Dec. 22, 1953 J. L. BOYER ET AL 2,663,824

VAPOR-ELECTRIC DEVICE

Filed Feb. 15, 1950 4 Sheets-Sheet 1

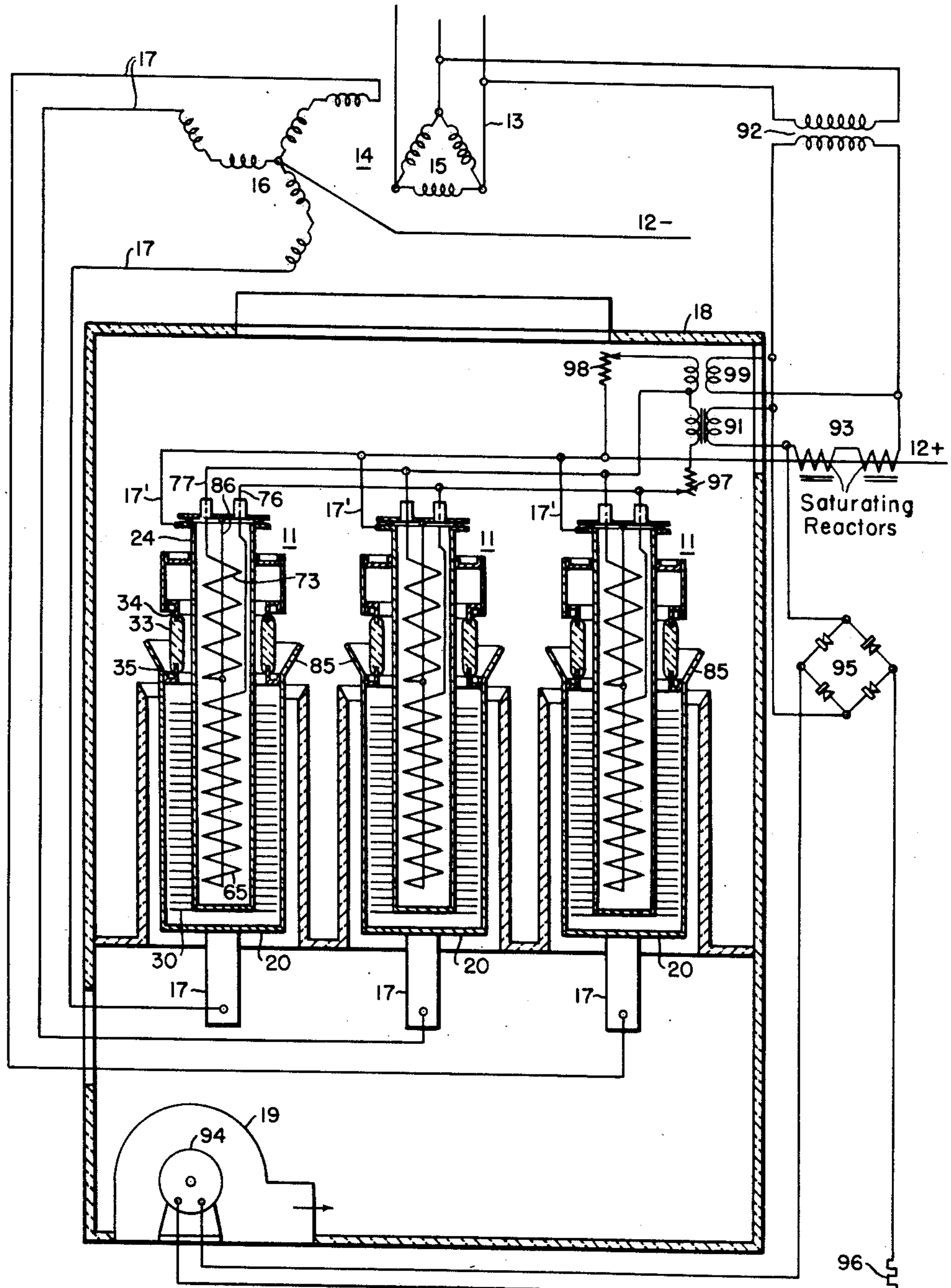

Fig.1.

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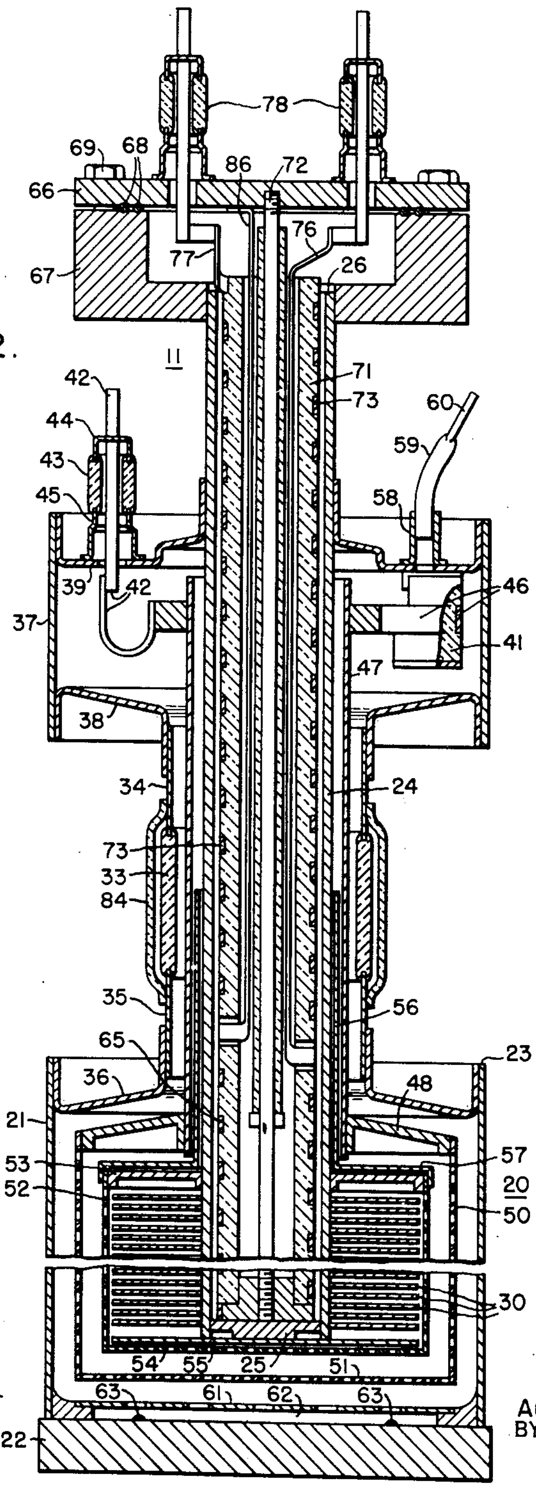
Fig. 2.



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VAPOR-ELECTRIC DEVICE

Filed Feb. 15, 1950 4 Sheets-Sheet 3

Fig. 3.

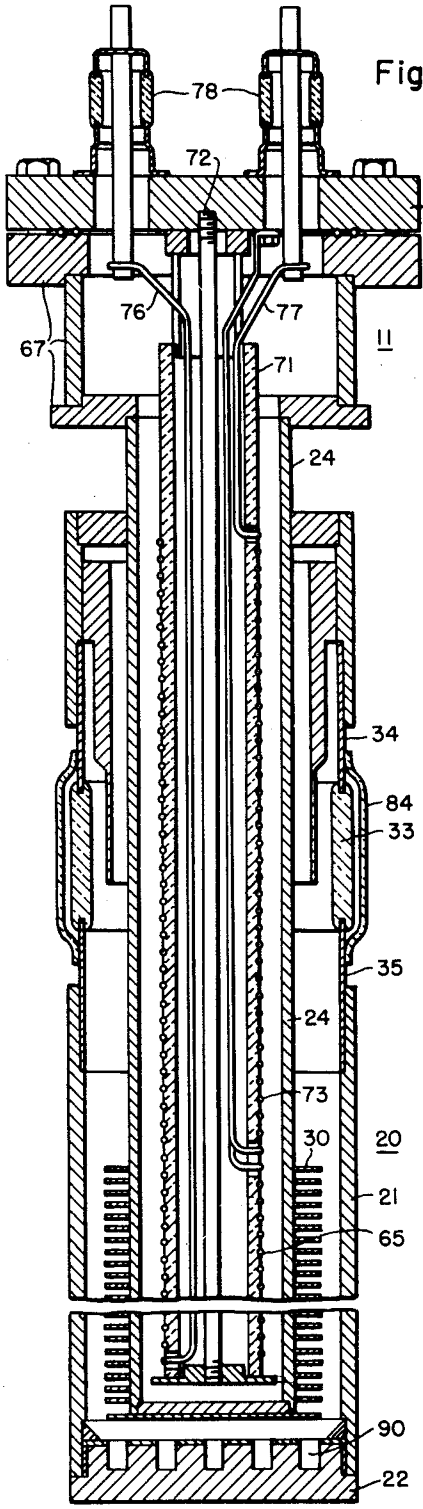
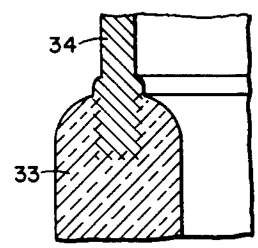


Fig. 4.



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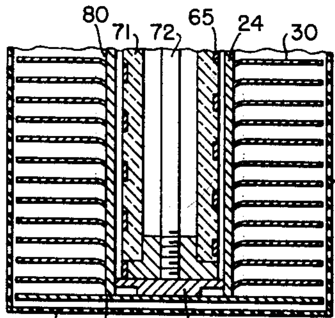

Fig. 5.

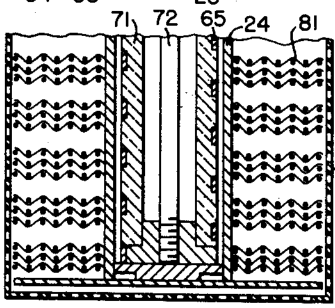

Fig. 6.

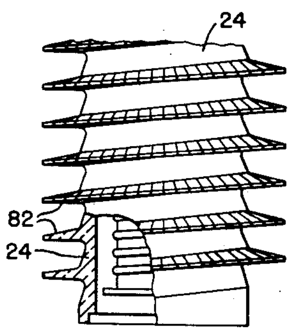

Fig. 7.

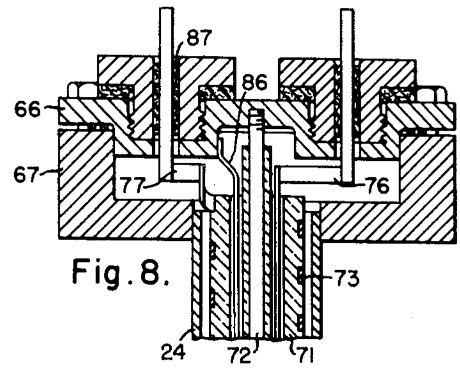

Fig. 8.

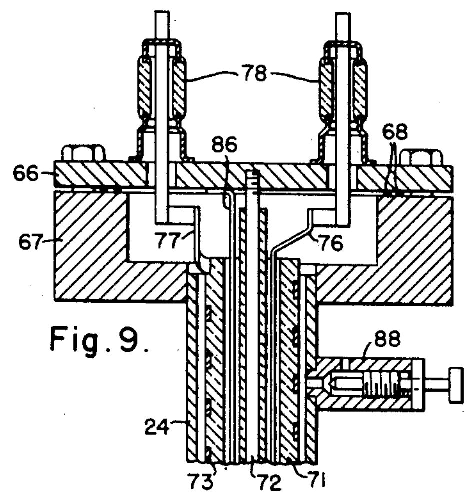

Fig. 9.

