

March 17, 1936.

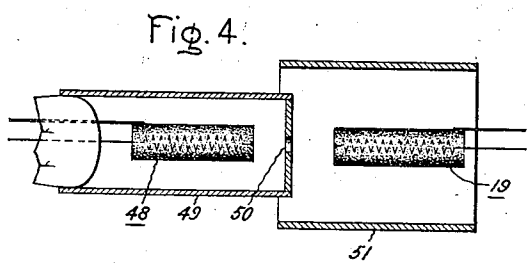
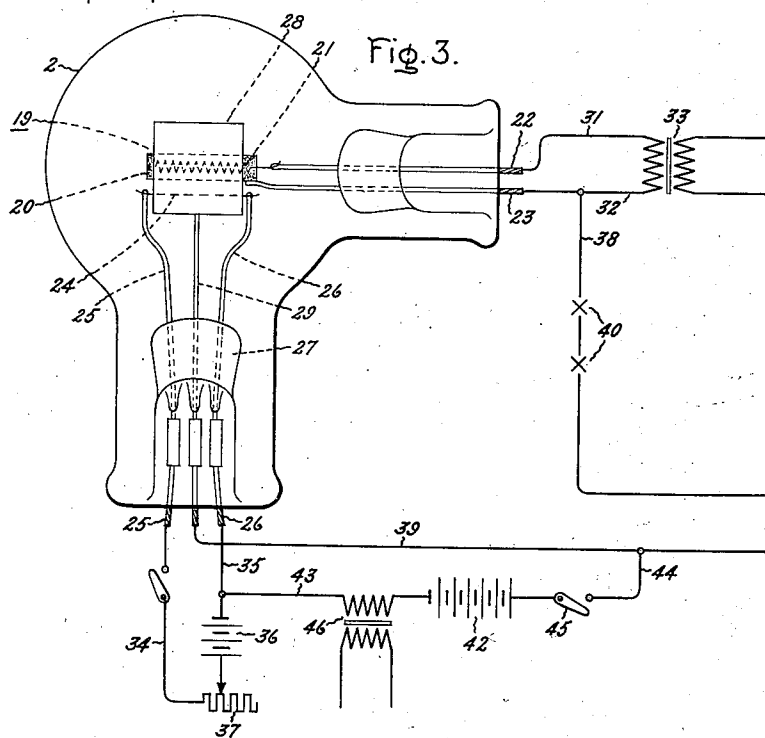
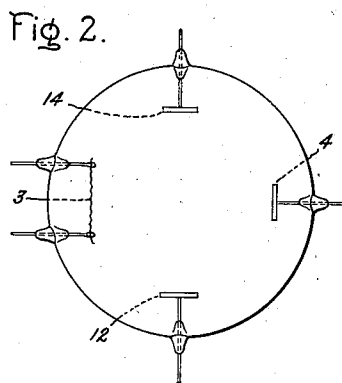
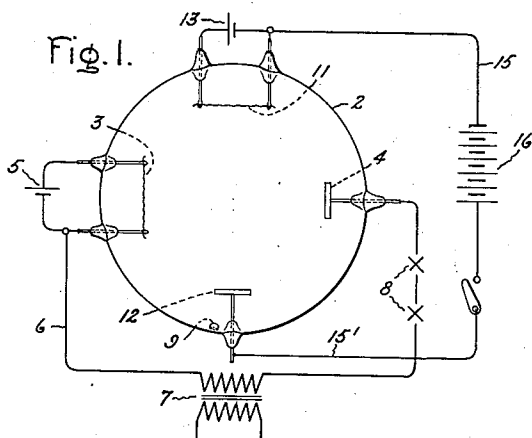
C. G. FOUND

2,034,571

ELECTRICAL DISCHARGE DEVICE AND METHOD OF OPERATING SAME

Filed Aug. 16, 1933

2 Sheets-Sheet 1



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ELECTRICAL DISCHARGE DEVICE AND METHOD OF OPERATING SAME

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2 Sheets-Sheet 2

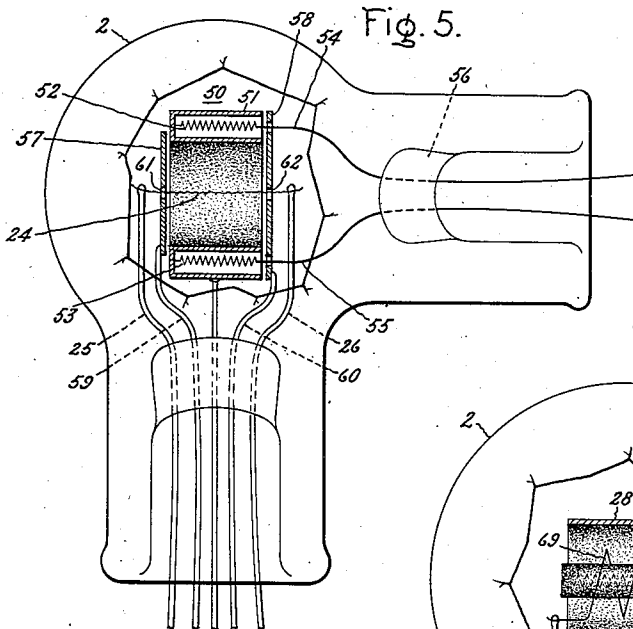


Fig. 8.

