Nov. 8, 1927. 1,648,458

G. M. J. MACKAY ET AL

ELECTRON DISCHARGE DEVICE AND METHOD OF OPERATING THE SAME

Filed Aug. 27, 1926 2 Sheets-Sheet 1

Fig.1.

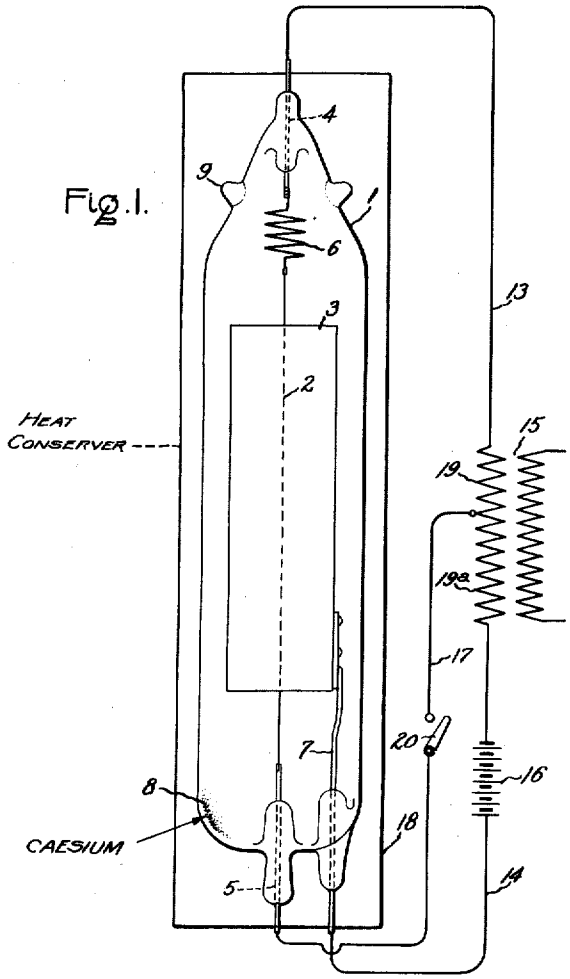


Fig.4.

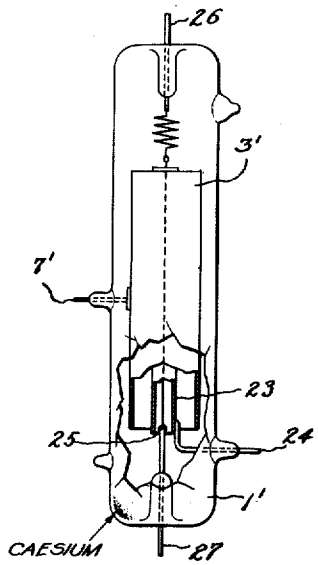


Fig.5.

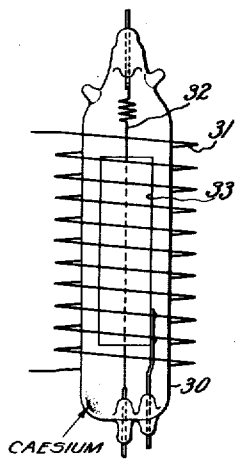


Fig.2.

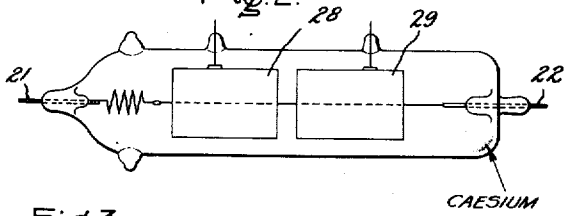
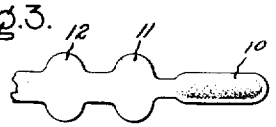


Fig.3.



Inventors:
George M.J.Mackay,
Ernest E.Charlton,
by Alexander S. Lane.
Their Attorney.

Nov. 8, 1927. 1,648,458

G. M. J. MACKAY ET AL.

ELECTRON DISCHARGE DEVICE AND METHOD OF OPERATING THE SAME

Filed Aug. 27, 1926 2 Sheets-Sheet 2

Fig.7.

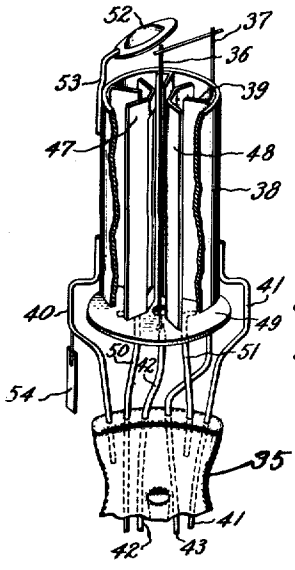


Fig.10.

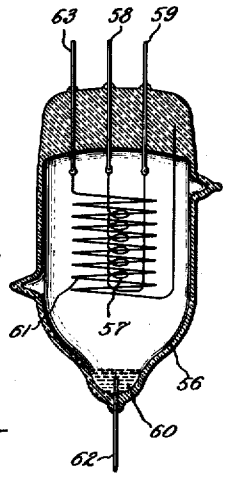


Fig.6.