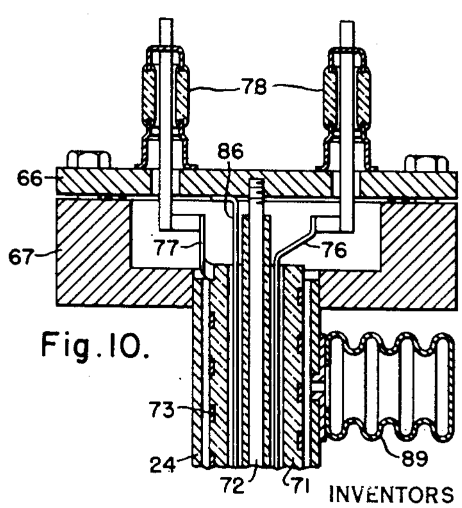

Fig. 10.

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2,663,824

UNITED STATES PATENT OFFICE

2,663,824

VAPOR-ELECTRIC DEVICE

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Application February 15, 1950, Serial No. 144,354

103 Claims. (Cl. 315—106)

Our invention relates to vapor-electric devices or tubes, and particularly to low-arc-drop hot-cathode arc-discharge devices using a vaporizable discharge-metal selected from the group consisting of potassium, rubidium and cesium. These three metals form a more or less distinctive class by themselves, which may be described as the alkali metals having four, five and six shells in the atomic structure, or the stable alkali metals having more than three shells. The entire group of alkali metals consists of six elements, of which the first two and the last are readily distinguishable from the other three, with which our invention is particularly concerned.

The two lightest alkali metals, lithium (Li) and sodium (Na) are separated, in some periodic tables, from the heavier light metals of the alkali-metal group (IA), as being distinctive because of their electron-grouping. The physical and chemical characteristics of these two lightest alkali-metals are also distinctively different from the group comprising potassium, rubidium and cesium. Sodium has a minimum breakdown voltage which comes at too low a pressure-distance product *pd* for our purposes, as will be understood from explanations given later on; and it is also too active, chemically. Lithium has a vapor-pressure which is much too low for our purposes, as this low vapor-pressure requires too high a temperature to obtain a practically usable vapor-pressure which is high enough to give a sufficiently high current-density to be practical for our purposes.

The sixth or heaviest alkali metal, No. 87 in the periodic table, was formerly called virginium, but has now been proved to be an element which is called francium (Fa), an unstable atomic-pile product which is very radio-active, and which has an extremely short half-life of only a few minutes, so that it is unsuitable for our purposes.

It is an object of our invention to produce, for the first time, a commercially practicable alkali-metal power-type rectifier, by which we mean a rectifier capable of handling currents of the order of 100 amperes or more (although it may be applicable also to tubes of lower current-ratings), and delivering such currents to direct-current lines having voltages ranging from 100 volts to 1000 volts, or more.

One of the first requisites of a commercial power-type rectifier is that it shall have a reasonably long life, of which 2000 hours would be the absolute minimum which could be considered commercially, and something like 10,000 to 20,000 hours is more often the minimum life required in commercial applications, while a life of more than 5 years is much to be preferred.

Heretofore, the primary life-limiting factor has been the seal, no commercially practicable seal having been known, which would last for anything approaching 2000 hours in the vapor of potassium, rubidium or cesium at the necessary operating-temperature of the seal. The seal-temperature is necessarily higher than the liquid temperature of the condensed metal in the tube, in order to prevent the condensation of the discharge-vapor across the seal, thus short-circuiting the insulator of the seal.

A second requirement of a commercially usable power-type alkali-metal rectifier is that it shall combine a high current-density per unit of volume of the space occupied by the cathode, with a high breakdown-voltage, or the ability to withstand a reasonably large back-voltage during the non-conducting periods of the rectifier.

In producing the first power-type alkali-metal rectifier which is really acceptable for ordinary commercial use, we have availed ourselves of many different design-features, which are combined together, in cooperation with each other, so as to produce our general objectives. Some of these design-features have been known in other arts, or in other devices, not in a commercially practicable power-type alkali-metal rectifier, while other design-features which we use are of our own devising.

Thus, it has long been known that the alkali metals have phenomenally low ionization potentials, of the order of 4 or 5 volts, which would cause an arc-discharge device to have a much higher efficiency than a normal rectifier-tube using mercury-vapor, for example, in which the ionization potential is of the order of 10.4 volts.

The broad principle of a cesium or other alkali-metal arc-discharge device, having a hot cathode of a metal having a work function higher than the ionization potential of the alkali metal, has long been known, as described in a paper by Irving Langmuir and K. H. Kingdom in Proceedings of the Royal Society, Series A, volume 107, 1925, beginning on page 61, and as also described in a book by L. R. Koller, on Physics of Electron Tubes, 2d ed., 1937, pages 18–21 and 53–64. The theory is that when the alkali-metal atoms which comprise the vapor come into contact with the heated high-work-function cathode-metal, the latter readily withdraws an electron from the alkali-metal atom, because of the high work function of the cathode-metal. This process leaves a probably monatomic layer of positively charged alkali-metal atoms on the cathode. This positively charged monatomic layer is very close to the surface of the cathode-metal, and its electrostatic field assists very materially in allowing the thermally excited electrons to escape from the heated cathode-metal, thus producing thermionic emitter of electrons, and thus a high-efficiency cathode.

The ionization potential of a single gaseous atom or molecule is the voltage-drop through which an electron must be freely accelerated to acquire enough energy to be able to ionize the atom or molecule on collison, by removal of one of its electrons.

The work function of a metal is the minimum energy which must be imparted to an electron inside of the metal, so that the electron can escape or be emitted from the surface of the metal at absolute zero temperature.

The General Electric Company, in its United States patent to Hull, No. 2,489,891, granted November 29, 1949, showed an arc-discharge diode using a nickel cathode, with an arc-carrying vapor of cesium or rubidium, without many of our refinements, and using an insulator-to-metal seal in which the insulator was a ceramic, preferably one of the alumina ceramics or one of the magnesium-silicate ceramics, preferably joined to the metal by an allegedly new bonding material, referred to only as "a manganese-molybdenum method," said to be described in an inaccessible patent-application. This patent condemned previously known seals as being unsuitable for cesium-arc rectifiers, in the following language:

"In prior art devices employing cesium, commercial life has not been obtained because of the very active nature of cesium and the distintegrating effect it has on insulators, such as glasses ordinarily used in tube construction."

The Gustin patent, 1,576,436, granted March 9, 1926, shows a glass-to-metal seal in which a leading-in wire is provided with a thin coating of chromium, which is preferably deposited by electrolysis, although the patentee states that the coating could be deposited by other methods such as sherardizing or calorizing. The patentee states that the chromium "readily wets with glass," although he does not describe the oxidation of the chromium surface, before bonding it to glass, other than in a reference to an oxidizing flame for fusing the glass. The patentee says nothing about diffusing the chormium into the base-metal of the wire, or otherwise securing a firm bond between the two metals; and he says nothing about use with a device containing an alkali metal.

The use of one of our preferred protective seal-metals, zirconium, has been known before, in various other seals, different from our seals, and not in the presence of an alkali-metal vapor. Thus, F. S. McCullough, in his United States Patent 1,615,023, granted January 18, 1927, mentioned a paste of zirconium oxide as a ceramic material for covering the joint between a metal and a porcelain to bond the two together; while the General Electric Company, in its British Patent 498,102, accepted January 3, 1939, mentioned a thick coating of zirconia which was placed around only a portion of a lead-in wire within a pinched-glass seal, the zirconia being for heat-insulating purposes and being described as being unreliable as a seal, so that the cooler

part of the wire was left uncovered, to make a good seal.

The Torrisi Patent 1,368,584, granted February 15, 1921, shows an audion having a removable heater inside of a cylindrical cathode of surface-oxidized platinum-coated nickel, which is closed at one end and open to the air at the other end, no alkali-metal vapor being used.

It is perhaps a first object of our invention, therefore, to discover and provide a seal which will have a length of life which will be at all acceptable in a commercial power-type rectifier using a vapor of potassium, rubidium or cesium. We prefer to use an insulator-to-metal seal in which the metal is either a solid homogenous metal, or coated with a properly adherent coating of a protective metal, the surface-metal having a lightly oxidized surface, and being selected from the group consisting of beryllium, zirconium and titanium, and probably also chromium, or other protective metal having a sufficiently high melting point to enable the formation of the seal by fusion, and having an oxidized surface which has a sufficiently high negative free-energy, as compared to the negative free-energy of the oxide of the vaporizable alkali metal, to resist reduction by said vaporizable metal during a work-life of considerably over 2000 working-hours at the operating-temperature of the seal. We prefer to use an ordinary glass-to-metal seal, thus protected; but our protective means are also applicable to ceramic-to-metal seals. Some of our protected seals give promise of an extremely long life, or a practically unlimited life.

It is a further object of our invention to use an emissivity-increasing expedient which has been found useful in connection with some other coated thermionic emitters, namely the use of an adsorbed surface-layer of oxygen, which is formed between the base-metal (by which we mean the surface-metal) of the cathode and the supposedly monatomic ionized layer of the alkali-metal which is being used. We have found that this expedient very greatly increases the electron-emission, thus producing a higher current-density at a given voltage-drop, or a lower arc-voltage for a predetermined current-density of the electron-emission. We believe that this expedient should be used with at least some, and probably all, of the high-work function cathode-metals which we prefer, as will be subsequently further described.

As most commercial applications of rectifiers for electric power-circuits require some sort of grid-control, it is an important object of our invention to provide a grid-controlled hot-cathode vapor-electric arc-discharge device using a discharge-metal selected from the group consisting of potassium, rubidium and cesium. The spacings between the various electrodes should preferably be small, in order to keep down the value of the arc-drop as much as possible, and keep the breakdown potential high. The grid is thus close to the heated cathode, which operates at an electron-emitting temperature, and the grid is also heated by the play of the arc which passes through and around it. The grid thus necessarily operates at a fairly high temperature, and it therefore involves a considerable problem to prevent the grid from emitting electrons, at its operating-temperature, in sufficient numbers to itself become a cathode, thus causing a backfire or failure of the tube.

It is therefore an object of our invention to provide several grid-improving means, which may be used either separately or all together, for reducing the electron-emissivity of the necessarily hot-operating grid. For one thing, in order to reduce the emissivity of the grid, it should be chosen just the opposite from the choice of the base-metal of the cathode, namely so that the surface-metal of the grid is a metal which has a work-function which is lower than the ionization potential of the varporizable discharge-metal which is being used. In this way, we prevent the grid from attracting, to its surface, a monatomic adhering layer of charged vaporizable-metal particles. Another expedient is to reduce the operating-temperature of the grid, so as to thereby reduce its efficiency of emission. The operating-temperature of the grid can be appreciably reduced by two practical means, namely the interposition of perforated heat-shields between the hot cathode and the grid, and the use of a special construction of both the grid and (if used) the heat-shields, by having a relatively poor heat-absorbent surface on the side toward the cathode, which is heated, and a relatively good heat-radiating surface on the side toward the anode, which is cooled.

Further objects of our invention relate to the provision of various constructional and operative details, which may be used either singly or in combination with other features of our invention, to provide, or contribute to, a commercially acceptable vapor-electric device of much higher efficiency, smaller size and weight for a given rating, much easier cooling, and other advantages which will be pointed out hereinafter.

With the foregoing and other objects in view, our invention consists in the structures, assemblies, combinations, systems, parts, and methods of design and operation, hereinafter described and claimed, and illustrated in the accompanying drawing, wherein:

Figure 1 is a somewhat diagrammatic sectional elevation of a three-phase assembly of vapor-electric devices embodying our invention;

Fig. 2 is a sectional elevation of a particular element or single-phase electronic tube embodying our invention, showing the same as a triode or grid-controlled tube;

Fig. 3 is a similar view of a modification showing a simplified discharge-device in the form of a diode;

Fig. 4 is a detail section showing our improved glass-metal seal;

Figs. 5 and 6 are sectional elevations, and Fig. 7 is an elevation, with parts broken away, showing various methods of constructing a high-efficiency cathode; and

Figs. 8, 9 and 10 are detail sectional views showing alternative structures for minimizing atmospheric leakage through the cathode-structure.