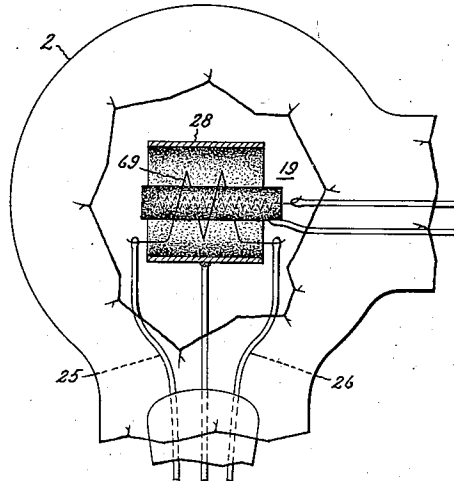


Fig. 6.

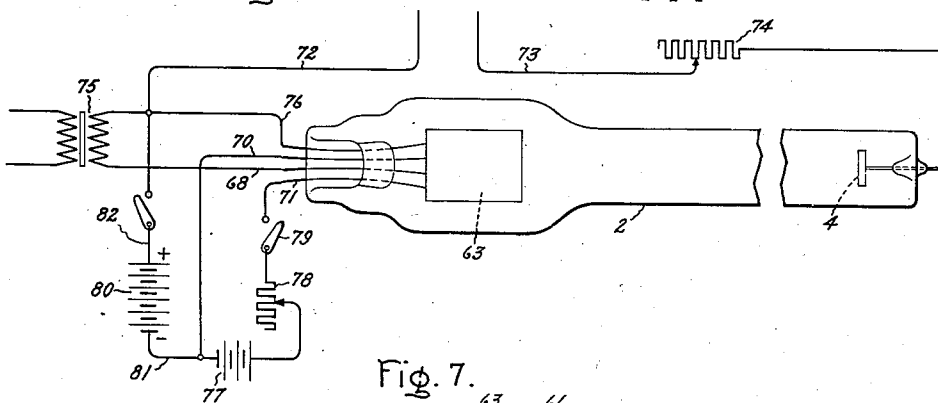
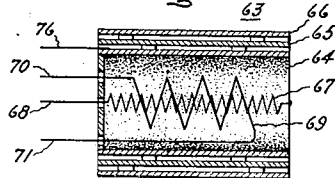


Fig. 7.



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UNITED STATES PATENT OFFICE

2,034,571

ELECTRICAL DISCHARGE DEVICE AND
METHOD OF OPERATING SAMEClifton G. Found, Schenectady, N. Y., assignor to
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New York

Application August 16, 1933, Serial No. 685,376

18 Claims. (Cl. 250—27)

The present invention comprises improved electrical discharge devices of the type in the operation of which ionization of contained gas plays an essential role and in particular to devices operating with electric discharges having the characteristics of an electric arc. It includes also a new method of operating such devices.

Heretofore in electrical devices in which gas at appreciable pressure has been provided as distinguished from the minute amounts of non-essential residual gas present in so-called pure electron discharge devices, the maintenance of the discharge has entailed a relatively considerable consumption of voltage, this voltage being required to ionize the gas. In devices containing gas at low pressures, by which are meant generally speaking pressures within a range of about one micron to a few millimeters of mercury, the drop of voltage in the device during operation has been greater than the ionization voltage of whatever gas was present. For example, in a rectifier containing mercury vapor at a pressure of one-hundredth of a millimeter (this value being chosen arbitrarily for illustrative purposes) and having a thermionic cathode capable of supporting a current of an ampere (also arbitrarily chosen) the drop or consumption of voltage has had a minimum value of about 10.5 volts. The ionization voltage of mercury is 10.4 volts. Ionization occurred only when the voltage expended in the gas (here mercury vapor) rose above ionization voltage. In a simple case the voltage automatically fixed itself at about one-tenth volt above ionization voltage.

At higher gas pressures the ionization phenomenon was modified and the drop of voltage was lowered, due to ionization by repeated electron impact, to a low value known as the excitation voltage.

In a rectifier containing mercury vapor at one centimeter pressure (again arbitrarily chosen), the drop or consumption of voltage may fall to a value as low as about 5 or 6 volts. This lower voltage drop entails a lower energy loss and hence is desirable but the use of relatively high gas pressures entails various limitations as is well understood.

In both types of discharge devices the incidental drop or consumption of voltage at the cathode (the nature of which will be more fully explained hereinafter) entailed a loss of energy which manifested itself as heat in the discharge device. Heat in an electrical power device not only is a waste of energy but must be dissipated as by

ventilation, water cooling or otherwise, with attendant complication of structure.