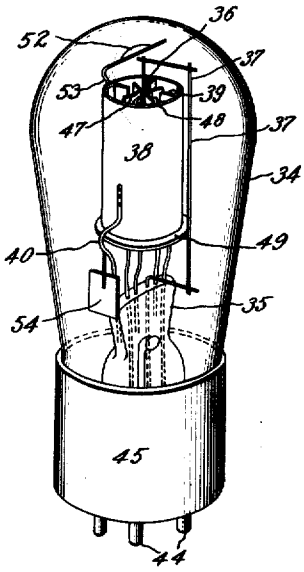


Fig.8.

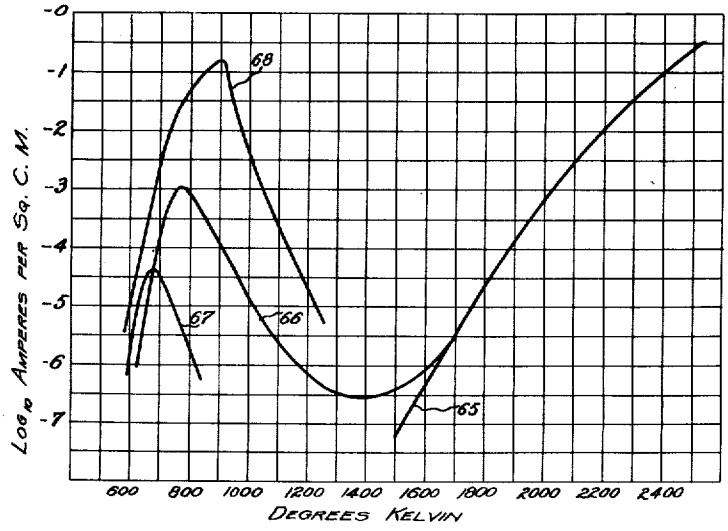
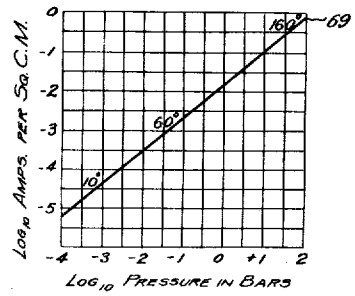


Fig.9.



Inventors:
George M.J. Mackay,
Ernest E. Charlton,
by Alexander S. Lewis.
Their Attorney.

Patented Nov. 8, 1927. 1,648,458

UNITED STATES PATENT OFFICE.

GEORGE M. J. MACKAY AND ERNEST E. CHARLTON, OF SCHENECTADY, NEW YORK, ASSIGNORS TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE DEVICE AND METHOD OF OPERATING THE SAME.

Application filed August 27, 1926. Serial No. 132,012.

Our present invention relates to electron discharge devices which are provided with one or more electrodes from which electrons are emitted by a thermionic effect, that is, by reason of the temperature of the emitting surface as distinguished from external forces, such as photo-electric action. As a consequence of our invention we have provided devices of the thermionic type which are operable at a materially higher efficiency than heretofore.

The electron emission from a thermionic cathode depends on several factors, the main controlling factors being the temperature at which the cathode is operated and the nature of the cathode material. The energy required to separate electrons from a thermionic cathode differs with the nature of the emitting surface. Each material has a characteristic "electron affinity." The energy required to obtain a given electron emission from a given material is dependent on the "work function" of the electron emitting material. This "work function" is a measure of the "electron affinity," that is, the attraction which the electron emitting surface possesses for the electrons.

As explained by various investigators, for example, by Langmuir in the "Transactions of the American Electrochemical Society," Vol. XXIX, 1916, page 125, there is an absorption of energy when electrons are emitted from heated metals, which is measurable as heat absorbed and which may be calculated in terms of a potential difference in volts, as a quantitative measure of work done in separating an electron from an emitting surface. It is this value which is called the "work function" of the electron-emitting material.

In the thoriated type of thermionic cathode the electron emissivity of the foundation material (ordinarily tungsten) is increased by forming on the surface of the cathode an adsorbed film of thorium. Because the thorium film has a lower work function than tungsten, a higher electron emission can be obtained at a given temperature from the thorium film than from tungsten. The present invention constitutes a further advance over the thoriated type of cathodes and results in a still higher efficiency of electron production.

In accordance with our invention the electron emissivity of thermionic cathodes is increased by a vapor of a substance which has a lower work function than the material constituting the cathode. We have discovered that vapors of low ionization potential, in particular the vapors of certain alkali metals, are capable of forming from the vapor phase upon the surface of a thermionic cathode an adsorbed film of low work function and, therefore, of high electron emissivity. In other words, in accordance with our invention, the effective work function of the cathode is substantially lowered to a value less than that characteristic of the foundation material of the cathode by presence of the vapor.

In the practice of our invention a useful electron emission may be obtained at such low temperatures that in some cases cathode materials,—such as nickel, for example,—may be used which even at their melting points would not be capable in the absence of these vapors of giving a useful emission of electrons. Molybdenum, tantalum and platinum may be used. We prefer, however, ordinarily to employ tungsten as the cathode foundation material, and preferably use cæsium as the material functioning from the vapor phase to increase the electron emissivity.