In the illustrated form of embodiment of our invention, as diagrammatically indicated in Fig. 1, three of our vapor-electric devices or tubes **11** are interposed between a direct-current power-circuit or load-device **12**+ and **12**—, and a three-phase input-circuit **13**, through a power-transformer **14** which is shown as having a delta-connected primary winding **15** and a zigzag-connected secondary winding **16**. The star point of the zigzag secondary winding **16** constitutes the negative output terminal **12**—, while the three phase-terminals of the zigzag-connected secondary winding **16** are connected to the respective anode-terminals **17** of the three tubes **11**. The cathode-terminals **17'** of the three tubes are all connected to the positive output-terminal **12**+. In Fig. 1, the tubes are represented, schematically, as diodes, because the external grid-circuits may be conventional, and form no essential part of our present invention in some of its broadest aspects. However, we wish it to be understood that, in most actual commercial forms of embodiment of our invention, the tubes **11** will be triodes, having one or more grids or discharge-controlling means such as magnetic or electrostatic control-means.

The three rectifier-tubes **11** are shown in Fig. 1 as being mounted or enclosed within a heat-insulating cabinet **18**, which is provided with a blower **19** for circulating a cooling fluid, preferably air, over the outsides, particularly the anodes **20**, of the tubes.

Before discussing the various materials and other special features of our invention, we will first describe the bare structure of one of the preferred forms of embodiment of our rectifier-tube **11**, as shown in Fig. 2, from which it can be seen that the outer tank or container of our tube consists essentially of the anode **20**. This anode **20** is in the form of a cylindrical anode-member **21**, which is closed at its bottom end **22**, and open at its top **23**. The rectifier-tube **11** is provide with a smaller-diameter cylindrical cathode-member **24**, which is closed at its bottom end **25**, and open at its top **26**. The closed bottom **25** of the cathode is spaced slightly above the closed bottom **22** of the anode. The cylindrical cathode-member **24** is considerably taller, or longer axially, than the cylindrical anode-member **24**, so that a portion of the cylindrical cathode-member **24** extends up beyond the open top **23** of the cylindrical anode-member **21**.

It is necessary, in any practical size of commercial arc-discharge rectifier-device of the hot-cathode type to which our present invention relates, to use some sort of finned construction for the cathode, so that the cathode will have a much larger electron-emitting surface-area than could be provided by any single cylinder or any single flat piece of metal. This finned construction is necessary in order that the cathode may emit enough electrons to carry a practically usable power-current of hundreds of amperes, which is often, but not necessarily, at least a hundred amperes, within a volume which is small enough to make a practically usuable device. We therefore provide fins **30** on the lower part of the cylindrical cathode-member **24**, that is, on the cathode-proper, or the part which lies inside of the cylindrical anode-member **21**.

Preferably, as shown in Fig. 2, and more in detail in Fig. 5, the fins **30** consist of a large number of spaced discs or washers of thin metal, which are pressed onto the bottom end of the cylindrical cathode-member **24**, or otherwise suitably secured thereto. We have found that fins **30** which encircle the cylindrical cathode-member **24** can be much more securely fastened to the outer surface of said cylindrical cathode-member **24** than axially extending fins, for example, which are apt to fall off, particularly if the cathode-member is made of a metal with which it is difficult to make firm joints.

An essential part of any tube embodying our invention is a suitable form of insulator-to-metal seal, which is used to provide an enclosure-means which joins the open-ended tops of the cylindrical anode-member **21** and the cylindrical cathode-member **24**. In the illustrated form of embodiment of our invention, as shown in Fig. 2, the insulator part of our seal is shown in the form of a glass tube 33 which surrounds the upstanding part of the cylindrical cathode-member 24, in spaced relation thereto. In the more generic aspects of our invention, however, we wish it to be understood that the glass tube 33 could be any other insulator, such as a ceramic tube, which might also be used in making a successful insulator-to-metal seal.

The top and bottom ends of the glass tube 33 are sealed to thin metal seal-forming tubes 34 and 35 respectively. In a known form of seal, for example, the glass tube 33 may be made of a borosilicate glass, and the top and bottom seal-forming metal tubes 34 and 35 may be made of a composition or alloy which fairly closely matches the thermal coefficient of expansion of the glass, a successful and well-known metal of this nature being a composition of nickel, cobalt and iron.

The bottom seal-forming metal tube 35 is hermetically joined to the top of the cylindrical anode-member 21, as by means of an annular metal header 36. The top seal-forming metal tube 34 is hermetically joined to the bottom of a cylindrical metal housing 37, as by means of another metal header 38. The top of the metal housing 37 is hermetically joined to the outer surface of the upstanding cylindrical cathode-member 24, somewhere near the top thereof, as by means of another metal header 39.

The cylindrical metal housing 37 is used as an expedient for providing a space within which can be mounted one or more grid-supporting insulators 41, and a grid-terminal conductor or lead 42. The grid-terminal conductor 42 is brought outside of the electronic device or tube by means of a suitable insulator-to-metal seal, which is illustrated as comprising a small glass tube 43 and top and bottom seal-forming metal tubes or caps 44 and 45, this grid-terminal seal being preferably similar to the larger seal 33, 34, 35.

The grid-supporting insulator or insulators 41 are each encircled by a metal band 46 which provides a bracket for supporting the top end of a cylindrical grid-supporting metal tube 47, which extends down between the upstanding cylindrical cathode-member 24 and the glass tube 33 of the main seal, in spaced relation to each. The bottom end of the cylindrical grid-supporting metal tube 47 carries an annular bracket 48, from the periphery of which is suspended a perforated cylindrical metal grid 50, which may be provided with a perforated bottom end-member 51 of the same material as the grid 50. The grid 50 is disposed between the finned cathode 24—30 and the anode 21.

Interposed between the periphery of the cathode-fins 30 and the cylindrical grid 50 is a perforated metallic heat-shield 52 which is shown as being supported, from its top, by means of a flanged disc 53 which is carried by the cylindrical cathode-member 24. The heat-shield 52 is also shown as being provided with a perforated bottom member 54, which is interposed between the bottom fin or plate 55 of the cathode-structure and the bottom end-member 51 of the grid. While we have shown only one heat-shield 52—54, it is to be understood, of course, that two or more of such shields could be used, preferably in spaced relation. It will be noted that the heat-shield 52 is in relatively poor heat-transfer relation to the cathode-structure, being secured thereto, at only one spot, by means of the flanged disc 53, so that any thermally conducted heat, which passes from the cylindrical cathode tube 24 through the

flanged disc 53 to the top of the cylindrical heat-shield 52, and then on down into the heat-shield, will have a long way to go in order to impart the heat of the cathode to the shield in this manner.

Sometimes, another heat-shield may be provided for the main seal 33—35. As shown in Fig. 2, such a heat-shield is shown in the form of an imperforate metal tube 56 which extends up to the level of the glass tube 33, illustrated as being disposed between the cathode-tube 24 and the grid-supporting tube 47, in spaced relation to each. The bottom end of this imperforate tubular shield 56 is supported in a relatively poor heat-transfer relation with respect to the cathode-tube 24, as by means of a flange 57 which makes contact with the top end of the cylindrical perforated heat-shield 52 between the cathode and the grid.

It will be noted that the complete enclosure for our electronic device or rectifier-tube comprises the closed-bottom tubular cathode-member 24, the header 39, the cylindrical metal housing 37, the header 38, the main seal 34—33—35, the header 36, and the closed-bottom cylindrical anode-member 20. The closed-bottom cylindrical cathode-member 24 thus constitutes a reentrant portion, sticking way down into the enclosed space of our electronic device or tube, so that the outer peripheral surface of this cylindrical cathode-member 24 is inside of the tube, while the inner surface or bore of this cylindrical cathode-member 24 is outside of the tube, being open to the surrounding atmosphere at the open top end of the said cylindrical cathode-member 24.

The enclosed space within our rectifier-tube may be evacuated by any convenient means. As shown in Fig. 2, the upper header 39, which joins the cylindrical metal housing 37 to the outside wall of the cylindrical cathode-member 24, is provided with a pumping-connection 58, which is engaged by a tubing 59 through which the interior space within our rectifier-tube may be evacuated, after which the evacuating tubing 59 may be sealed off, as indicated at 60.

Before our evacuated electronic device or rectifier-tube is finally sealed off at 60, a small quantity of one of our preferred alkali metals is inserted into our tube, with the usual proper precautions which are necessary in handling the alkali metals. As stated before, our preferred alkali metal is selected from the group consisting of potassium, rubidium and cesium. In the actual working of the tube, this metal is partly in the vapor or gaseous phase, and partly in the liquid phase, so that the vapor-pressure of the metal is determined by the temperature of the liquid portion of the metal. The vaporized portion of the metal serves the double function of carrying the arc-discharge within the tube, and also providing an adsorbed ionized coating or layer on the cathode, for greatly increasing the electron-emissivity or current-carrying ability of the cathode, as will be subsequently described.

This vaporizable discharge-carrying alkali-metal, when it is condensed to liquid form, may cling, in small globules, to any portion of the inner surface of the anode-member 20, without requiring any particular place for it to go. In some instances, however, we may equip the anode-structure 20 with a perforated false bottom 61 to provide a space 62 thereunder, wherein one or more globules of the alkali-metal may accumulate, as indicated at 63.

A heating-means is provided, for predeterminedly heating the cathode-tube **24**, and particularly the lower end of this tube, which is provided with the fins **30**, and which constitutes the effective or active part of the cathode. To this end, we insert, down into the open top end of the tubular cathode-member **24**, a resistance-type cathode-heater **65**, which is preferably carried by a top flange **66** which is removably connectable to the open top of the tubular cathode-member **24**, by means of a ring or flange **67** which is carried by said top end. The top flange **66** of the cathode-heater **65** thus constitutes an end-closure for the open end of the cylindrical cathode-member **24**.

In some cases, as for example when the cylindrical cathode-member **24** is made of a thin tube of nickel, this cylindrical cathode-member **24** may not be absolutely gas-tight, but may permit a small quantity of oxygen and hydrogen to slowly permeate, in a matter of months or years, through the walls of the cathode-tube, from the air into the interior of our electronic arc-discharge device or tube. This leakage is apparently not an actual physical diffusion, but more a chemical diffusion or permeation. Any oxygen or hydrogen which thus enters the arc-discharge tube through the walls of the cylindrical cathode-member **24** will instantly be absorbed by the alkali metal within the tube, which will unite therewith to form a chemical combination, but this combined alkali metal no longer functions as the vaporizable discharge-metal within the tube, so that it is desirable to limit the quantity of oxygen and hydrogen which thus enters the arc-discharge device or tube, through the walls of the cylindrical cathode-member **24**.

In cases such as have just been described, we prefer to provide some means for preventing or limiting the leakage of oxygen or other atmospheric constituents into the enclosed or evacuated space within our tube. This may the most simply be done, as shown in Fig. 2, by making the removable end-closure **66**, at the top end of the cylindrical cathode-member **24**, approximately gas-tight, as by means of gaskets **68** which are disposed between the two flanges **66** and **67**, and which may be drawn down tight by means of suitable bolts **69**. With such a construction, any oxygen (for example) which leaks through the walls of the cylindrical cathode-member **24**, into the enclosed space of our tube, simply robs or impoverishes the oxygen-content of the enclosed heater-space inside of the cylindrical cathode-member **24**, using up the oxygen therein, which is not replaced, in any substantial volume, because of the approximately gas-tight gaskets **68**, so that the slow seepage of oxygen into the evacuated space within our arc-discharge tube is limited to the small amount of oxygen which was originally contained within the hollow cylindrical cathode-member **24**, and this small amount of oxygen will usually be found to be quite tolerable by our arc-discharge device.