In accordance with my present invention the drop of voltage at the cathode required to produce the necessary ionization heretofore considered unavoidable in the operation of electrical gas ionization discharges, both of the low pressure and high pressure type, may be reduced to a low value, or, indeed, may be eliminated entirely. As later more fully explained, this result is accomplished by producing the positive ions required for the operation of the electrical discharge by a separate mechanism at materially higher efficiency. While some energy is expended in the independent production of ions a substantial net saving of energy is effected.

In the accompanying drawings Figs. 1 and 2 are diagrammatic representations of typical devices embodying my invention; Fig. 3 illustrates in front elevation, with accompanying electrical connections, a device embodying my invention in which the main and auxiliary cathodes have a common anode; Fig. 4 illustrates partly in section a modified cathode structure; Fig. 5 illustrates in front elevation a modification which is adapted particularly for power rectifier purposes; Figs. 6 and 7 respectively illustrate a positive column lamp embodying my invention and a modified cathode structure therefor; and Fig. 8 illustrates another modification (parts of the envelope being broken away).

Fig. 1 of the drawings shows conventionally a simple embodiment of my invention in a thermionic rectifier. Before describing its novel features I shall describe first the fundamental ionization characteristics of a low gas pressure type discharge. In the illustrative example the device has a sealed envelope 2, commonly consisting of glass, although other materials may be used. The thermionic cathode 3 here shown is of filamentary form, although other forms may be used. It will be understood, however, that my invention is chiefly concerned with solid cathodes as, for example, the separately heated filamentary type from which a substantial number of electrons may be emitted as a heat phenomenon even in the absence of an inter-electrode discharge. This is in distinction to the liquid pool cathode which requires the presence of a sustaining arc to keep its surface in electron-emitting condition. The anode 4 may consist of a simple plate of metal, for example, nickel or tungsten. A heating means for the cathode is represented here conventionally by a battery 5. A work circuit 6 contains the secondary of a

transformer 7, representing a source of electric energy. A load is represented by the crosses 8.

The envelope 2 is freed from water vapor and other deleterious gas by the most approved methods of exhaust used in the preparation of high vacuum tubes. After evacuation it is charged with a desired gas which may be assumed for purpose of illustration to be mercury vapor furnished by a droplet of mercury 9. Other gases, of course, can be used, as, for example, one of the rare gas group, or other metal vapors, or a mixture of gas and vapor, or gases and vapors. For convenience, I shall hereafter refer to any of the gases and vapors or their combination by the term gaseous filling. While the gas pressure may be as low as about one micron, it preferably should be higher.

Electrons emitted by the cathode 3 passing through the gas to the anode 4 under the influence of the impressed voltage collide with molecules of the gas filling (in the illustrative case with atoms of the monatomic mercury). If the electrons have been accelerated by a voltage exceeding a certain critical value, differing for each gas, the collision may result in ionization thereby producing additional electrons and also ions. The newly liberated electrons together with the electrons emitted by the cathode pass to the anode while the positive ions are attracted to the cathode. The ions travel to the cathode much more slowly than the electrons travel to the anode. Each positive ion as long as it remains in the space neutralizes the negative charge on an electron. In the absence of positive ions the presence of the electrons in the space produces a negative charge (commonly known as electron space charge or negative space charge), which opposes the flow of current. Positive ions remain in the path of the current many times longer than electrons, hence any given ion will neutralize the negative space charge of a great number of electrons. When equilibrium is established in the tube, the negative charge of the electrons and the positive charge of the ions are practically equal in the region where the ions are produced, creating a relatively field-free region which is called "plasma". Consequently the drop of voltage in the plasma is very small.

An electron must travel a certain distance after leaving the cathode under the influence of the electric field before it acquires the critical energy necessary to ionize a gas atom. Expressed in equivalent volts this energy corresponds to 10.4 volts for mercury vapor, which may be termed the minimum arc-sustaining voltage of mercury. There is a region, close to the cathode, through out which the electrons are being accelerated but have not yet reached this critical value. Hence ions cannot be produced in this region. The negative space charge of the electrons in this region can be neutralized only by ions formed in that region where the electrons have attained at least their critical energy, that is, by ions formed in the plasma. The migration of ions from the plasma toward the cathode will be limited by a positive ion space charge set up by the ions close to the plasma.

Thus, there is a narrow zone between the cathode and plasma which is called the "cathode sheath" in which the applied voltage must overcome both the negative space charge near the cathode boundary and the adjacent positive space charge at the plasma boundary. The term "arc" heretofore has been used in the field of this invention to designate electric discharges in a gas or

vapor which have a voltage drop at the cathode of the order of the minimum ionizing or minimum exciting potential of such gas or vapor, and which have a negative or practically zero volt-ampere characteristic. The term "exciting potential" will be later explained. The cathode voltage drop here referred to is the voltage drop in the cathode sheath. Due to space charge conditions there exists in a gas ionization discharge a definite relation between the number of ions reaching the cathode and the number of electrons which can leave it, that is, the electron current from a cathode is determined by the ion current which reaches the cathode.