The electron affinity (or work function) of tungsten is 4.52 volts, whereas the ionization potential of cæsium vapor is about 3.9 volts. If a cæsium atom comes near a tungsten surface, the tungsten, having a higher electron affinity than the cæsium atom, robs the cæsium atom of an electron and leaves it in the form of a positive ion. These cæsium ions when close to the tungsten surface induce a negative charge on the tungsten surface and are, therefore, held to the tungsten surface by electrostatic force. It is this force which causes the formation of the adsorbed film of cæsium. A more detailed discussion of the subject may be found in the Physical Review, Vol. 24, page 510 (1924) and the Proceedings of the Royal Society A, Vol. 107, page 61, (1925).

As the rate of evaporation of such a film is of a lower order of magnitude than the rate of evaporation of an alkali metal in bulk, such a film will function at sufficiently high cathode temperatures to obtain an advantageous electron emission from the film.

Under some conditions rubidium can be used for practical purposes in place of cæsium for obtaining the benefits of our invention.

As a consequence of our invention electron discharge devices may be operated for various technical purposes at cathode temperatures so much lower than heretofore required for the same purposes that the useful life of the devices may be greatly increased; also by reason of the decreased heating energy required, the cost of electron production is reduced materially.

Adsorption of a film of alkali metal does not occur on thoriated tungsten to an effective extent, the work function of thorium being lower than that of the alkali metals. The benefits of alkali metal of enhancing the electron affinity of a cathode of the "thoriated type" can be obtained only under such conditions that such a cathode fails to form a complete thorium film on its surface.

The formation and maintenance of adsorbed films of otherwise vaporous materials may occur under two distinct sets of conditions, which, for the sake of simplicity, may be classified as "pressure conditions" and "vacuum conditions."

Pressure conditions.

The high electron emission characteristic of our invention may be obtained by heating a suitable thermionic cathode to a chosen electron emitting temperature in the presence of a suitable alkali metal vapor at a sufficiently high vapor pressure. The high electron emission under these relatively high vapor pressure conditions is due mainly to the large number of atoms of the alkali metal striking and condensing on the heated cathode.

Vacuum conditions.

The high electron emission characteristic of our invention can be obtained at vapor pressures of alkali metal too low to permit of appreciable ionization by collision, that is, at vapor pressures corresponding to bulb temperatures below about 65° C.

For example, an emission of electrons is obtainable from an ordinary tungsten filament operating at a temperature somewhat below 800° K. (527° C.) in the presence of cæsium vapor corresponding to a bulb temperature of about 60° C., which is substantially equal to the electron emission from such a filament operating in a vacuum at about 2,000° K. (1727° C.). The low pressure type of thermionic devices embodying our invention and methods of their manufacture are covered by a copending application of Kenneth Kingdon and Irving Langmuir, Serial No. 673,165, filed November 6, 1923.

For every vapor pressure of alkali vapor, the electron emission rises from a minimum cathode temperature to an optimum cathode temperature and then decreases with further rise of cathode temperature, the adsorbed film being driven off. As at lower vapor pressures the maximum emission occurs at lower cathode temperatures, the adsorbed film becomes less effective as the vapor pressure decreases. However, the emission is greater even at low vapor pressures than the characteristic emission from an uncoated cathode at the same temperature, as will be hereinafter more fully explained in connection with Fig. 8.

For commercial or other uses, however, requiring substantial current, the electron emission under conditions of low vapor pressure of the alkali metal here called vacuum conditions, may be and preferably is enhanced by forming upon the cathode a layer of a material having the property of tenaciously holding the alkali metal film upon the cathode. Electronegative substances, and in particular oxygen, increase the electron affinity of the cathode and hold the alkali metal upon the heated cathode more tenaciously.

Methods of obtaining the benefits of the high electron emission from alkali metals most advantageously under vacuum, or low pressure conditions by the aid of such material are, however, not of our invention, but are described and claimed in said copending application filed by Kingdon and Langmuir on November 6, 1923, Serial No. 673,165.

Our invention which is of a broader and more comprehensive nature, will be described in connection with the accompanying drawings which show in Figs. 1, 2, 4 and 5 different modifications of thermionic rectifying devices embodying our invention; Fig. 3 shows a reduction tube from which a charge of alkali metal may be introduced; Figs. 6, 7, and 10 illustrate three-electrode devices embodying our invention; and Figs. 8 and 9 are curves indicating the relation of electron emission to such other factors as cathode temperature and vapor pressure of activating material.

We will explain our invention by describing first the fabrication of a device in which the pressure of the vapor of the activating or film-forming material is relatively substantial, corresponding for example, to a bulb temperature of 150° C. and second the fabrication of a device in which the vapor of the activating material is low, as is the case in a device operated at or only slightly above room temperature, say at a bulb temperature of 25° to 50° C.

