the current carrying direction less than the disintegration voltage for the gas, an electric supply source connected to said anode and cathode having a voltage materially above the ionization voltage of said gas, and means in combination with said device for limiting the current transmitted therethrough to a value at which cathodic sputtering is inappreciable.

2. An electric rectifier for alternating current comprising the combination of an envelope, a gaseous filling for said envelope having a pressure less than about 200 microns of mercury, and electrodes therein comprising a thermionic cathode constituted of a body of sheet nickel, a heater therefor of a metal more refractory than nickel and a coating for said body consisting of alkaline

earth material, the electron emissivity of said cathode being sufficiently high to support a current materially greater than an ampere at an operating temperature of inappreciable thermal evaporation and with a voltage drop at the cathode less than about 25 volts.

3. The combination of an electric current source having a voltage materially greater than fifty volts, an electrical discharge device connected thereto comprising a thermionic cathode, an anode, a container therefor, and a gas therein having a pressure within the range of several microns to several millimeters of mercury and means for maintaining the ion bombardment voltage with respect to said cathode less than a critical value characteristic of the nature of the gas in said container at which destructive disintegration of said cathode would occur.

4. The combination of an electric discharge device comprising a thermionic cathode, an anode, an enclosing envelope and a monatomic gas therein having a pressure within the range of several microns to several millimeters of mercury, an electric current source connected to the electrodes of said device and having a voltage sufficiently high to cause destructive disintegration of said cathode by positive ion bombardment and means in circuit with said electrodes for preventing during normal operation a rise of voltage between said electrodes materially in excess of about fifty volts.

5. The combination of an electric discharge device comprising a thermionic refractory metal cathode provided with a material having a higher electron emissivity than said metal, an anode and a charge of monatomic gas at a pressure of the order of about 100 microns of mercury, a source of current connected to said electrodes having a voltage many times greater than the ionization voltage of said gas and means in circuit with said electrodes and said source for limiting the ion bombardment voltage with respect to said cathode to a value slightly above the ionization voltage of said monatomic gas but below a sputtering voltage.

6. An electrical discharge device having a designed current carrying capacity of at least an ampere and comprising a container, electrodes therein including an anode and a thermionic cathode, means whereby said cathode may be heated to maintain a substantially equable temperature, an ionizable gas in said container chemically harmless with respect to the cathode, said cathode being constructed to provide a thermionic electron emission at the operating temperature thereof sufficient to supply the maximum current the device is designed to carry, a sufficient quantity of said gas being present during operation to furnish the requisite number of positive ions to neutralize space charge for the designed current carrying capacity of the device at a gas pressure too low appreciably to protect the cathode against thermal evaporation, said cathode and anode being spatially related so that the device will carry its designed current at the operating pressure of the gas with a voltage drop in the neighborhood of the cathode above the ionization voltage of the gas and below the disintegration voltage for the gas.

7. An electrical discharge device comprising a container, electrodes therein including an anode and a thermionic cathode, means for heating said cathode, means for neutralizing space charge comprising a gas chemically harmless with respect to said cathode having an ionizing voltage below the disintegration voltage and having during operation of the device a pressure between the limits of about one micron and one millimeter of mercury, said cathode having an electron emitting surface of sufficient area to provide in the absence of positive ion bombardment and at a temperature below that at which the loss of active material of the cathode due to thermal vaporization would be appreciable in vacuum a thermionic electron emission sufficient to support the maximum current the device is designed to carry, said device being designed and constructed to carry currents of at least several amperes with a voltage drop in the neighborhood of the cathode above the ionizing voltage of said gas but below the disintegration voltage for said gas.

8. An electrical discharge device comprising a container, electrodes therein including an anode and a thermionic cathode, means whereby said cathode may be heated to maintain a substantially equable temperature with a maximum potential difference between parts electrically connected to the cathode small compared with the disintegration voltage of mercury vapor, a charge of mercury in said container out of electrical contact with said cathode adapted during operation of the device to maintain sufficient mercury vapor in said container to furnish when ionized a sufficient number of positive ions to neutralize space charge for the designed current carrying capacity of the device, said cathode being constructed to provide a thermionic electron emission at the operating temperature thereof sufficient in the absence of positive ion bombardment to supply the maximum current the device is designed to carry, said cathode and anode being spatially related so that the device will carry its designed current with a voltage drop in the neighborhood of the cathode above the ionization voltage of mercury vapor and below the disintegration voltage for mercury vapor.

9. An electrical discharge device comprising a container, electrodes therein including an anode and a thermionic cathode, means for heating said cathode, a gas in said container which is chemically harmless with respect to

said cathode, said gas having a pressure within the range of about 1 to about 200 microns of mercury, said cathode being constructed and arranged to be substantially heat equalized throughout its electron emitting portions during operation, and having at a temperature below that at which the life of the cathode is materially reduced by thermal vaporization an electron emission in excess of that corresponding to the maximum current the device is designed to carry, said device being adapted to carry such maximum current with a voltage drop at the cathode above the ionization voltage but below the disintegration voltage for said gas.