Our cathode-heater **65** is preferably mounted at the lower end of a downwardly extending cylindrical insulator **71**, which is supported by a long bolt or rod **72**, depending from the top flange or closure-member **66**. We also prefer to provide a second resistance-type heater **73**, on this same cylindrical insulator **71**, disposed above the cathode-heater **65**, at a level suitable for heating the main seal **34—33—35** and all of the upper portions of the evacuated tube, including the grid-supporting insulators **41** and the grid-leak insulator **43**, so as to prevent alkali-metal condensation thereon, during the operation of our device, such condensation being prevented by maintaining the insulator-surfaces at a higher temperature than the temperature of the liquid portion of the alkali metal. Such condensation is to be avoided, in order to avoid the short-circuiting of the insulators by a deposited film of condensed metal.

Preferably, the cathode-heater **65** and the seal-heater **73** are separate from each other, and separately controllable, as by having separate leads **76** and **77**, respectively, which may be brought out, through the top-closure **66**, through suitable seals or insulators **78** which may be of ordinary design, as they are not subjected to any alkali-metal vapor.

In the foregoing description of the structure which has been chosen for illustration in Fig. 2, we have undertaken to give merely a picture of the physical formation of the structure, without much indication of the necessary fine points of our design, some or all of which are necessary to the successful production of an alkali-metal rectifier. We will now undertake to describe our invention from the standpoint of the points which must be observed, in order to attain the fullest measure of success.

The physical characteristics of our three preferred vaporizable discharge-carrying alkali-metals are given in Table 1 as follows:

Table 1.—Characteristics of our discharge-metals

Metal		Atomic number	Melting point, ° C.	Boiling point, ° C.	Ionization potential, volts	Work function, ϕ electron-volts
Potassium	K	19	62.3	760	4.32	1.76–2.25
Rubidium	Rb	37	38.5	700	4.16	1.8 –2.19
Cesium	Cs	55	26	670	3.88	1.80–1.96

It is important that proper knowledge and care should be applied to the choice of the active surface-metals of the cylindrical cathode-tube **24**, and particularly the cathode-fins **30** and **55**. Perhaps not so vitally important, but very often necessary nevertheless, is the proper knowledge and care which must be applied to the choice of the surface-metal of the perforated cylindrical grid **50** and its perforated bottom end-member **51**, if used, these grid-members **50** and **51** being the hottest portions, and the active portions, of the grid-structure.

As to the active or electron-emitting surface-metal of the cathode, it is necessary that this metal shall be capable of ionizing atoms of the vaporized alkali-metal which come into contact therewith, so that such ionized atoms will adhere, by intermolecular electrostatic attraction, to the active surface of the cathode. As has already been indicated, we believe that this requirement necessitates the choice of a cathode surface-metal which has a work function which is higher than the ionization potential of the alkali metal which is being used. We are certain that such an adsorbed surface-layer of ionized alkali-metal atoms greatly increases the electron-emissivity of the cathode, and greatly reduces the energy, and hence the temperature, which is necessary to liberate the emitted electrons from the cathode-metal or from the adsorbed ionized monatomic layer of the alkali metal.

We are not sure whether, or to what extent, the electron-emission is dependent upon the magnitude of the difference between the work function of the cathode-metal and the work function or the ionization potential of the discharge-metal or alkali metal. Although there is a theory, which is commended by a considerable weight of plausibility, that a maximum, or fairly large, difference between the work function of the cathode-metal and the ionization potential of the discharge-metal is desirable, there is also much to commend the viewpoint that a lower work function of the cathode-metal is desirable, with the resultingly lower difference between the work function of the cathode-metal and the ionization potential of the discharge-metal. There is some reason for us to believe that the efficiency of the electron-emission may be improved by making the difference between the work functions of the cathode-metal and the alkali metal as small as possible, which is another way of saying, by choosing a conveniently acceptable or a conveniently workable cathode-metal having the lowest possible work function which is still higher than the ionization potential of the alkali metal which is being used. Whether this difference between the work functions is significant or not, we believe that it is still desirable to choose an otherwise-acceptable cathode-metal having the lowest possible work function which will still be higher than the ionization potential of the alkali metal, because the voltage-difference which is necessary to draw electrons out of an emitter is dependent upon the work function of the emitter.

In considering very small fractional voltage-differences between the supposed work function of the cathode-metal and the ionization potential of the chosen alkali metal, it may be desirable to avoid relying upon a very extremely small fractional voltage-difference between these two quantities. In the first place, the work functions of metals are not known within too great a degree of accuracy. To a smaller extent, this may be true also of the ionization potential of gases. The emission of electrons from an emitter is apparently affected by the past treatment of the emitter, and by sometimes very small traces of other substances, so that it is extremely difficult to obtain very precisely accurate repetitions of experimental data with regard to work functions, and we are also not sure that the apparent work function of our cathode-metal will not change with age. With these precautions against reliance upon two minute fractional voltage-differences between the work function of the cathode-metal and the ionization potential of the chosen alkali metal, we believe that it will be advantageous if, from among those metals which are available and otherwise suitable for a cathode, a suitable cathode electron-emitting surface-metal can be found, or is chosen, having a work function which is between zero and 0.6 electron-volt higher than the ionization potential of the chosen alkali metal, considering the values of work function and ionization potential to the nearest tenth of an electron-volt.

The emission-efficiency of the cathode will also be affected by the thermionic-emission constant A of the cathode-metal. Most of the pure metals, for which this constant has been measured, appear to have a value in the neighborhood of 60 for this constant, but there are a few emitter-metals for which tests have been made, indicating a wide departure of the thermionic-emission constant from the value of 60. In almost all of such cases, other tests have indicated values in disagreement with these unusual values of the thermionic-emission constant, so that a suspicion is raised as to the purity of the metal or the rigidity of the control of the test-conditions, in many cases. The thermionic-emission constant A appears in the formula for the current-density I of thermionic emission, in amperes per square centimeter, as follows:

$$I=AT^2\epsilon^{-b/T} \qquad (1)$$

which usually approximates

$$I=AT^2\epsilon^{-e\phi/kT}$$
$$=AT^2\epsilon^{-11,608\ \phi/T} \qquad (2)$$

where

T=the absolute temperature in degrees Kelvin.
e=the electron-charge in coulombs$=1.602\times10^{-19}$.
ϕ=the work function in electron-volts.
k=the Boltzmann constant in joules/° Kelvin. $=1.380\times10^{-23}$.

Insofar as the values of the thermionic-emission constant A are determinable, therefore, this constant might be used in aiding in the selection of a cathode-metal which will give efficient electron-emission. We believe, however, that such values of the thermionic-emission constant A should be used with caution, and not as necessarily or irrevocably indicating that any particular cathode-metal, apparently having a high constant A in the pure state, would be better than another metal, having a lower apparent value of this constant.

Equation 2 also indicates the advantage of a metal having a low work function ϕ, in choosing the metal for the electron-emitting surface of the cathode, because the value of the coefficient $\epsilon^{-11,608\ \phi/T}$ is larger, at any given absolute temperature T, the smaller the value of the work function ϕ.

We have also found much more copious electron-emission, and also an upward-pushing of both the vapor-pressure and the cathode-temperature at which the maximum electron-emission is obtained, by using a cathode having an adsorbed, supposedly monatomic, surface-layer of oxygen, which is interposed, probably, between the cathode-metal and the ionized layer of alkali-metal atoms. The oxygen atoms are not necessarily in chemical combination with either the cathode-metal or the oxide metal of the ionized layer, although we are not sure on this point; and we do not know for sure whether the oxygen is in chemical union with either the base-metal or the superposed layer, or in chemical union to some extent with both metals, or whether it makes any difference which metal, if any, is in chemical union with the oxygen which is adsorbed on the surface of the cathode.

We do know that, in some instances at least, it is extremely desirable to have such oxygen present, and that this effect can be obtained either by a preliminary treatment of the cathode so that its surface is lightly oxidized, or by introducing very small amount of free oxygen in the tube, which seems to find its way to the boundary-layer between the cathode-metal and the adsorbed alkali-metal layer.

There is a certain amount of oxygen always available in alkali-vapor tubes, however, because the surfaces of the insulators contain either oxides or silicates or both, and this available oxygen is slowly adsorbed by the oxygen-hungry alkali metal over an extended period of time. The oxide of the alkali metal, thus formed, or some of it, seems to eventually find its way to the adsorbed surface-layer on the cathode, so that, even if the oxygen-layer were not initially present on the surface of the cathode, we believe that such a layer would eventually be formed, if the tube has a long enough life to last that long. We prefer to make sure of the formation of this oxygen-layer in the first place, thus avoiding a subsequent change in the characteristics of the tube because of a subsequent formation of such an oxygen-layer.

In addition to all such properties and speculations bearing upon the emission-efficiency of the cathode-metal, the metal must also obviously have a sufficiently high melting point to safely withstand the operating-temperature of the cathode, without too much mechanical weakening; and the cathode-metal must also have a sufficiently low vapor-pressure, at the operating-temperature of the cathode. When the vapor-pressure of the cathode-metal is too high, at the operating-temperature of the cathode, an excessive quantity of the vapor of the cathode-metal permeates all over the space within the tube, and condenses more or less all over the inside surface of the tube, resulting eventually in the building up of a conducting film which short-circuits the necessary insulator or insulators which constitute parts of the enclosure-walls of the tube, and also resulting in some deposits of cathode-metal on the anode, on the grid, and on the heat-shield.

Where a good long tube-life is desired, with a good factor of safety, we believe that the cathode-metal should not have a vapor-pressure higher than 10^{-3} microns of mercury at the operating-temperature of the cathode. Expressed a little differently, we believe that the vapor-pressure of the cathode-metal should be less than 10^{-2} microns of mercury at a temperature of 1000° C. These expressions are not exactly consistent with each other, and perhaps it is wise, from the standpoint of making an extremely safe design, to keep well away from both pressure-limits, whichever way these limits are expressed.

When it comes to a choice of the grid-metal, or the metal which constitutes the surface of the grid, the electron-emissivity considerations, which control the choice of the metal, are just the opposite of those which have been outlined for the case of the cathode-metal. In the case of the grid, any considerable electron-emission is apt to cause a failure of the tube, by reason of back-firing, and hence it is desirable to choose a grid having a poor emission-efficiency; and to this end it is important to choose a grid-metal which will not attract or form an adhering layer of ionized alkali-metal atoms, particularly if the grid-temperature is unusually high. In other words, it is frequently quite important to choose, for the grid, a metal having a work function which is lower than the ionization potential of the alkali metal which is being used. As the grid necessarily operates at a fairly high temperature, it is also desirable that the work function of the grid-metal shall not be any lower than it needs to be, in order to safely avoid the formation of an ionized alkali-metal surface-layer thereon, because a low work function means more electron-emission.

In respect to the necessity for a high melting-point, reasonable metal-strength at elevated temperature, and reasonably low vapor-pressure at elevated temperature, the same considerations prevail, in the case of the grid, as in the case of the cathode.

In Table 2, we show the work functions, so far as they are known or reported, of the more important high-melting-point metals, using the most recent and authoritative values, tabulated from many different sources, as given in a paper by Herbert B. Michaelson, entitled "Work functions of the elements," published in Journal of Applied Physics, volume 21, June 1950, pages 536–540. Like Michaelson, we use average values of the work function when several reports give different values. Except in the case of copper, all of these metals have a melting point higher than 1100° C. We have not listed the rare earth metals because of their cost and their general unavailability.