The device shown in Fig. 1 comprises a sealed envelope 1, consisting of glass, quartz or other suitable material, and containing a filamentary cathode 2 and a cylindrical anode 3. The cathode conveniently is sup-

ported by leading-in conductors 4, 5 which are sealed into the envelope at opposite ends, a light tungsten spring 6 being provided to maintain the filament taut. The cathode may consist of tungsten, molybdenum, nickel or other suitable refractory material. The anode 3 also may consist of tungsten, molybdenum, nickel, or other suitable conductive material, and has because of its size a sufficiently high heat dissipating capacity to operate at a temperature too low for electron emission. It is supported by a stiff tungsten wire 7 sealed into the envelope and serving also as a current-supply lead. The envelope 1 also contains a quantity of cæsium as indicated at 8, but otherwise preferably is evacuated.

We have referred in the following description and in the accompanying claims specifically to cæsium but wish it to be understood that rubidium may be similarly used and therefore, constitutes an equivalent for cæsium.

Cæsium preferably is introduced in the following manner:

The container 1 first is connected by fusion to a reduction tube, such as shown in Fig. 3, adapted to introduce cæsium preferably by reduction from a compound. The two containers are baked out at a temperature as high as the glass will permit, say about 300° C., while gases and vapors are exhausted. The chamber 10 then is opened and a mixture of a cæsium compound, such as the chloride, and a reducing agent, calcium, for example, is introduced. The chamber 10 then is again sealed, and the two containers are again heated with the vacuum pump (not shown) in operation until the charge and the containers are moisture-free. Thereafter sufficient heat is applied to the chamber 10 to cause the reduction of the cæsium compound and the distillation of metallic cæsium from chamber 10 successively into the chambers 11 and 12, and from thence into the main container.

Two separate operations for evacuating and introducing the alkali metal are not necessary. As described in connection with Figs. 6 and 7, the preparation of the devices may occur by a modified process whereby the alkali metal is released by reduction within the evacuated container. Sufficient cæsium should be introduced so that an excess of unvaporized cæsium will be present in the container 1 at the operating temperature. The cæsium reduction tube is finally sealed from the main receptacle by fusion in the usual manner, as indicated at 9.

The method of introducing cæsium is described in a copending application, Serial No. 97,717, filed March 26, 1926, by Ernest E. Charlton.

When the operating temperature is maintained above room temperature the container 1 is surrounded by a suitable heat conserving jacket or a heater indicated by dotted lines 18.

Fig. 1 shows the cathode and anode connected by conductors 14 and 17 to the secondary of a transformer 15 in series with a load device, represented for illustrative purposes by a storage battery 16. The cathode 2 has been shown as heated by connection across a section 19 of the secondary winding by the conductors 13 and 17. A given electron emission may be obtained under these conditions with an ordinary tungsten cathode operating at a substantially lower temperature than would be required to produce the same emission in the absence of cæsium.

For the rectification of alternating current of substantial value, for technical purposes, as for example, to charge a storage battery, we prefer to operate the device at a temperature high enough to raise the pressure of the cæsium vapor to a point at which the pressure of the cæsium vapor is relatively substantial. For example, at a bulb temperature of about 150° C. the cæsium vapor will have a pressure of about 0.02 mm. of mercury and will be ionized by the passage of current therethrough. In some cases it is preferable to first operate the bulb at a higher temperature, say, at 200° C. and upon aging, to gradually reduce the temperature to 150° C. The voltage impressed upon the tube by the transformer section 19^a depends on conditions, particularly on the size of the battery but should be high enough to produce an ionization discharge in the vapor.

The positive ions produced under these conditions bombard the cathode and thereby cause sufficient electron emission so that external heating means for the cathode is unnecessary. The switch 20 in the heating circuit, therefore, may be opened.

A system such as shown in Fig. 1, will select only one set of half waves of the alternating current. If desired, a plurality of anodes may be provided, as shown in Fig. 2 in order to secure complete rectification. The device shown in this figure has two cylindrical anodes 28 and 29 to be connected in the usual well-understood manner to a source of alternating current supply.

We have shown in Fig. 4 a device embodying our invention in which the cathode 23 is constituted by a small cylinder of molybdenum, tungsten or nickel connected to a sealed-in conductor 24, and heated to the operating temperature by a resistance heater 25, which is adapted to be heated by current supplied by the conductors 26, 27. The anode 3′ consists of a cylinder of tungsten, molybdenum, nickel or other suitable material. It is supported by the sealed-in

conductor 7'. The container 1' is suitably evacuated and provided with a quantity of cæsium or equivalent material.

A device for rectifying alternating current (to charge a storage battery for example), as shown in Fig. 1 may be provided with a tungsten cathode consisting of a filament about two inches long and four one thousandths of an inch in diameter. The anode may consist of a metal cylinder of nickel, or other suitable material. The cathode is operated at a temperature of about 1400 to 1700° K. (1127 to 1427° C.), which is well below white incandescence, the usual operating temperature of a tungsten cathode. The bulb is heated to a temperature of 150° C. by enclosing it in a heat insulating envelope and utilizing the heat dissipated by the filament or using an external heating unit. When the tube is connected in a circuit with an alternating current power supply as shown in Fig. 1 with sufficient alternating current voltage impressed to satisfy the constants of the circuit (for example, an alternating current voltage varying from 5 to 100 or more), a rectified current of one half to one ampere can be obtained with a direct current potential drop in the tube between cathode and anode of five volts or less.