Two possible types of electron emission by the cathode will be separately considered as they are effected somewhat differently by positive ions produced independently in accordance with my invention. In one type, first to be considered, the emission of the cathode independent of applied voltage will be assumed to be greater than the discharge current through the tube which is assumed to be limited by some external means. The ratio of electron current to ion current will have a definite value for each gas which is approximately equal to the ratio of the square root of the mass of an ion to the mass of an electron. The positive ion current to the cathode is proportional to the positive ion density in the plasma, and the positive ion density in the plasma in turn is determined by the ionizing power of the electrons.

As has been indicated, the voltage drop in the cathode sheath determines the ionizing power of the electrons, the efficiency of ionization being roughly proportional to the excess of this voltage drop over the ionizing potential. In a discharge of the first type now being considered the voltage drop at the cathode adjusts itself to that value which will produce such concentration of ions in the plasma that the number of ions reaching the cathode bears the definite relation to the electron current above indicated.

In the case of mercury vapor (still assuming the same condition of cathode emission) a cathode drop of about one-tenth volt above ionization voltage satisfies this condition.

If the electrons are accelerated by a voltage which exceeds the ionization voltage by as small a margin as one-tenth volt, the probability of ionization being produced by a single collision between an electron and a gas molecule is extremely small, so that many unsuccessful collisions, either elastic or exciting, are required on the average before an electron can produce ionization. Each of these unsuccessful collisions results in a slight loss of energy, and as a result of a number of these unsuccessful collisions a large proportion of the electrons have their energy so reduced by the unsuccessful collisions that their energy is reduced to a value less than that required to produce ionization, so that the over-all efficiency of ionization—that is, the ratio of the energy used in ionization to the energy imparted to the electrons—is extremely low. If the voltage margin is progressively increased, however, the average number of collisions required decreases, with the result that this over-all efficiency rises extremely rapidly, reaching a maximum of approximately 39% when the cathode fall is approximately 30 volts. Beyond this voltage other factors cause the over-all efficiency to slowly decrease. As a result ionization may be produced much more efficiently at 30 volts than with lower voltages. For example, with

a cathode fall of 30 volts the over-all efficiency is of the order of 200 fold that with a cathode fall of 10.5 volts.

In the device conventionally illustrated in Fig. 1 there is provided for the purpose of my invention a second filamentary cathode 11 which may be assumed to consist of tungsten, or other suitable material, and a second anode 12, the cathode being heated by a battery 13. The auxiliary cathode 11, in Fig. 1, has been shown as a thermionic cathode. The auxiliary cathode may be nonthermionic as well as thermionic, as illustrated at 14 in Fig. 2. The electrodes 11, 12 (Fig. 1) are connected by the conductors 15, 15' to a source of energy represented by a battery 16. When the cathode 11, due to its size, temperature and character has a relatively low electron emissivity it may be so operated that all of the available electrons are carried away, a condition known as saturated electron emission. When operating under a condition of "saturated electron emission" the voltage applied to the emission-limited cathode is under control and may be made any desired value above ionization voltage. By the application of a higher voltage the electrons produce ionization of the gas more efficiently. This ionizing voltage for the auxiliary or additional discharge is furnished by the battery 16 which is representative of any suitable source. When the main discharge has a current value of about two amperes, the auxiliary discharge need have a value of only about ten milliamperes, assuming a voltage of at least thirty volts.

Assuming the auxiliary discharge to have the proper spatial relation to the main discharge, so that the ions produced in the gas filling by the auxiliary discharge are available to reduce or eliminate space charge of the electrons flowing between the main electrodes, it becomes unnecessary for the electrons of the main discharge to generate ions. It is no longer necessary that the voltage drop at the main cathode should exceed the ionization voltage. Thus by the practice of my invention it is possible to reduce to a desired degree the voltage drop in the neighborhood of the main cathode. As long as the plasma and sheath of the discharge between the main electrodes 3, 4 are supplied with a sufficient number of positive ions generated by the discharge between the electrodes 11, 12 to neutralize substantially the space charge of the electrons carrying the current at any given time, there can be no appreciable voltage drop between such electrodes.

In some cases, as will be later described, it may be desirable to maintain the voltage drop at some predetermined value lower than the ionization voltage. As described in my copending application Serial No. 685,377 filed August 16, 1933, a voltage drop of 2.2 volts is maintained in a sodium lamp between the main electrodes by the practice of my invention.

The energy loss in the auxiliary discharge between electrodes 11, 12 is more than off-set by the gain due to increased efficiency of ionization effected by the higher velocity of electrons from the auxiliary cathode 11. Besides, there is obtained the added advantage of controllability of voltage drop and controllability of discharge current. For example, as will be described in greater detail in connection with other figures of the drawings, the main current flowing in the work circuit 6 of Fig. 1 may be varied or modulated by varying the ion-producing current in the cir-

cuit 15, proper coordination of voltages being assumed.