Table 2.—Work functions of high-melting-point metals

Metal		Work function ϕ, electron volts	Remarks
Platinum	Pt	5.29	
Rhenium	Re	5.1	
Nickel	Ni	4.84	
Palladium	Pd	4.82	
Rhodium	Rh	4.65	
Iridium	Ir	4.57	
Osmium	Os	4.55	
Ruthenium	Ru	4.52	
Chromium	Cr	4.51	High vapor-pressure.
Tungsten	W	4.50	
Copper	Cu	4.47	High vapor-pressure and low melting point.
Iron	Fe	4.36	
Molybdenum	Mo	4.27	
Cobalt	Co	4.18	
Tantalum	Ta	4.12	
Vanadium	V	4.11	
Titanium	Ti	4.09	TiO_2 has a large free-energy = −193 at 300° C.
Columbium	Cb	3.99	
Manganese	Mn	3.95	High vapor-pressure.
Zirconium	Zr	3.84	ZrO_2 has a large free-energy = −235 at 300° C.
Hafnium	Hf	3.53	
Thorium	Th	3.41	
Beryllium	Be	3.37	BeO has a large free-energy = −332.5 at 300° C.

Chromium, manganese and copper have been included in Table 2, even though they have too high a vapor-pressure for safe or satisfactory operation at a temperature of the order of 1000° C., and copper also has too low a melting-point for such operation, but if the maximum operating-temperature were considerably below 1000° C., say between 500° C. and 800° C., it may be that all three of these metals would be satisfactory, so far as either their vapor-pressure of their melting-point would be concerned.

The metals which are listed in Table 2 are all available, either in sheet (bulk) form, or as a surface-coating which could be applied, in one manner or another, to a less expensive or otherwise more desirable base-metal, as is known in the metallurgical arts. There are certain precautions, of course, which must be observed in the handling of some of these metals. For example, beryllium is poisonous under some conditions but not so much so that it could not be successfully plated on a base-metal under satisfactory commercial factory-conditions; osmium forms a tetroxide which boils at 100° C. and is very poisonous; titanium burns in nitrogen at 800° C.; palladium is a particularly powerful gas-occluding agent, having particular affinity for hydrogen; and both osmium and palladium, in common with other members of the platinum family, are powerful catalysts, particularly in the finely divided state.

Some of the metals which are included in Table 2 are scarcely obtainable in a very pure form, certain groups of metals being commonly mixed together, with such similar chemical properties as to almost defy their separation. In practically every case, it may be assumed that the listed metals may be used either in their reasonably pure form, as commercially available, or alloyed with other metals or with nonmetals.

In using Table 2 as an aid in the selection of either a suitable cathode-metal or a suitable grid-metal, reference should be made to Table 1, in which it is shown that the ionization potential of potassium is apparently 4.32 volts, while the ionization potentials of rubidium and cesium are apparently 4.16 and 3.88 volts, respectively.

Among the metals listed in Table 2, chromium has too high a vapor pressure for the most satisfactory operation at a temperature approaching anywhere near 1000° C., in any tube which is expected to have a reasonably acceptable length of life, according to commercial standards for power-tubes. As the work functions of the metals listed in Fig. 2 become more accurately available, they should be included in their proper place in Table 2, arranged in the order of descending values of the work functions.

If potassium is used as the vaporizable discharge-metal, the electron-emitting surface of the cathode should be of a high-melting-point metal, selected from Table 2, having a work function higher than 4.32 electron-volts. These metals consist of iron, tungsten, ruthenium, osmium, iridium, rhodium, palladium, nickel, rhenium and platinum, and if the selection is limited to cathode-metals having a work function not more than about 0.6 volt higher than the potassium ionization potential of 4.32 volts, then the list of usable cathode-metals is limited to iron, tungsten, ruthenium, osmium, iridium, rhodium, palladium and nickel, and probably also including a borderline-list including rhenium and platinum. We believe that iron is a particularly desirable metal which has much to commend it as a cathode-material.

If rubidium is chosen as the discharge-metal, it is desirable to limit the choice of preferred cathode-metals to those high-melting-point metals, in Table 2, having a work function between the rubidium ionization potential of 4.16 volts and something like 4.76 volts. These metals probably include cobalt, molybdenum, iron, tungsten, ruthenium, osmium, iridium and rhodium, and probably also a borderline-list including palladium and nickel. Iron may prove, in the long run, to be one of the best cathode-metals to use in a rubidium-vapor rectifier.

If cesium is chosen as the discharge-metal, it is desirable to limit the choice of preferred cathode-metals to those high-melting-point, low-vapor pressure metals, in Table 2, having a work function between the cesium ionization potential of 3.88 volts and something like 4.48 volts. This list apparently includes columbium, titanium, vanadium, tantalum, cobalt, molybdenum and iron, and probably also tungsten, ruthenium and osmium. In the case of rectifiers using cesium for the vaporizable material, it may be quite desirable to use iron for the cathode-metal.

In the case of the surface-metal of the active portion of the grid (which is also the hottest portion), it is desirable to choose one of the high-melting-point, low-vapor-pressure metals, from Table 2, having a work function lower than the ionization potential of the chosen alkali metal, so as to avoid an adhering ionized surface-coating, thus reducing electron-emission. Thus, for a potassium-vapor tube, a preferred grid-metal is either molybdenum, cobalt, tantalum, vanadium, titanium, columbium, zirconium, hafnium, thorium, and beryllium. For a rubidium-vapor tube, the list of preferred grid-metals probably starts with tantalum. Manganese is a rather doubtfully desirable grid-metal, because of its rather high vapor-pressure, whether potassium or rubidium is used as the discharge-metal. In a cesium-vapor tube, the list of preferred grid-metals starts with zirconium, which, because of its relatively low cost (as compared to hafnium, thorium and beryllium), its non-toxicity (as contrasted with beryllium), and its high melting point, is a pre-eminently desirable grid-surface material for cesium tubes. Some of the metals in Table 2, such as thorium and possibly others, may have to be rejected as being possibly undesirable grid-metals because of their high electron-emissivity when activated by a surface-layer of oxygen, although this point has not been proved, in any of our tubes.

In some instances, the heat-shield 52, or such portions thereof as are out of the arc-path within the tube (as for instance the upstanding heat-shield 56 for the seal), should be made of a low-work-function metal for the same reason as the grid, namely to reduce the danger of enough electron-emission to produce a cathode-spot.

When our rectifier-tube is operating, the cathode is maintained, by suitable energization or control of the cathode-heater 65, at a suitable electron-emitting temperature for the highest obtainable efficiency or copiousness of electron-emission. This will give the highest current for any given arc-drop, or the lowest arc-drop for any specified current. As the cathode-temperature is increased more and more, the electron-emissivity or current-strength at first increases, and then finally begins to decrease, after reaching a maximum point, the decrease presumably corresponding to conditions under which the adhering surface-film or films on the cathode are beginning to boil off or to be driven off by the thermal agitation of the molecules.

When an intermediate adhering surface-layer of oxygen is not used on the cathode-metal, this temperature of maximum emissivity usually occurs at a temperature which is lower than the cathode-metal will stand. The cathode-temperature of maximum emission is different for different cathode-metals, and it is also especially different for the different alkali metals, depending upon whether potassium, rubidium or cesium is selected as the alkali metal to be used.

However, when an intermediate absorbed surface-layer of oxygen is used on the cathode, it will generally be found that the electron-emissivity increases up to the highest temperature at which it is safe to operate the cathode, this temperature being limited only by the vapor-pressure of the cathode-metal. In such cases, we believe that the cathode-temperature should be at least 800° C. In other cases, it is possible that cathode working-temperatures of 700° C. or more may be used, but we would still prefer to choose a cathode-metal having a satisfactorily low vapor-pressure at 800° C., or whatever higher temperature is used for the cathode.

If the cathode is operated at too high a temperature, its vapor-pressure will increase to the point at which it gives off enough vapor of the cathode-metal to eventually foul up the other surfaces of the tube, where no cathode-metal is wanted, thus limiting the useful life of the tube. Whatever cathode-metal vapor is produced will condense somewhere else on the tube, on the insulators, on the grid, and on the surface of the anode, etc. Deposits of the cathode-metal are particularly objectionable on the insulators, where such deposits will short-circuit the insulators; and perhaps also on the grid, where any such deposits, because of the necessarily high operating-temperature of the grid, may cause cathode-spots and consequent back-firing. The maximum allowable operating-temperature of the cathode must be limited, therefore, with a reasonable factor of safety, so that the useful life of the tube will not be limited by this accumulation of deposits resulting from the condensation of the vapor of the cathode-metal. This permissible cathode-temperature will be dependent upon the vapor-pressure characteristics of the cathode-metal.

When nickel is used as the cathode-material, for example, the limiting safe cathode-temperature, from the standpoint of vapor-pressure of the nickel, will be about 850° C. This is some 300° less than the temperature at which the vapor-pressure of the cathode-metal (nickel) would be as much as 10^{-2} microns. On a similar basis, it is expectable that a reasonably long life, with a satisfactory margin of safety, so far as the vapor-pressure of the cathode-metal is concerned, would be obtained with a tube in which the electron-emitting surface of the cathode is platinum at about 1300° C., or palladium at about 850° C., or iron at about 800° C., or osmium at about 1800° C., or rhodium at nearly 1400 C., or tungsten at possibly over 2200° C., or molybdenum at about 1600° C., or cobalt at about 950° C., or zirconium at upwards of 1200° C., or tantalum at possibly 2100° C., or columbium at nearly 1900° C. These estimated temperature-figures, on the basis of cathode-metal vaporization, are subject to verification as a result of longlife-tests.

These are the probable limiting cathode-temperatures so far as the vaporization of the cathode-metal is concerned. It is probable that the highest cathode-temperatures which have been mentioned would not be attainable because it would be found that the cathode-emissivity would reach its peak, and then start falling off, because of loss of its surface-film, long before the highest of these suggested cathode-temperatures would be reached: in other words, it is probable that the permissible cathode-temperature of the low-vapor-pressure cathodes would be limited by the emissivity-curve, rather than by the vapor-pressure of the cathode-metal.

The vapor-pressure of the alkali metal is dependent upon which of the three preferred alkali metals is chosen, and it is also dependent upon the temperature at which the anode 20 is held. The electron-emission of the cathode is more copious, the higher the anode-temperature, because the higher alkali-metal vapor-pressures which correspond to the higher anode-temperatures result in a larger number of alkali-metal atoms being present per cubic centimeter of the space within the tube, thus making more alkali-metal atoms available for attachment to the surface of the cathode, and for ionization. However, as the vapor-pressure of the alkali-metal goes up (with increasing anode-temperatures), the breakdown voltage of the alkali-metal vapor goes down, in a curve which finally becomes fairly flat. Most commercial rectifier-tubes are operated reasonably close to the breakdown limit of the vapor, with a reasonable factor of safety included. In other words, the breakdown voltage of the vapor should be substantially more than 2.5 times the voltage of the direct-current circuit 12+, 12−, to which the rectifier is connected.

The breakdown voltage of the vapor within a tube is a function of the vapor-pressure p, multiplied by the distance d across which the breakdown voltage is being measured. In the case of a grid-controlled tube, as shown in Fig. 2, this distance d would be the distance between the grid 50 and the anode 21. If this distance is made as small as it is practicable to make it, all things being considered (so as to reduce the total arc-drop within the tube), a distance of the order of 1 centimeter, in a large tube, or possibly one-half of a centimeter in a small commercial power-tube, might be expectable. It is this product pd which controls the breakdown voltage, and hence limits the permissible direct-current voltage of the tube.

For a 600-volt rectifier, the anode-temperature range which would give a breakdown voltage of somewhat more than 1500 volts, for satisfactory operation, would be about as follows, according to the alkali-metal which is chosen for the vaporizable discharge-metal:

	° C.
Cesium	150–190
Rubidium	210–240
Potassium	310–340

For a 300-volt rectifier, the following anode-temperature ranges could be used:

	° C.
Cesium	190–220
Rubidium	230–260
Potassium	320–350

For rectifiers designed to be operated on direct-current load-circuits of higher or lower voltages, corresponding changes would be made in the permissible (and hence desirable) anode-temperatures.