If the bulb temperature is raised to 200° C. and the cathode is maintained at a temperature of 2000° K. a voltage drop in the tube of one to two volts and in some cases one tenth of one volt has been obtained. An electron emission from the cathode of the order of 3.5 amperes per sq. cm. of cathode surface can be obtained.

We have found that a magnetic field applied so as to increase the length of path of the electrons enables us to obtain a given current under the same conditions at a materially lower vapor pressure of cæsium or the like. In the devices shown in Fig. 5 the discharge tube 30 is surrounded by a magnetic winding 31 which generates a magnetic field substantially parallel to the cathode 32. The electrons passing to the anode 33 are deflected in spiral paths about the cathode. We have obtained in a device having the construction shown in Fig. 5, whereby a magnetic field was generated, a substantial current at lower bulb temperatures than could be obtained without a magnetic field.

We will now explain our invention in connection with devices operating under low pressure conditions.

We have shown for illustration in Figs. 6 and 7 a low pressure or vacuum device operating without substantial gas ionization and embodying the principles of our invention in a preferred form. This device in its more specific structural aspects, embodies also the invention of Kenneth H. Kingdon described and claimed in a copending application filed on March 6, 1926, Serial No. 92,946. Another form of low pressure device is described later in connection with Fig. 10.

As shown in both Figs. 6 and 7 the device comprises a sealed envelope 34, on the stem 35 of which are mounted the electrodes and other metal parts of the device. The cathode in this type of device is constituted by a straight or rectilinear filament 36 (preferably consisting of a closely wound, small diameter spiral) which is supported by an anchor 37. The lower end of the anchor is sealed in the stem 35, the anchor extending to the upper part of the bulb where it is connected to the upper end of the cathode filament 36. The cathode 36 preferably consists of tungsten and, as will be hereinafter described, this tungsten cathode preferably should be provided with an oxygenous or oxygen-treated surface so as to provide a foundation in which an adsorbed filament of cæsium, or other material of high electron emissivity, is formed more readily than upon an ordinary tungsten surface. The anode 38 which is cylindrical in form and preferably consists of nickel, is provided upon its interior with a number of vanes 39 extending radially toward the cathode filament. The cylinder is supported by stout anchor wires 40, 41 which are fusion sealed into the stem 35. Both the cathode leads 42, 43 and the anode lead 41 are conducted through the stem 35 in the usual manner and are lead to external contacts 44 of a standard base 45. A control electrode or grid which also may consist of nickel is constituted by the vanes 47, 48 which are affixed upon a plate 49 which conveniently is made circular in form and is positioned closely adjacent but out of contact with the lower end of the cylindrical anode 38. The plate 49 is supported upon the stem 35 by anchor wires 50, 51 and is provided with a hole through which the cathode lead passes. It serves to shield the stem 35 and the surrounding space from the cathode so as to reduce ionization and electron bombardment, thereby the formation of conducting deposits on the stem.

In the preparation of the described device the bulb is thoroughly evacuated after the electrodes have been mounted in position. The bulb when constituted of glass, preferably is heated during evacuation to a temperature of about 300° C. The filament preferably is heated to a temperature of about 2000° K. to free its surface from impurities and to remove occluded gas. During evacuation which may be carried out by a mercury pump, water vapor may be adsorbed by a quantity of phosphorus pentoxide contained within a branch of the exhaust system (not shown). The use of this material is accompanied by better results

than the use of liquid air in a trap in the evacuating system.

After the bulb has been evacuated, about 100 microns of oxygen are admitted to the container, the cathode filament then being heated to a temperature of about 2000° K, for about one minute in order to cause the formation of a thin layer of adsorbed oxygen upon the cathode. The uncombined oxygen then is pumped out and a quantity of activating material, preferably cæsium or rubidium, is admitted into the container. This material conveniently may be evolved by chemical reduction of a corresponding compound of the desired metal contained in a capsule 52 which is affixed by wire 53 to any convenient support within the device, such as the anode 38. For example, the capsule 52 may contain a mixture of cæsium chloride and finely-divided calcium and may be brought to a reaction temperature by the application, in the usual manner, of a high frequency magnetic field.

It is not essential that the device should be evacuated as completely as possible and then pure oxygen separately admitted in order to provide a thin layer of adsorbed oxygen upon the cathode. It is practicable to produce a satisfactory oxygenous surface condition upon the cathode by leaving in the bulb several hundred microns of air and then heating the cathode in this residual air in order to form the desired foundation surface for the film of cæsium or the like. It is also desirable to have present in the bulb a source of oxygen, such as a small piece of oxidized copper 54. During the operation of the tube a reaction occurs which forms cæsium oxide and the resulting mixture of cæsium and cæsium oxide eliminates deleterious gases such as hydrogen and carbon monoxide when evolved in minute quantities from the metal and glass parts of the device. The three-electrode device here described is of particular utility as amplifier of weak currents, such as occurring in radio circuits.