In the second type of electron emission to be considered (still referring to a low pressure device), the thermionic emission of the cathode independently of the applied voltage may be assumed to be less than the discharge current through the tube instead of greater as assumed previously. The cathode may be of such a character that its electron emission is increased by the effect of positive ions. An example of such a cathode is the Wehnelt type cathode, which may be a cathode of nickel, platinum or other metal which is coated with alkaline earth oxide, such, for example, as barium oxide. Another example is a cathode of tungsten on the surface of which a film of thorium or caesium is maintained during operation. A thoriated form of cathode is described in Langmuir U. S. Patent No. 1,244,216, patented October 23, 1917. A cathode coated with caesium is described in Mackay and Charlton U. S. Patent No. 1,648,458, patented November 8, 1927. Any cathode of this type at sufficiently low current values will operate as a cathode which was first considered, and which will be referred to as a type one cathode.

When the main cathode 3 of Fig. 1 is of the second type, then the drop of voltage in the sheath (disregarding for the moment the additional electrodes 11, 12) will adjust itself at a value exceeding the ionization voltage by a greater margin than in type one cathode. In the case of a tube containing a Wehnelt type of cathode and provided with mercury vapor, the drop of voltage at such a cathode may be as high as about 17 volts. As described in Hull U. S. Patent No. 1,790,153 care should be exercised in this case not to draw so much current from the cathode that the voltage drop will rise to a value at which destructive disintegration of the cathode may take place. For mercury vapor the disintegration voltage is about 17.

It is well known that the electron emission from a cathode of the second type increases with increase of electric field at the cathode. The influence of the field is particularly great up to fields of about 10,000 volts per centimeter and thereafter falls off to a value in agreement with the well known Schottky law. The electron emission from a cathode of this second type may increase ten to a hundredfold in going from zero field to a field of 10,000 volts per c. m. When a Wehnelt cathode, or its equivalent, operates as an unsaturated cathode, above referred to as type one, then there is no field at the cathode. When the discharge current is increased until the Wehnelt cathode operates as a type two cathode, then the additional emission is obtained by creating an electric field at the cathode. This field is created by an increase of the positive ion current from the plasma to the cathode, which necessitates a higher cathode drop in order to increase the efficiency of ionization. The field is created primarily by an increased ion current rather than by increased voltage. For example, in the case of a cathode of the second type operating with a current density of about one-half ampere per square centimeter and with a drop of 17 volts, sufficient ions are produced to create an electric field at the cathode of about 6,000 volts per centimeter.

With this second type of cathode positive ions also may be supplied advantageously by an auxiliary discharge in accordance with my invention, although here the gain in efficiency will not be

as great as with the first type. With a drop at the cathode of 17 volts, about six of which are usefully employed in ionizing gas, the ionization efficiency is greater than in the case previously considered. The efficiency of ionization then will be at least about sixty times as great as when the difference is but one-tenth volt.

With the present invention voltages higher than the disintegration voltage can be used in the auxiliary circuit in which the cathode can be chosen to be little affected by disintegration, for example, by using ordinary tungsten. Thereby positive ions necessary for the establishment of the cathode field can be produced and the field itself can be created by the application of a low voltage between the main electrodes. This voltage may be a fraction of a volt or any desired value up to the ionization potential.

In this case also the current from the main cathode may be controlled by appropriately varying the gas ionization produced by the auxiliary cathode.

In the illustrations above given, the gas pressures have been assumed to be so low that ionization occurs preponderantly by a single impact of gas molecules and electrons. At gas pressure as high as several millimeters of mercury and upward (the particular pressure depending on the nature of the gas and other conditions) ionization of gas may occur by a different mechanism resulting in a drop of voltage at the cathode which is less than the ionization voltage. Due to the higher density of the gas, it appears that the impacts of gas molecules and electrons occur so frequently that a given gas molecule has not time to recover from a partially ionized condition before it receives a second electron impact fully ionizing it. The definition of an "arc" above quoted refers to the "excitation voltage". This is the voltage below ionization voltage at which ionization can occur at relatively high gas pressures. The gain in efficiency due to my invention at such higher gas pressures at which ionization of gas occurs below the ionization voltage will not be as great as in the case above considered but many of the advantages of my invention still may be obtained.

As will be shown in connection with Fig. 3, it is quite possible to use the same anode both for the main discharge and for the auxiliary discharge, the important thing being that the main discharge shall flow in a region where the plasma of the auxiliary discharge is capable of furnishing enough ions to effectively reduce the voltage drop of the main discharge.

In the device shown in Fig. 3 the glass envelope as before is designated by the numeral 2, the main cathode, however, being designated by 19. The cathode has been shown as a so-called equipotential cathode comprising a shell 20 of nickel, iron or other suitable metal coated with barium oxide, or other known electronically active material and an internal heater 21. This heater 21, which may conveniently consist of tungsten or molybdenum wire is connected at one end to the current supply wire 22 and at its other end to the shell 20 which in turn is connected to a second supply wire 23. The auxiliary cathode 24 is shown as a filament which may consist conveniently of tungsten, or other refractory metal, or may consist of platinum, nickel or a nickel alloy. It may be either uncoated or coated with an oxide of an alkaline earth or may contain, dispersed in the metal of the cathode, a material such as thorium or ceria for enhancing the elec-

tron emissivity of the cathode. Ordinarily the auxiliary cathode is left uncoated. It is connected to supports 25, 26, which are sealed into a stem 27 in the usual well understood manner. The anode 28 is shown as a cylinder surrounding the main cathode 19 and the auxiliary cathode 24, and being supported by a conductor 29 which is sealed into the glass stem 27. The anode is made of nickel, iron, molybdenum, or other suitable conductive material.