From the standpoint of the breakdown curve, as a function of pressure-distance pd, without considering anything else, some tests indicate that rubidium is slightly better, and other tests indicate that it is slightly worse, than cesium, at direct-current voltages of 100 to 600 volts, but not nearly as good as potassium at either voltage. However, the total arc-drop of the tube is proportional to the ionization potentials of the several vaporizable metals, which are listed in Table 1. For a pairly large commercial power-tube, with a grid in it, the total arc-drop will ordinarily be something like 150 per cent of the ionization potential of the vaporizable metal, or something like 5.8 volts for cesium, 6.2 volts for rubidium and 6.5 volts for potassium, or perhaps a little higher arc-drop than these voltages just stated. In a tube operating at 300 direct-current volts or more, these differences in the arc-drops for the different vaporizable metals of our invention are perhaps not so important, but in 100-volt rectifier, these differences in the arc-voltage correspond practically to differences in the efficiency, so that they are much more important.

The choice of the vaporizable alkali metal, whether it is to be potassium, rubidium or cesium, thus depends largely upon the operating-voltage and the importance which is to be given to the efficiency, as well as the size of rectifier which will be required for obtaining any given current-carrying capacity. In all respects except the arc-drop, and hence the efficiency, and possibly also excepting the current-carrying ability, potassium seems to be the best of the three comparable alkali-metals, but our experience with these tubes is not sufficient, at present, to enable us to give a final answer, which is free of all guess-work based upon deductions from our tests thus far.

All of the alkali metals, including the three of our choice, are very active chemically, and have an especially high affinity for oxygen, so that they attack most oxides and other oxygen-containing compounds such as silicates. The alkali-metals thus attack most glasses and most ceramics, but when the available insulating materials (glasses and ceramics) are properly chosen, the rate at which they are attacked is so slow, and the penetration of the attack is so small, that such attacks by the alkali metals which we use do not seriously limit the life of our tube, particularly when a proper choice is made, using alkali-resistant glazes and ceramics or ceramic coatings. For example, various sodium-resistant glazes are known, which are used to coat the inside glass surfaces of sodium-vapor lamps.

The principal place where the affinity of alkali meals for oxygen is strongly felt, in the design of a long-life alkali-vapor tube, is in the insulator-to-metal seal. In most such cases, particularly in glass seals, there must be an approximate matching of the thermal expansion rates of the metal and the insulator or glass, and also the surface of the metal must be lightly oxidized, so that it can be wetted by the oxides or the silicates of the glass or ceramic binder which makes a sealing joint between the metal and the insulator. The strong affinity of the alkali metals for oxygen causes the vapor of these metals to attack the metallic oxides or the oxide-containing fluxes at these joints, unless very special attention is paid to the design of such joints, with a view to alkali-vapor operation at a long life, much longer than is commonly regarded as being an acceptable life in a sodium-vapor lamp.

We have solved this alkali-resistant seal-problem by using a seal-metal having a vapor-resistant surface which is lightly coated with an oxide of the surface-metal, said metal being so chosen that its oxide has a sufficiently high negative free-energy, as compared to the negative free-energy of the oxide of the vaporizable alkali metal, that is, potassium, rubidium or cesium, as the case may be, to resist reduction by said vaporizable metal during a reasonably long working life. As previously indicated, such a working life, in any commercially acceptable power-type rectifier for competition with other known or available forms of power-type rectifiers, must at the very least be 2,000 to 20,000 hours, and it should preferably be very much longer than this, preferably more than five years, for the working life of the tube.

The thermodynamics of reactions at non-standard temperatures, that is, reactions at temperatures other than 25° C., are perhaps not settled beyond dispute as to theory, and the theory is subject to equations involving a knowledge of the so-called free-energy of the substances at the temperature at which the reaction is to be tested, that is, at the temperature at which it is desired to determine whether the available oxygen of an oxide will attach itself to one metal or the other. There is a paucity of data regarding the free-energies of most metal oxides, particularly at non-standard temperatures.

With such data (probably not perfectly reliable) as is available, and limiting our study to suitable sealing-metals which, in the metallic state, have a melting point of say 950° C. or higher, there seem to be only four metals which are useful as the surface-metals of seals for resisting the attack of the vapors of potassium, rubidium or cesium at a reasonable seal-operating temperature of say 300° C., for example. These four metals, listed in the order of the apparent ability of their oxides to resist reduction in the presence of these alkali-metal vapors, starting with the metal whose oxide apparently has the highest resistance against potassium, rubidium and cesium, are beryllium, zirconium, titanium and chromium.

Of these four protective sealing-metals, chromium seems to be pretty close to a borderline metal, whose oxide may not be quite able to forever resist reduction by the vapor of any one of the three chosen alkali-metals, potassium, rubidium and cesium; but the deleterious reaction, if any, which exists in the case of chromium, is so slow that a seal having a chromium-surfaced sealing-metal has a life at least of the order of 2,000 to 20,000 hours in the presence of such vapors at the operating temperature of the seal. We believe that the other sealing-metals which we have mentioned have much longer lives, the exact actual lives of which have not yet been ascertained. Judging from the data which we have, we believe that neither potassium, rubidium nor cesium vapor will ever reduce or otherwise attack the oxides of either beryllium, zirconium or titanium, and we believe that a chromium-plated seal, properly prepared, will stand up with an extremely long life, or even for ever, in potassium vapor, which may be less active, in this respect, than either cesium or rubidium.

The high negative free-energies of the oxides of zirconium, beryllium and tianium have been indicated in Table 2, in order to call attention to a possible difference in their electron-emission performance, as cathode-metals or grid-metals, in respect to adhering monatomic surface-films of oxygen and the alkali metal which is being used in the tube. We are not prepared to state conclusively what this difference in emissivity-performance is, or whether there is any difference, either for the better or for the worse, but theory indicates that there may be some difference, by reason of the apparent inability of either potassium, rubidium or cesium to reduce the oxides of zirconium, beryllium or titanium, as has just been mentioned in our discussion of the seal-metals.

In the preceding discussions, we have had a great deal to say about the surface-metals of the cathode, the grid, and the seals. We have used this sort of expression because, so far as electron-emissivity is concerned, and so far as chemical reactions with the alkali metal are concerned, it is only the surface-metal which is significant, so long as it is intact. Underneath the surface-layer, the cathode, the grid, or the seal-metal could be anything, so far as the operation or the life of the tube is concerned, assuming, of course, that there is a suitable bond between the surface-layer and the underlying portion of the member, and that the underlying portion has the requisite strength. In some cases, the chosen metal will be used as a solid piece, or in sheet-form, whereas, in other cases, the chosen metal will be used as a surface-coating, properly prepared on an underlying metal having a lower cost, or having better characteristics which are useful in other respects, such as mechanical strength at the operating temperature, imperviousness to gaseous diffusion, a better coefficient of thermal expansion, etc.

When metal coatings are used, the best known metallurgical arts and practices should be observed, so as to obtain a good coverage of the underlying metal and a good bond with respect to said underlying metal. For instance, when chromium is electroplated on an alloy of iron, nickel and cobalt, for one of the glass seals **34—33—35** or **44—43—45**, the usual precautions should be taken in the way of first thoroughly cleaning and polishing the surface of the alloy, thus removing all oxides or impurities therefrom, then electroplating with chromium, and then adopting the perhaps unusual procedure of heating the plated member in a non-oxidizing atmosphere such as dry hydrogen for a half hour or more at a suitable temperature such as 1000° C. or 1200° C., for the purpose of diffusing the coating-metal into the underlying metal, so as to prevent the scaling off of the coating, after which the coated member is heated in an oxidizing atmosphere, such as wet hydrogen, for another half hour or longer, at a suitable high temperature which may be of the order of 1100° C. We believe that this combination of dry-hydrogen and wet-hydrogen treatment is new.

As pointed out in the Gustin patent, such a chromium plating on the sealing metal does not need to be thick enough to have any material effect upon the over-all coefficient of thermal expansion of the metal. Gustin, however, was not concerned with the problem of alkali-metal reactions, or with the problem of the diffusion of the chromium plating into the underlying metal in order to make a firm bond which will resist pealing.

We have found that a chromium-plating thickness of the order of ½ to 1 mil is desirable. Otherwise stated, the thickness of the chromium plating on the inside, or vapor-exposed side, of the sealing metal should preferably be of the order of 1/20 of the total thickness of the sealing metal.

When the surface of the chromium plating is lightly oxidized, it forms a thin coating of chromic oxide, Cr_2O_3, which is readily wetted by glass. It is best to first glaze this chromic-oxide surface with thin layer of a bonding-glass, before undertaking to unite the same, by heat and pressure, with the glass part, **33** or **43**, of the seal.

Beryllium is best deposited as a surface-coating on an underlying metal by vaporizing the beryllium and letting the vapor condense on the underlying metal in a vacuum. Beryllium can also be coated on the underlying metal by electrolytic deposition from a fused salt bath, such as a bath containing one part of sodium chloride, one part of sodium fluoride, and two parts of beryllium fluoride at about 750° C.±25° C. The beryllium coating, after being deposited, is then first diffused into the underlying metal, and finally lightly surface-oxidized, by the combination of a hot dry-hydrogen treatment, followed by a hot wet-hydrogen treatment, as has been described for the case of chromium.

Zirconium is best deposited as a surface-coating on an underlying metal by condensation in a vacuum. The zirconium layer should be diffused into the underlying metal, as in the case of chromium or beryllium, but it is unnecessary to use the peroxidization step, as the oxidation which is inherent in the glass-sealing process is quite sufficient for providing enough zirconium oxide for bonding with the glass. Zirconium can also be used in sheet form, without having to coat it on an underlying metal, as it has a coefficient of thermal expansion which is readily matchable with available glasses, so that it can be used, in the solid form, as distinguished from the plated form, as the metallic part of a glass-to-metal seal.

The foregoing discussions of various metal-coating processes, and the use of solid or uncoated metals whenever their cost or their physical properties will permit, are intended to be suggestive, and not as an exhaustive treatment of the metallurgical art of metal-coating. It will be readily understood, by those skilled in the metallurgical arts, that there are also other metal-coating processes which are available.

A peculiarity of the operation of hot-cathode arc-discharge devices, using the vapor of potassium, rubidium or cesium, with a cathode-metal having a higher work-function than the ionization potential of the vapor, is that the arc-drop is dependent upon the amount of current which is carried by the tube. Speaking now of that portion of the arc-drop which is close to the cathode (or the arc-drop of a tube having no heat-shield and no grid, with the closest possible spacing between the anode and the cathode), this arc-drop is less than 1 volt for low currents, and it increases nearly linearly to a voltage which is about equal to the ionization potential of the vapor, for high currents. Any increase in the current beyond this point, causes the arc-drop to increase quite fast, thus imposing a practical upper limit which establishes the practical current-rating of the tube. The over-all arc-drop, in a grid-controlled tube having a heat-shield and a grid, will run usually at least 50 per cent higher than the figures which have just been given for the cathode end of the arc-drop.

The current-rating of the tube is also increased as the anode-temperature is increased, but the back-voltage that the tube can withstand decreases with increasing anode-temperatures, and that is why the anode-temperature which is chosen as the operating-temperature is always the highest temperature which will enable the tube to safely withstand the back-voltage which is impressed thereon during the non-conducting periods.

There is also a certain automatic current-limiting action, within the tube, which limits the ability of the tube to carry excessive overcurrents for any material length of time. The passage of an excessive current quickly heats the cathode to abnormally high temperatures, and a point is usually soon reached at which the cathode-emissivity is greatly reduced by the boiling off or loss of the monatomic ionized alkali-metal layer.

The use of fins, such as **30**, on the cathode, is quite advantageous, not only in producing a cathode which has a large area for electron-omission, without requiring an inordinately large tube, but also in providing a cathode which has a relatively small effective heat-radiating area, in proportion to its electron-emitting area, thus reducing the amount of energy which needs to be put into the cathode-heater **65**.