When a vacuum device prepared as above described is operated after the introduction of cæsium, or the like, with the cathode at a temperature of about 900° K. the bulb as a whole being at a temperature of about 30° C. (303° K.) an electron emission is obtained from the cathode of the order of 300 milliamperes per sq. c. m. This emission is of the same order of magnitude as the emission from a tungsten filament when operating in the vacuum in the absence of an activating substance at a temperature of about 2500° K.

It is not essential, however, in order to secure benefits of our invention at low vapor pressures to pre-treat the cathode with an electronegative gas, such as oxygen, as embodied in the devices of Figs. 6 and 7, which include also improvements covered by the other applications referred to herein. A low pressure device in which the cathode has not been treated is shown in Fig. 10, this device being adapted to operate at enhanced efficiency as an amplifier or radio detector.

This device comprises an evacuated receptacle 56, a spiral filamentary tungsten cathode 57 adapted to be heated by current supplied through the leading-in conductors 58, 59, and anode 60, consisting of cæsium and a grid electrode 61, consisting of a spiral conductor surrounding the cathode. Connections to the anode and grid may be made through the leading-in conductors 62 and 63. The container is first exhausted and then a small quantity of the desired metal, (preferably cæsium) is introduced into the receptacle before sealing. The cæsium or other alkali metal may be generated in a side chamber (not shown) containing a mixture of cæsium chloride and calcium or magnesium turnings or powder.

During operation the bulb 56 preferably should be maintained at a pressure of .02 micron, corresponding to a bulb temperature of about 50° to 60° C. By proper proportioning of the device, the heat supplied by the cathode may be made sufficient to heat the device as a whole to the desired operating temperature. The cathode should be operated at a tempearture of about 800° K. At temperatures materially above 1000° K. the electron emission decreases. The electron emission falls to a very low value at about 1100 to 1200° K. When rubidium is used instead of cæsium in the bulb a somewhat higher bulb temperature should be used.

The energy required to heat a cathode in a tube embodying our invention is very much less than the heating energy required for a device unprovided with activating vapor but otherwise similar. It is less than the energy required to obtain the same emission from a tungsten filament of the thoriated type.

The relations between the electron emission from a tungsten filament which has not been treated with oxygen in the presence of cæsium, the emission from an oxygen treated tungsten filament in the presence of cæsium are compared with electron emission from tungsten by curves in Fig. 8. It should be understood that when reference is made herein to a "tungsten filament" (without other qualification) it is intended to designate a filament giving the characteristic emission of unalloyed tungsten, as distinguished from film forming electrodes, such as thoriated filaments, or electrodes coated with metallic oxides. In Fig. 8 the ordinates represent logarithms of the current values and the abscissæ represent absolute temperatures (Kelvin scale). The current values are plotted as logarithms because the differences in the values of the currents from the treated and untreated filaments are of a different order of magnitude and could not otherwise be

plotted together on the same scale. The curve 65 shows the characteristic electron emission from a tungsten filament at temperatures ranging from about 1500 to 2500° K. The curve 66 shows the electron emission at different temperature from a tungsten filament in the presence of cæsium vapor in a bulb heated to 60° C. for filament temperatures within the limits of about 600 to 1600° K. It will be observed that the emission from such a filament rises to a maximum at a filament temperature of about 700 to 800° K. when the electron emission is about equal to the emission characteristic of tungsten alone at about 2000° K. The emission then decreases with a rise of temperature until it becomes the same as the electron emission from tungsten in a vacuum. At cathode temperature of about 1650° K., cæsium vapor at a pressure corresponding to 60° C. no longer has an appreciable effect upon the electron emission of tungsten.

At pressures of cæsium vapor corresponding to temperatures less than 60° C., the enhancement of electron emission from a tungsten filament due to the adsorption of cæsium is less, but is still observable. The curve 67 shows the electron emission from tungsten in the presence of cæsium vapor at a bulb temperature of about 20° C. The maximum emission is obtained at a lower cathode temperature, that is, between 600 to 700° K. At this cathode temperature the electron emission becomes nearly equal to the emission from tungsten at about 1850° K. in the absence of activating vapors, namely about fifty to sixty microamperes per sq. c. m. of emitting surface.

When the tungsten previously has been provided with an adsorbed film of oxygen, the effectiveness of the cæsium is increased enormously. The curve 68 shows the electron emission from an oxygen-treated tungsten filament which rises to a maximum at about 900° K. when it is several hundred milliamperes per square centimeter of cathode surface, which is comparable to the characteristic emission from tungsten at 2450° K. As already stated above, the improvement in adsorption and electron emission due to the electronegative foundation on the cathode is the invention of Langmuir and Kingdon, but is here set forth as a preferable embodiment of our broad invention.

Fig. 9 shows the relation of the electron emission of a heated tungsten surface to the pressure of the activating vapor (in this case cæsium vapor) the ordinates representing logarithms of maximum electron emission measured in amperes and the abscissæ representing logarithms of vapor pressure of cæsium measured in bars (1 bar equals 0.00075 m.m.). A range of bulb temperatures from about 10° to 160° C. is covered.