The envelope or bulb 2 contains a suitable gaseous filling. As already indicated above in connection with Figs. 1 and 2, the gas may be one of the rare gases, or may be a vapor of a metal such as mercury or sodium, or of appropriate mixtures. The gaseous filling ordinarily should be at a low pressure, for example between the pressure of one micron and two or three millimeters of mercury, the preferred pressure being about 50 to 500 microns of mercury. The terminals 22, 23 leading to the cathode heater are shown as being externally connected by the conductors 31, 32 to a secondary winding of a transformer 33. The conductors 25, 26 leading to the auxiliary cathode 24 are connected by the conductors 34, 35 to a suitable source of energy here represented by a battery 36 and in series with an adjustable resistance 37. The conductor 38, which is connected to the main cathode 19, and the conductor 39, which is connected to the anode 28 through its stem 29, supply energy from an external source (not shown). The conductor 38 contains load devices 40 here represented by crosses.

Energy for the auxiliary discharge, whereby ions are supplied to create a plasma for the main discharge, is supplied by a suitable source here represented by a battery 42. The latter is connected to the auxiliary cathode lead 35 by a conductor 43 and to the main anode by a conductor 44 which also contains a switch 45. The conductor 43 has in circuit the secondary winding of a transformer 46. By the latter an alternating voltage may be superimposed on the unidirectional voltage of the battery 42. By varying the alternating voltage of the source 46, the number of ions generated by the auxiliary source can be varied and hence the current from the main cathode 19 may be controlled at will.

Fig. 4 discloses a modification of cathode construction in which the auxiliary cathode 48 may be separated from the main cathode 19 by a constricted path. This is accomplished by mounting the auxiliary cathode 48 in a housing 49 having an aperture 50 through which the auxiliary discharge passes from the auxiliary cathode 48 to the main anode 51 which is shown as a cylinder. It is found that when a discharge passes through a small aperture from a region of larger cross-sectional area a voltage drop is established at the aperture. This voltage drop causes an increased production of ions by increasing the velocity of the electrons going through the aperture and producing ionization in the space between the main electrodes 19 and 51. By choosing the size of the constriction the voltage drop may be increased to the same order of magnitude as described above.

The auxiliary cathode 48 here has been shown as being of the unipotential type comprising a coated shell and an internal heater.

Fig. 5 shows another modification of a rectifier embodying my invention. It comprises a sealed envelope 2 containing a gaseous filling at low pressure as described in connection with Figs.

1, 2 and 3. The main cathode 50 here assumes the form of double-walled hollow cylinder 51 having a plurality of heaters as indicated at 52, 53. One end of these heaters is connected to the cathode cylinder 51, the opposite end of each being connected respectively to the conductors 54, 55 which are sealed into a stem 56. The auxiliary cathode 24 and its supports 25, 26 are similar to corresponding parts of Fig. 3. The anode is constituted by the two plates 57, 58 which preferably are conductively connected externally through their conductors 59, 60. The auxiliary cathode 24 passes through holes 61, 62 in the anode plates 57, 58 as indicated in the drawings. The construction shown in Fig. 5 has the advantage that the structure comprising the main electrodes substantially completely encloses the auxiliary or ion-forming electrode so that substantially all of the ions which are formed must eventually reach the main cathode 50. Thus, all of the positive ions formed are utilized to the best possible advantage by the main discharge. In some cases these anode elements may be electrically independent, as is usual in a full wave rectifier.

In the device above described the path of the main discharge is a short one, such devices being intended primarily for rectification, control or modification of the current passing through them rather than for the use of such current in the tube itself. In the device shown in Fig. 6 my invention is embodied in a luminescent lamp of the positive column type. The main envelope 2 in this case is greatly elongated, being shown broken in the drawing to bring it within the confines of the sheet of drawings. At the left-hand end of this elongated tube is a main cathode 63 which is shown in greater detail in Fig. 7. At the right-hand end of the tube is a main anode 4. The envelope is freed from deleterious gases and charged as above described with a suitable gaseous filling. In the case of a lamp, however, the gas pressure is higher than in a rectifier and preferably is of the order of one to several millimeters of mercury. Lamps of the hot cathode positive column type are well known in the lighting art. Such lamps are described in Hull Patent 1,929,143, issued October 3, 1933, (reissued on January 23, 1934, Reissue Patent 19,057).

The cathode 63 is shown in section in Fig. 7 and comprises a cylinder 64 surrounded by spaced heat-conserving cylinders or shields 65, 66 and the interior surface of the cylinder 64 is coated by thermionically active material, such as an alkaline earth oxide as described above. In good heat transfer relation to the cylinder 64 is a resistance heater 67 which is connected electrically at one end to the cylinder 64 as indicated and at its opposite end to a supply conductor 68. The auxiliary cathode is constituted by a filament 69 which is connected to conductors 70, 71, and is located between the heater 67 and the cathode cylinder 64. The auxiliary cathode 69 assists the heater 67 in maintaining the main cathode cylinder 64 at an electron-emitting temperature.