The amount of heat-input into the cathode can also be minimized, by designing the internal, or electron-emitting, surfaces of the finned cathode so as to have highly polished surfaces, thus reducing the heat-emissivity of these surfaces. In other words, the cathode has a relatively poor heat-radiating or heat-transfer surface on the side toward the grid and the anode. On the contrary, the outer surface of the cathode, that is, the surface which is exposed to the outside atmosphere, which, in our illustrated device, is the inside surface or bore of the cathode-tube 24, should advantageously be roughened, so that it acts as a relatively good heat-absorbing surface for absorbing the heat of the cathode-heater 65.

For similar reasons, it is desirable that attention should be paid to the heat-transfer qualities of the respective surfaces of the grid 50, and also the heat-shield 52, particularly where the heat-shield is in poor conductive heat-transfer relation to the cathode. The surfaces of these elements, on the side toward the heated cathode, should be highly polished, so as to reduce their heat-absorbent ability to a minimum, while the surfaces on the side toward the cooled anode should be roughened, so as to be relatively good heat-radiating surfaces. This reduces the temperatures at which the grid operates, which is extremely advantageous in reducing the electron-emissivity of the grid, thus reducing the danger of backfiring. This cooling of the grid can be still further improved by multiplying the number of heat-shields which are interposed between said grid and the cathode. If the grid is adequately heat-shielded, or otherwise used so as not to run too hot, it may be successfully made with a metal-surface having a work function higher than the ionization potential of the discharge-metal.

When a grid is used in the tube, the inner surface of the anode 21 should best be made with a roughened surface, in order to present a good heat-transfer surface toward the grid, so as the more effectively to cool the grid. When a grid is not used, the inner surface of the anode should preferably be polished, in order to reduce its cooling effect on the hot cathode, thus reducing the amount of heating-energy which must be put into the cathode-heater in order to maintain the cathode at the desired operating-temperature.

Since the anode operates at a relatively cool temperature, difficulties are not commonly encountered with respect to any material amount of electron-emissivity (which would produce a danger of backfiring), or with respect to low melting-points of any metals which would commonly be considered for the tube-construction. We ordinarily use an anode 20 which is made of steel or stainless steel.

It is a characteristic of our alkali-metal tube, that the working-temperature of the anode, while considerably lower than the working-temperature of the cathode, is nevertheless several hundred degrees above room-temperatures, thus being higher than the outer-surface operating-temperatures of other types of commercial power-rectifier tubes, such as mercury-vapor rectifiers or ignitrons. The fact that our anode runs at a temperature which is considerably higher than room-temperature is one of the sometimes important advantages of our device, in that it makes it possible to use air-cooling, as has been illustrated in Fig. 1 as distinguished from other rectifier-systems which have required liquid-cooling. Air-cooling is particularly important on vehicles or in other places where space and weight are at a premium.

An advantage of our preferred structural assembly, as shown in Fig. 2, is that the grid-assembly is mounted as a unit on the cathode-structure, before the latter is inserted into the anode-assembly or outer housing of the tube.

All of the insulators, such as 33 and 43, which are a part of the enclosure or housing of the tube, and which are thus exposed to the alkali-metal vapor within the tube, should be held to a temperature of 250° C. or higher. In fact, whatever may be the operating-temperature of the anode of any particular tube, these insulators should be kept at a temperature which is safely higher than the anode-temperature, so as to avoid the possibility of the alkali-metal vapor condensing and depositing on the inner surfaces of the insulators.

In the preferred cathode-construction, as shown more particularly in Fig. 5, the cathode-tube 24 has applied thereto a plurality of spaced-apart washers or fins 30 of the same cathode-metal. The bore 80 of these fins 30 is initially slightly smaller than the outer diameter of the central tubular cathode-member 24, and the fins 30 are assembled with a press fit. If a non-elastic metal, such as nickel, is used for the cathode, it is sometimes found that these fins 30 have a tendency to be, or to become, loose on the cathode-tube 24. We have found, in such a case, that the fins may be firmly anchored in place by a coating of a relatively thin, yet sufficiently thick, layer of the same cathode-metal (such as nickel, for example), so that the cathode-fins 30 are rigidly held in place on the cathode-tube 24.

Instead of using a relatively thin washer-like material, it is possible to use fins 81 composed of mesh-material, as shown in Fig. 6. In other words, a wire screen, or a plurality of wire screens, in the form of washers, may be substituted for the solid fins 30 of Fig. 5.

As another alternative, shown in Fig. 7, the cathode-tube 24 can be made of a substantial thickness, and its peripheral surface may be formed or turned, as by means of a cutting tool (not shown), to provide ridges or fins 82 which are integral with the cathode-tube 24 itself.

In addition to providing the main seal 34—33—35 with a heater 73, and internally shielding the lower portion of this seal from the cathode-temperature by means of the imperforate upstanding heat-shield 56, shown in Fig. 2, we preferably externally protect the seal by means of an external thermal shield or heat-insulator 84 which is disposed around the sealing structure 33, outside of the tube, as shown in Fig. 2, so that the external ventilating gas, which is used to cool the tube, as shown in Fig. 1, will have only a small cooling-effect upon the seal 34—33—35.

Instead of using an external heat-insulator 84 for the shield, as shown in Fig. 2, it may be desirable, in certain circumstances, to use an air-baffle 85, as shown in Fig. 1, to deflect the air or other cooling fluid away from the insulator 33, so that there will be little radiation or conduction of heat from the seal, thus permitting the seal to be more easily maintained at a temperature above the condensation-temperature of the vapor in the device. A similar treatment may be applied, if necessary, to the grid-terminal seal 44—43—45.

The cathode-heater 65 is the most vulnerable or short-lived portion of the device, and that is the reason why we have mounted this heater on a removable closure or cap 66, so that the heater is substantially independent of the structure of the arc-discharge device, and hence can be replaced from time to time, thus substantially extending the useful life of our device.

In those cases in which it is necessary or desirable to prevent the access of atmospheric gases to the outside-exposed wall (inner bore) of the cathode-tube 24, as when this cathode-tube is made of nickel and is operated at a temperature in excess of 600° C. or 700° C., the gas-tight gaskets 68 may be used, as shown in Fig. 2, so as either to prevent entrance of the atmosphere, or to retain a reduced-pressure gas-filling in the hollow tubular cathode-body 24. This reduced pressure may be readily accomplished by energizing the heaters 65 and/or 73, to expand the gases within the cathode heater-chamber, after which the gaskets 68 are pulled down tight to prevent any further ingress of atmospheric gases; or the space may be substantially evacuated.

In the preferred embodiment of our heaters 65 and 73 as shown in Fig. 2, the seal-heater 73 and the cathode-heater 65 have a common junction 86 to the cap 66, and the heater-terminals 77 and 76 are brought out in gas-tight relation through normal glass-metal seals 78.

In some cases, as shown in Fig. 8, it may not be necessary to provide completely vacuum-tight seals 78 for the heater-leads, and an only approximately gas-tight insulating packing 87 may be substituted.

A further method of eliminating the gases in the heater-chamber within the tubular cathode-portion 24 is disclosed in Fig. 9, where a needle-valve 88 is applied to the heater-chamber, so that the gaskets 68 may be pulled down tight before energizing the heater-elements 65 or 73, and then, after the heater has been energized, and has expelled a large portion of the atmosphere within the heater-chamber, the valve 88 may be closed to maintain a low pressure.

Of course, in either of these cases, the atmospheric gases contained in the chamber will diffuse into the alkali-vapor device, if the cathode-metal is at all permeable at its operating-temperature, but these infiltrating gases are in such small quantities that many years would pass before sufficient atmospheric gases would enter to cause any appreciable detrimental effect in the tube. To completely eliminate the detrimental effects of the permeation of the atmospheric gases, the heater-chamber may be filled with a gas, preferably a gas having a high thermal conductivity, such as nitrogen, argon, krypton, neon or helium, which will not permeate through the offending cathode-metal, such as nickel.

In order to prevent loss of the non-diffusing gas, or undue differences of pressure, when such a gas is used in the heater-chamber, we prefer to provide an expansible chamber 89 (Fig. 10) in communication with the heater-chamber, so that the heated gases may expand into said chamber 89 without causing undesirable pressures or any tendency for breathing between the heater-chamber and the external atmosphere.

In a simplified embodiment of the device, as shown in Fig. 3, the control-grid may be omitted, where current-control is not desired, particularly for high-current, low-voltage operation. Also, as shown in Fig. 3, a reservoir or reservoirs for the liquid alkali metal may be provided by one or more holes or depressions 90, drilled in the bottom 22 of the anode 20, rather than using the false bottom 61 of Fig. 2.

When no current is flowing in the tube, relatively small amounts of heat are transferred to the anode 20, and almost no cooling is required When current flows between the anode and the cathode, a certain amount of energy is taken out of the cathode 24—30, as a result of its work function, thus tending to cool the cathode, and it is usually necessary to increase the heater-current in order to compensate for the energy carried away by the electrons. Conversely, the bombardment of the electrons on the anode 20 releases a substantial amount of energy, which raises the temperature of the anode 20, and it is necessary to increase the cooling, almost directly proportionally to the current carried by the tube.

Since the heat required to maintain the cathode-temperature, and the cooling required to maintain the anode-temperature, are substantially dependent upon the load through the device 11, we may provide a heater-control having one source of substantially constant potential, and having another source of a potential which is dependent upon the load through the device. Thus, as shown in Fig. 1, we have provided a variable heating current for the cathode-heater 65 by means of a step-down or low-voltage transformer 91, the primary of which is connected to an auxiliary supply-transformer 92 in series with a variable saturable reactor 93, the saturating current of which is the load-current of the vapor-electric device.

The cooling of the anode 20 may also be caused to be substantially dependent upon the heat-flow from the cathode 24—30 to the anode 20, which is again substantially dependent upon the load-current. Thus, as shown in Fig. 1, the speed of our blower 19, which drives cooling air over or around the anodes 20, is controlled by the variable voltage which energizes the primary circuit of the cathode-heater transformer 91. This variable voltage is applied to the blower-motor 94 by means of a rectifier-bridge 95.

As the load-current of the vapor-electric devices increases, the saturation of the reactor 93 increases, thus reducing its impedance and causing the supply-transformer 92 to apply an increasingly greater potential to the rectifying device 95, and thence to the blower-motor 94. Consequently, the rate of flow of the cooling fluid is directly dependent upon the load-current.

In the same manner, the variable-voltage cathode-heater transformer 91 receives a voltage which increases with the load-current, so that the heating of the cathode 24 increases sufficiently to compensate for the heat carried away from the cathode by the electrons flowing therefrom.

In addition to, or instead of, the automatic control which has just been described for the heater and the ventilating-blower, we may provide adjustable rheostatic controls, such as a variable resistor 96 in series with the blower-motor, another variable resistor 97 (or other variable impedance) in series with the cathode-heater terminal 76, and still another variable resistor 98 which is connected between the seal-heater terminal 77 and a step-down or low-voltage transformer 99 which is shown as being energized from the secondary of the auxiliary supply-transformer 92 in Fig. 1. The variable resistors 96, 97 and 98 may be manually or thermostatically controlled for maintaining predetermined operating-temperatures in conformity with our invention.

While, for the purpose of illustration, we have shown preferred embodiments of our invention, and have described the same to the best of our present knowledge, including some metals and metal-combinations about which our test-data is less complete than others, and some which we have not tried but only advocate from theoretical considerations, we wish it to be understood that such disclosure is only exemplary, and that changes and modifications can be made therein without departing from the true spirit of our invention or the scope of the appended claims.