The curve 69 shows that the maximum emission rises continuously with increase of vapor pressure. At vapor pressures corresponding to temperatures above about 50 to 60° C. the electron emission without an electronegative foundation layer becomes substantial, being about one milliampere per square centimeter (in the case of cæsium) using an untreated tungsten filament. At vapor pressures corresponding to bulb-temperatures of about 150 to 160° C. the electron emission amounts to several hundred milliamperes per square centimeter, a value which is of the same order of magnitude as the emission at 20° C. bulb temperature in the case of an oxygenated tungsten cathode. This fact will explain why in a device operating at relatively high vapor pressure, such as the rectifier shown in Fig. 1, it is unnecessary to provide the cathode with an electronegative film in order to secure a high electron emission.

At the high vapor pressure corresponding to a temperature of 150° C. a large amount of positive ionization occurs in the discharge space. When a device such as shown in Fig. 1 is operated with an impressed voltage at least as high as about five volts the discharge assumes an arc-like character, and is accompanied by luminosity. At these high vapor pressures the number of atoms of cæsium, or other activating vapor, striking the cathode is greater than under vacuum conditions and hence at a sufficiently high vapor pressure, the characteristic emissivity of an adsorbed film of the material constituting the vapor appears even in the absence of an electronegative film.

Although the distinction between the types of thermionic devices embodying our invention has been pointed out in detail above, we desire to point out as a recapitulation that these devices may be grouped as:

(*a*) Devices operating at bulb temperatures high enough to obtain ionization in the vapor may be grouped together as "pressure devices" containing high efficiency thermionic film-coated cathodes unprovided with an electronegative foundation layer.

(*b*) Devices operating at bulb temperatures too low to obtain appreciable ionization by collision in the vapor may be grouped as "vacuum devices". This group includes devices in which film formation and hence electron emission is enhanced by treatment of the cathode with oxygen or other electronegative material, but of course, it is not restricted to such devices.

Devices of the first group form the subject matter of our prior application, Serial No. 604,077, filed November 29, 1922, of which the present application is in part a continuation; devices of the second group are de-

scribed and claimed in Langmuir and Kingdon application Serial No. 673,165 of November 6, 1923.

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

1. An electron discharge device containing electrodes including a thermionic cathode, and means for maintaining in the space surrounding said cathode the vapor of a material having a lower electron affinity than said thermionic cathode, said vapor having during normal operation of the device a pressure capable at the operating temperature of the cathode of causing said cathode to have a substantially higher electron emission than said cathode would have in the absence of said vapor.

2. An electron discharge device comprising a thermionic cathode, an anode, an enclosing evacuated container, a charge therein of alkali metal having a lower electron affinity than said thermionic cathode, and means for maintaining said container during operation at a temperature at which pressure of said metal is sufficient to cause an electron emission to be obtained from said cathode for a range of cathode temperatures which is of a higher order of magnitude than the emission obtainable for said range of cathode temperatures in the absence of said vapor.

3. An electron discharge device comprising a thermionic cathode, an anode, and means for surrounding said cathode with vapor of material having a lower electron affinity than said cathode and having the property during normal operation of the device of coacting with said cathode to cause a substantial electron emission at a cathode temperature at which the electron emission in the absence of said vapor is negligibly low.

4. An electron discharge device comprising a container, electrodes therein which include a thermionic cathode, means for heating said cathode, a material in said container the vapor of which is capable of imparting to said cathode a substantial electron emissivity at a cathode temperature at which the characteristic electron emission of said cathode is negligible, and means for maintaining said container at a temperature above about 65° C.

5. An electron discharge device comprising a thermionic cathode, an anode, an enclosing evacuated container and a charge of cæsium in said container, the surface material of said cathode having a work function so related to the ionizing potential of cæsium vapor that said cathode has a materially higher electron emission in the presence of said vapor than in its absence over a range of cathode temperatures below about 2000° K.

6. An electron discharge device comprising a sealed evacuated receptacle, electrodes therein including a thermionic cathode, means for heating the cathode, a charge of alkali metal in said receptacle having a lower electron affinity than said cathode, and heat-conserving means for maintaining the vapor pressure of said alkali metal sufficiently high to cause a given electron emission to be obtained from said cathode at a materially lower cathode temperature than would be required for the same emission in the absence of said alkali metal.

7. An electron discharge device comprising a cathode adapted to operate at an elevated temperature, means for heating said cathode, an anode, an enclosing sealed receptacle, and means for providing cæsium vapor to the space within said receptacle at a pressure sufficiently high to raise the electron emissivity of said cathode to value materially higher than the characteristic emissivity of said cathode in the absence of said vapor.

8. An electrical discharge device comprising an evacuated container, a thermionic cathode therein, means for heating said cathode, an anode, and means for delivering to the space between said electrodes cæsium vapor at a pressure sufficiently high both to enable appreciable ionization by collision to occur and to materially increase the electron emissivity of the cathode at operating temperatures.

9. An electron discharge device comprising an evacuated envelope, an anode constituted of a solid conductor, a tungsten cathode, means for heating said cathode by passage of current, a charge of cæsium in said envelope and means for maintaining the temperature of said envelope at about 150° C. during operation.