The electrical connections in Fig. 6 are similar to those already described. Energy is delivered from a source (not shown) by conductors 72, 73 which are respectively connected to the cathode and the anode. The conductor 73 contains in its circuit a resistance 74. The cathode heater 67 is supplied with heating energy by the transformer 75 through the conductors 68 and 76. The auxiliary or additional cathode 69 is heated by current supplied from a battery 77 through the con-

ductors 70, 71. The conductor 71 contains a resistance 78 and a switch 79. The energy for the ion-forming discharge is supplied from a battery 80 by the conductors 81 and 82 which are connected to the auxiliary cathode conductor 70 and the main cathode conductor 76.

During the operation of such a lamp a discharge of relatively small current value and energy consumption, say 10 milliamperes at 30 volts, emanates from the auxiliary cathode 69 and passes to the cathode shell 64. Between the main electrodes 63 and 4 is operated a luminosity-producing discharge, the voltage drop of which will vary with the length of the positive column. Such lamps may be readily constructed to be operated at ordinary distribution voltages of 110 to 115 volts, the lamps being started into operation by a known mechanism which is not here illustrated. Because of the positive ions generated independently at the cathode by the auxiliary discharge the drop of potential at the main cathode is lower, thereby increasing the efficiency of light production. A hollow cathode which is unprovided with an auxiliary source of positive ions tends to overheat by reason of the energy received from the discharge. This overheating may occur even when during operation the cathode heater is deenergized. This effect which is particularly marked in discharges in neon and helium, less so in argon and mercury, is much reduced in devices provided with an auxiliary source of ions in accordance with my invention because of the resulting lowering of the cathode drop. The ions and the radiations furnished by the discharge from the cathode 69 also facilitates the starting of the main positive column.

In the device shown in Fig. 8 the additional cathode 69 externally surrounds the main cathode 19, both cathodes being surrounded by the anode 28. Parts of the envelope 2 are shown broken away but it is to be understood to be similar to the envelope of Fig. 3 and to contain similarly a suitable gaseous filling. Owing to the proximity of the auxiliary cathode 69 to the main cathode 19 barium or active material from the latter is deposited on the electrode 69. It is not always necessary to heat the electrode 69 by energy supplied by the conductors 25, 26 from a separate source, as due to its location it is heated by radiation from the cathode 19 to an elevated temperature at which it emits electrons. Although normally the voltage in the ionizing circuit will exceed the disintegration voltages at which ions bombarding the cathode 69 remove active material, in the described construction the cathode 69 does not lose its activity as its active material is continually replenished by evaporation from the main cathode 19. By the omission of a separate heating source for the auxiliary cathode and utilization of radiated heat to maintain the auxiliary cathode at an emitting temperature a further saving of energy is effected. A particular device constructed as shown in Fig. 8 has been operated with a current of about five amperes at one volt drop in the main circuit, the auxiliary discharge operating with a current of about 30 milliamperes at about 30 volts, no external heating for the cathode 69 being required.

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

1. The method of reducing the energy consumption in an electrical thermionic discharge in a gas between electrodes one of which is separately heated which consists in maintaining in

effective spatial relation to said discharge an auxiliary discharge at a voltage materially exceeding the ionizing voltage of said gas.

2. The method of increasing the power efficiency of an electrical thermionic discharge in a gas between a solid thermionic cathode and an anode which consists in generating ions in effective relation to said electrodes by an independent discharge having a lower current value and a higher fall of voltage.

3. The method of controlling an arc discharge between a thermionic cathode and an anode which consists in separately heating said thermionic cathode to an electron emitting temperature and operating independently an auxiliary discharge in the presence of said arc discharge and varying said auxiliary discharge to produce corresponding variations in said arc discharge.

4. The method of controlling a discharge between a thermionic cathode and an anode in a gas at a pressure of at least about three microns of mercury which consists in separately heating said thermionic cathode to an electron emitting temperature and operating independently thereof an auxiliary discharge of lesser current value and higher voltage and varying said auxiliary discharge to produce corresponding variations in said main discharge.

5. An electrical discharge device comprising the combination of main electrodes including a solid thermionic cathode and a main anode, a gas at a pressure sufficiently high to reduce the cathode drop in said device to approximately the ionization voltage of said gas, and auxiliary discharge means including a thermionic cathode operable to produce positive ions in the space between said main electrodes to further reduce the cathode drop.

6. An electrical discharge device comprising an envelope, main electrodes including a solid thermionic cathode mounted therein, 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 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 whereby ionization produced by such auxiliary discharge will permit of operation below normal arc-sustaining voltage of a discharge of so much greater current value between said main electrodes that the net energy consumption in said device may be decreased by said auxiliary means.