10. An electrical discharge device comprising a container, electrodes therein including an anode, a thermionic cathode and a control grid for controlling the discharge between cathode and anode, means whereby said cathode may be heated while maintaining the cathode at a substantially uniform potential, means for neutralizing space charge comprising a charge of mercury for maintaining a pressure of mercury vapor in said container of between about 1 and about 100 microns of mercury, said cathode being constructed to provide a thermionic electron emission at the operating temperature thereof sufficient in the absence of positive ion bombardment to supply the maximum current the device is designed to carry, said device being designed and constructed to carry such maximum current with a voltage drop between cathode and anode less than the disintegration voltage for mercury vapor.

11. An electrical discharge device comprising a container, electrodes therein including an anode, a thermionic cathode and a control electrode for the discharge between cathode and anode, means for heating said cathode, a quantity of gas in said container at a pressure sufficiently high to furnish the requisite number of positive ions to neutralize space charge for an operating current of at least an ampere with a voltage drop less than the disintegration voltage for the gas, said cathode including a metal surface coated with activating material of higher electron emissivity than the foundation metal and being constructed and proportioned to provide a thermionic electron emission at an operating temperature at which thermal evaporation in vacuum is inappreciable substantially sufficient to supply such operating current, the pressure of said gas being below a value sufficient appreciably to reduce thermal vaporization of the cathode at its operating temperature.

12. An electrical discharge device for connecting alternating and direct current circuits comprising a container, electrodes therein including an anode and a thermionic cathode, means for heating said cathode, a quantity of gas in said container at a pressure sufficiently high to provide the requisite number of positive ions to neutralize space charge for the operating current with a voltage drop in the current carrying direction less than the disintegration voltage for the gas but below a pressure that will permit a glow discharge between the electrodes at reverse voltages of the order of 1000 volts, said cathode being constructed and proportioned to provide a thermionic electron emission sufficient to support the operating current.

13. An electric discharge device comprising a sealed envelope, a gas for said envelope having a pressure within the range of about 1 to 1000 microns of mercury to furnish the number of positive ions requisite to neutralize space charge for the operating current, electrodes including an anode and a cathode, said cathode comprising a body coated with activating material of higher electron emissivity than said body and constructed and arranged to have a thermionic electron emission sufficient to supply an operating current of the order of 100 amperes at an operating temperature at which the loss of activating material is inappreciable from thermal evaporation and with a voltage drop in a range between the ionization voltage of said gas and the disintegration voltage for said gas.

14. An electric discharge device comprising an envelope, electrodes therein including a thermionic cathode constituted of a base metal coated with a layer of higher electron emissivity than said metal, a heater for said cathode, a charge of monatomic gas having between 0° C. and 100° C. a pressure between 1 and 200 microns of mercury pressure, the cathode of said device being shaped and proportioned to be capable of giving an electron emission of at least an ampere at a cathode temperature at which thermal vaporization thereof is inappreciable, and means for limiting the drop of voltage at the cathode below disintegration voltage.

15. In combination, an electrical discharge device comprising a container, electrodes therein comprising a thermionic cathode and an anode, and a quantity of gas in said container to furnish sufficient positive ionization to eliminate space charge for the operating current through the device, said cathode being constructed and proportioned to provide a thermionic electron emission sufficient in the substantial absence of positive ion bombardment to supply the major portion of the operating current, and means for limiting the operating current to a value at which positive ions strike the cathode with an energy less than a value represented by the disintegration voltage for the gas.

16. The method of operating an electrical discharge device including an anode and a thermionic cathode in a low pressure gas for eliminating space charge by positive ioniza-

tion, which includes maintaining the current through said device at a value which said cathode is adapted to supply by thermionic electron emission at a temperature at which thermal evaporation of said cathode is negligible while maintaining the maximum voltage drop at the cathode in the current carrying direction below the disintegration voltage for said gas.

17. An electrical discharge device designed to carry currents of at least an ampere comprising a container, electrodes therein including an anode and a thermionic cathode which has, at a temperature below that at which its life would be materially reduced by thermal vaporization, an electron emission in excess of that corresponding to the maximum current the device is designed to carry, a gas in said container which is chemically harmless with respect to said cathode and having at operating temperatures of said device a pressure of about 1 micron to 200 microns of mercury, said device being constructed to conduct such maximum current with a voltage drop at the cathode above the ionization voltage but below the disintegration voltage for said gas.

In witness whereof, I have hereunto set my hand.

ALBERT W. HULL.