10. An electric rectifier comprising an evacuated container, a thermionic cathode, means for heating said cathode, an anode operable below electron-emitting temperatures, a filling of cæsium, and means for maintaining said container at an elevated temperature at which a discharge of substantial current value may be maintained therein at a cathode temperature which the characteristic emission from said cathode is inappreciable.

11. An electrical discharge device comprising cooperating electrodes, means for enclosing the space between said electrodes, and a quantity of cæsium, said device being constructed to operate at temperatures at which cæsium has vapor pressure of about 0.02 mm. of mercury.

12. The method of operating an electron discharge device containing a cathode which is operable at an elevated temperature which consists in bringing cæsium vapor into contact with said cathode and operating said cathode at a temperature at which the elec-

tron emission from said cathode is increased by said cæsium vapor.

13. The method of operating an electron discharge device comprising a cathode adapted to be heated, and an anode, which consists in supplying cæsium vapor to the space between cathode and anode at a pressure high enough to produce positive ionization by electron impact, and heating the cathode below white incandescence to a temperature at which a substantial electron emission occurs due to said cæsium vapor, and producing an electron discharge while the cathode is at said temperature.

14. The method of operating an electron discharge device comprising a cathode adapted to be heated and an anode, which consists in heating the cathode to a temperature of about 1400 to 1700° K., and increasing the electron emission from the cathode by supplying cæsium vapor at a pressure high enough to permit of sufficient ionization by collision to materially lower the space charge between the electrodes.

15. The method of operating an electrical discharge device containing a cathode operable at an elevated temperature, an anode and a quantity of cæsium which consists in heating said device to a temperature of about 150° C. during operation, and applying to said electrodes a voltage sufficient to maintain a discharge which will heat the cathode to an electron emitting temperature, below white incandescence.

16. The method of operating a thermionic discharge device containing a charge of alkali metal, the vapor of which has a lower ionization potential than the work function of the cathode of said device, which consists in maintaining said device at a temperature above about 65° C., operating said cathode at a temperature below about 1700° K. and impressing a voltage between said electrodes capable of producing an ionization discharge in the vapor of said alkali metal.

17. An electric discharge device comprising a cathode and an anode, a sealed container therefor, and a vapor in said container which has a lower ionization potential than the work function of said cathode and which is capable under normal operation of the device of materially decreasing the effective work function of said cathode.

In witness whereof, GEORGE M. J. MACKAY has hereunto set his hand this 25th day of August, 1926, and ERNEST E. CHARLTON has hereunto set his hand this 13th day of August, 1926.

GEORGE M. J. MACKAY.
ERNEST E. CHARLTON.

tron emission from said cathode is increased by said cæsium vapor.

13. The method of operating an electron discharge device comprising a cathode adapted to be heated, and an anode, which consists in supplying cæsium vapor to the space between cathode and anode at a pressure high enough to produce positive ionization by electron impact, and heating the cathode below white incandescence to a temperature at which a substantial electron emission occurs due to said cæsium vapor, and producing an electron discharge while the cathode is at said temperature.

14. The method of operating an electron discharge device comprising a cathode adapted to be heated and an anode, which consists in heating the cathode to a temperature of about 1400 to 1700° K., and increasing the electron emission from the cathode by supplying cæsium vapor at a pressure high enough to permit of sufficient ionization by collision to materially lower the space charge between the electrodes.

15. The method of operating an electrical discharge device containing a cathode operable at an elevated temperature, an anode and a quantity of cæsium which consists in heating said device to a temperature of about 150° C. during operation, and applying to said electrodes a voltage sufficient to maintain a discharge which will heat the cathode to an electron emitting temperature, below white incandescence.

16. The method of operating a thermionic discharge device containing a charge of alkali metal, the vapor of which has a lower ionization potential than the work function of the cathode of said device, which consists in maintaining said device at a temperature above about 65° C., operating said cathode at a temperature below about 1700° K. and impressing a voltage between said electrodes capable of producing an ionization discharge in the vapor of said alkali metal.

17. An electric discharge device comprising a cathode and an anode, a sealed container therefor, and a vapor in said container which has a lower ionization potential than the work function of said cathode and which is capable under normal operation of the device of materially decreasing the effective work function of said cathode.

In witness whereof, GEORGE M. J. MACKAY has hereunto set his hand this 25th day of August, 1926, and ERNEST E. CHARLTON has hereunto set his hand this 13th day of August, 1926.

GEORGE M. J. MACKAY.
ERNEST E. CHARLTON.

CERTIFICATE OF CORRECTION.

Patent No. 1,648,458. Granted November 8, 1927, to

GEORGE M. J. MACKAY, ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 7, line 25, claim 2, before the word "pressure" insert the words "the vapor"; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 27th day of December, A. D. 1927.

Seal.

M. J. Moore,
Acting Commissioner of Patents.

CERTIFICATE OF CORRECTION.

Patent No. 1,648,458. Granted November 8, 1927, to

GEORGE M. J. MACKAY, ET AL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 7, line 25, claim 2, before the word "pressure" insert the words "the vapor"; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 27th day of December, A. D. 1927.

M. J. Moore,
Acting Commissioner of Patents.

Seal.