7. An electric discharge device comprising an envelope, a gas content therein, main thermionic discharge electrodes including a solid thermionic cathode, auxiliary electric discharge electrodes arranged to produce an ionizing discharge in close proximity to said cathode for reducing the voltage drop of a discharge between said main electrodes having a current flow of a higher order of magnitude than said ion producing discharge.

8. An electrical discharge device comprising the combination of a sealed envelope, main electrodes therein including a solid thermionic cathode, 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, whereby

the gas between said main electrodes becomes conducting for a discharge of many times the current value of said ionizing discharge at a voltage below normal arc-sustaining voltage.

9. An electrical discharge device comprising a sealed envelope, main electrodes mounted therein including a solid thermionic cathode, a gaseous filling at a pressure high enough to permit an electric arc to be formed therein, and means including an additional thermionic cathode operable to produce an ionizing discharge at a voltage materially above the ionization voltage of said gas whereby sufficient ionization of said gaseous filling results to permit a discharge between said main electrodes at a potential below the ionization voltage of said gas and at a current at least several times the current value of said ionizing discharge.

10. An electrical discharge device comprising the combination of a sealed envelope, a gas therein at a pressure within the limits of several microns and several millimeters of mercury, main electrodes therein including a solid thermionic cathode and means for ionizing said gas independently of a discharge operating between said main electrodes and at a voltage materially above the discharge sustaining voltage for said gas.

11. An electrical discharge device comprising a sealed envelope, main electrodes provided therein including a thermionic cathode, a gaseous filling at a pressure at which an electric arc may be formed therein, and discharge means including an additional thermionic cathode for producing an ionizing discharge at a voltage materially above ionization voltage of said filling whereby an arc-like discharge may be operated between said main electrodes at a potential of about one volt.

12. An electrical discharge device comprising the combination of a sealed envelope, cooperating electrodes therein including a solid thermionic cathode, a gaseous filling at a pressure high enough to permit an arc-like discharge to be operated between said electrodes, and means for producing an electrical discharge between said electrodes at a voltage below the normal arc-sustaining voltage for said gas said means including a thermionic cathode capable of operating under a condition of saturated electron emission.

13. An electrical discharge device comprising a sealed envelope, main electrodes provided therein including a solid thermionic cathode, a gaseous filling at a pressure at which an electric arc may be formed therein, and auxiliary discharge electrodes including a thermionic cathode capable of operating in a condition of saturated electron emission, whereby an arc-like discharge may be operated between said main electrodes at a voltage substantially below the normal arc-sustaining voltage of said gaseous filling.

14. An electrical discharge device comprising the combination of a sealed envelope, a gas therein at a pressure within the limits of several microns and several millimeters, a main anode, a main thermionic cathode, an auxiliary cathode of materially smaller electron emissivity mounted adjacent said main cathode, a main discharge circuit connected between said main electrodes, a source of energy in said circuit, an auxiliary discharge circuit connected between said auxiliary cathode and said main cathode and a source of energy in said auxiliary circuit.

15. An electrical discharge device comprising the combination of an envelope, cooperating main electrodes including a solid thermionic electrode which contains a cavity, a gaseous filling at a

pressure high enough to give to a discharge between said electrodes the characteristics of an arc, an auxiliary cathode which is located in said cavity and a source of energy connected to operate an electric discharge between said auxiliary cathode and said main cathode, the characteristics of said auxiliary cathode and the operating source being correlated to produce a discharge in which the fall of voltage is materially above the arc-sustaining voltage of said gaseous filling.

16. An electrical discharge device comprising an envelope, a quantity of gas therein at a pressure of at least about one micron of mercury, main discharge supporting electrodes including a separately heated thermionic cathode operable to conduct through said gas a discharge of arc-like characteristics and additional discharge means operable to produce through said gas a discharge having a voltage materially above normal arc-sustaining voltage but of a materially lower current value than said first-named discharge, said additional means being located adjacent the discharge path between said main electrodes.

17. An electrical discharge device comprising the combination of an envelope, a gas therein, cooperating main electrodes including a thermionic cathode, an auxiliary cathode, a diaphragm containing a restricted aperture separating said auxiliary cathode from said main cathode, and means for drawing electrons from said auxiliary cathode through said aperture into ionizing relation with the gas surrounding said main cathode.

18. An electrical discharge device comprising the combination of an envelope, a gas therein, cooperating main electrodes including a thermionic cathode, an auxiliary cathode, an enclosure for said auxiliary cathode having a restricted aperture therein, and means for drawing electrons from said auxiliary cathode through said aperture into ionizing relation with the gas surrounding said main cathode.

CLIFTON G. FOUND.

CERTIFICATE OF CORRECTION.

Patent No. 2,034,571.

March 17, 1936.

CLIFTON G. FOUND.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, second column, line 14, for "expanded" read expended; page 3, second column, line 37, for "exercized" read exercised; page 6, first column, lines 28 and 29, claim 4, strike out the words "said auxiliary discharge to produce corresponding variations"; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 28th day of April, A. D. 1936.

(Seal)

Leslie Frazer
Acting Commissioner of Patents.