We claim as our invention:

1. A vapor-electric device comprising spaced electrodes between which an electric current can flow, and an enclosure-means including an insulator-to-metal seal, said device including a quantity of a vaporizable metal selected from the group consisting of potassium, rubidium and cesium, and further characterized by the metal part of said insulator-to-metal seal having a lightly oxidized vapor-resistant surface composed of a metal having a sufficiently high melting point to enable the formation of said seal, and having an oxidized surface, said seal-metal being one of the chemical group of metals whose oxides have a relatively high negative free-energy, as compared to the negative free-energy of the oxide of said vaporizable metal.

2. A vapor-electric device comprising spaced electrodes between which an electric current can flow, and an enclosure-means including an insulator-to-metal seal, said device including a quantity of a vaporizable metal selected from the group consisting of potassium, rubidium and cesium, and further characterized by the metal part of said insulator-to-metal seal having a lightly oxidized vapor-resistant surface composed of a metal selected from the group consisting of beryllium, zirconium, chromium and titanium for resisting reduction by said vaporizable metal at the operating-temperature of the seal.

3. A vapor-electric device comprising spaced electrodes between which an electric current can flow, and an enclosure-means including an insulator-to-metal seal, said device including a quantity of a vaporizable metal selected from the group consisting of potassium, rubidium and cesium, and further characterized by the metal part of said insulator-to-metal seal having a lightly oxidized vapor-resistant beryllium surface for resisting reduction by said vaporizable metal at the operating-temperature of the seal.

4. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals having a work function higher than the ionization potential of the discharge-metal, and also having an adsorbed surface-layer of oxygen, and further having a melting point higher than the maximum operating temperature of the cathode.

5. The invention as defined in claim 4, characterized by the electron-emitting surface of said cathode being a metal having a vapor-pressure sufficiently low to avoid objectionable deposits thereof on other surfaces within the device when said metal is operated at a temperature in excess of 800° C., and said heating-means maintaining a substantial portion of said cathode at an operating temperature in excess of 700° C.

6. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals having a work function higher than the ionization potential of the discharge-metal, and also having a vapor-pressure sufficiently low to avoid objectionable deposits thereof on other surfaces within the device when said metal is operated at a temperature in excess of 800° C., said device being further characterized by said heating-means maintaining a substantial portion of said cathode at an operating temperature in excess of 700° C.

7. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals having a work function higher than the ionization potential of the discharge-metal by an amount between the limits of zero and about 0.6 electron-volts, considering the values of work function and ionization potential to the nearest tenth of an electron-volt.

8. The invention as defined in claim 7, characterized by the discharge-metal being potassium.

9. The invention as defined in claim 7, characterized by the discharge-metal being rubidium.

10. The invention as defined in claim 7, characterized by the discharge-metal being cesium.

11. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of potassium within the device, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-

emitting surface selected from the group of metals consisting of iron, tungsten, ruthenium, osmium, iridium, rhodium, palladium and nickel.

12. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of rubidium within the device, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals consisting of cobalt, molybdenum, iron, tungsten, ruthenium, osmium, iridium, rhodium, palladium and nickel.

13. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of cesium within the device, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals consisting of columbium, titanium, vanadium, tantalum, cobalt, molybdenum, iron, tungsten, ruthenium and osmium.

14. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface of iron.

15. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of potassium within the device, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface of iron.

16. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of rubidium within the device, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface of iron.

17. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of cesium within the device, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface of iron.

18. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, an anode, enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals having a work function higher than the ionization potential of the discharge-metal, said device being further characterized by having one or more perforated heat-shields interposed between the relatively hot cathode and the relatively cool anode, at least one of said heat-shields being in relatively poor heat-transfer relation to the cathode and having a relatively poor heat-absorbent surface on the side toward the cathode and a relatively good heat-radiating surface on the side toward the anode.

19. A vapor-electric arc-discharge device comprising spaced electrodes between which an electric current can flow, and a quantity of a vaporizable metal therein, selected from the group consisting of potassium, rubidium and cesium, said device including a substantially non-emitting solid-metal member within the device, enclosure-means including an insulator-to-metal seal, and means for maintaining the seal at a working-temperature higher than the working-temperature of the liquid portion of the vaporizable metal, said device being characterized by at least a portion of said substantially non-emitting

member having a surface selected from the group of metals having a work function lower than the ionization potential of the vaporizable metal, and having a melting point higher than the maximum operating temperature of said substantially non-emitting electrode.

20. The invention as defined in claim 19, characterized by at least a portion of the surface-metal of the substantially non-emitting member being zirconium.

21. The invention as defined in claim 19, characterized by the vaporizable metal being potassium.

22. The invention as defined in claim 19, characterized by the vaporizable metal being rubidium.

23. The invention as defined in claim 19, characterized by the vaporizable metal being cesium.

24. A vapor-electric arc-discharge device comprising spaced electrodes between which an electric current can flow, and a quantity of potassium therein, said device including a substantially non-emitting solid-metal member within the device, enclosure-means including an insulator-to-metal seal, and means for maintaining the seal at a working-temperature higher than the working-temperature of the liquid portion of the potassium, said device being characterized by at least a portion of said substantially non-emitting member having a surface selected from the group of metals consisting of molybdenum, cobalt, tantalum, vanadium, titanium, columbium, zirconium, hafnium, thorium, and beryllium.

25. A vapor-electric arc-discharge device comprising spaced electrodes between which an electric current can flow, and a quantity of rubidium therein, said device including a substantially non-emitting solid-metal member within the device, enclosure-means including an insulator-to-metal seal, and means for maintaining the seal at a working-temperature higher than the working-temperature of the liquid portion of the rubidium, said device being characterized by at least a portion of said substantially non-emitting member having a surface selected from the group of metals consisting of tantalum, vanadium, titanium, columbium, zirconium, hafnium, thorium, and beryllium.

26. A vapor-electric arc-discharge device comprising spaced electrodes between which an electric current can flow, and a quantity of cesium therein, said device including a substantially non-emitting solid-metal member within the device, enclosure-means including an insulator-to-metal seal, and means for maintaining the seal at a working-temperature higher than the working-temperature of the liquid portion of the cesium, said device being characterized by at least a portion of said substantially non-emitting member having a surface selected from the group of metals consisting of zirconium, hafnium, thorium, and beryllium.

27. A vapor-electric arc-discharge device comprising spaced electrodes between which an electric current can flow, and a quantity of cesium therein, said device including a substantially non-emitting solid-metal member within the device, enclosure-means including an insulator-to-metal seal, and means for maintaining the seal at a working-temperature higher than the working-temperature of the liquid portion of the cesium, said device being characterized by at least a portion of said substantially non-emitting member having a surface of zirconium.

28. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, a grid, an anode, enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals having a work function higher than the ionization potential of the discharge-metal, and having a melting point higher than the maximum operating temperature of the cathode, said device being further characterized by the surface of at least the hottest portions of said grid being selected from the group of metals having a work function lower than the ionization potential of the discharge-metal, and having a melting point higher than the maximum operating temperature of the grid.

29. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, a grid, an anode, enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals having a work function higher than the ionization potential of the discharge-metal, and having a melting point higher than the maximum operating temperature of the cathode, said device being further characterized by at least the hottest portions of the grid having a relatively poor heat-absorbent surface on the side toward the cathode and a relatively good heat-radiating surface on the side toward the anode.

30. A hot-cathode vapor-electric arc-discharge device comprising a finned cathode having a large electron-emitting surface within a relatively small volume, a grid, an anode, enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature, said device being characterized by said cathode having an electron-emitting surface selected from the group of metals having a work function

higher than the ionization potential of the discharge-metal, and having a melting point higher than the maximum operating temperature of the cathode, said device being further characterized by having one or more perforated heat-shields interposed between the cathode and the grid.

31. A hot-cathode vapor-electric arc-discharge device comprising a cylindrical anode-member closed at one end, a cylindrical cathode-member closed at one end, the closed end of the cylindrical cathode-member being spaced from the closed end of the cylindrical anode-member, a plurality of axially spaced cathode-fins encircling said cathode-member near its closed end, the peripheries of the cathode-fins being spaced from the cylindrical portion of the anode-member, enclosure-means including an insulator-to-metal seal joining the open-end portions of said cylindrical anode-member and said cylindrical cathode-member, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, cooling-means for predeterminedly cooling the anode-member to a substantially non-emitting temperature and for providing a condensing surface which determines the working vapor-pressure of the discharge-metal, heating-means for predeterminedly heating the cylindrical cathode-member to a suitable electron-emitting temperature, and means for maintaining the seal at an intermediate working-temperature.

32. A hot-cathode vapor-electric arc-discharge device comprising a cylindrical anode-member closed at one end, a cylindrical cathode-member closed at one end, the closed end of the cylindrical cathode-member being spaced from the closed end of the cylindrical anode-member, the cylindrical cathode-member having a plurality of electron-emitting fins near its closed end, the peripheries of the cathode-fins being spaced from the cylindrical portion of the anode-member, enclosure-means including an insulator-to-metal seal joining the open-end portions of said cylindrical anode-member and said cylindrical cathode-member, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, cooling-means for predeterminedly cooling the anode-member to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, a removable heater disposed within said cylindrical cathode-member, and means for maintaining the seal at an intermediate working-temperature.

33. The invention as defined in claim 32, in combination with an approximately gas-tight removable end-closure for the open end of the cylindrical cathode-member.

34. A hot-cathode vapor-electric arc-discharge device comprising a cylindrical anode-member closed at one end, a cylindrical cathode-member closed at one end, the closed end of the cylindrical cathode-member being spaced from the closed end of the cylindrical anode-member, the cylindrical cathode-member having a plurality of electron-emitting fins near its closed end, the peripheries of the cathode-fins being spaced from the cylindrical portion of the anode-member, the cylindrical cathode-member being longer than the cylindrical anode-member so that the open end of the cylindrical cathode-member extends beyond the open end of the cylindrical anode-member, enclosure-means including an insulator-to-metal seal joining the open-end portions of said cylindrical anode-member and said cylindrical cathode-member, said seal being spaced around the extending end of the cathode-member, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, cooling-means for predeterminedly cooling the anode-member to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and heating-means disposed within said cylindrical cathode-member for differently controllably heating the finned portion of the cathode-member and the portion of the cathode-member near said seal.

35. A hot-cathode vapor-electric arc-discharge device comprising a substantially cylindrical anode, a hollow nickel cathode-body inside of and spaced from said anode, an enclosure-means including an insulator-to-metal seal, a quantity of a discharge-metal within said device, said discharge-metal being selected from the group consisting of potassium, rubidium and cesium, said seal being a vitreous seal joining said anode to said cathode, said seal consisting of sealing strips of an alloy of iron, nickel and cobalt separated by a body of borosilicate glass with a thin layer of beryllium interposed between the glass and the alloy, a removable heater element in said cathode body, a grid interposed between said anode and cathode, at least the active surface of said grid consisting of cobalt, that surface of the grid exposed to the cathode being finished as a thermal reflector and that surface exposed to the anode being finished as a thermal radiator.

36. A cesium vapor-discharge device comprising a substantially cylindrical anode, a hollow nickel cathode-body inside of and spaced from said anode, a vitreous seal joining said anode to said cathode, said seal consisting of sealing strips of an alloy of iron, nickel and cobalt separated by a body of borosilicate glass with a thin layer of beryllium interposed between the glass and the alloy, a removable heater element in said cathode body, a grid interposed between said anode and cathode, at least the active surface of said grid consisting of cobalt, that surface of the grid exposed to the cathode being finished as a thermal reflector and that surface exposed to the anode being finished as a thermal radiator.

37. A vapor-electric device comprising a substantially tubular cathode-body, means on a portion of said body increasing the surface area per unit length thereof, a resistance-type heating-element in said cathode adjacent said portion of said cathode-body, a substantially tubular anode spaced from said cathode, a glass insulating bushing between said anode and cathode, said bushing being sealed vacuum tight to said anode and cathode by a metal having an oxide inert to the vapors of cesium, rubidium or potassium, a reservoir in said anode, a quantity of discharge metal selected from the group consisting of cesium, rubidium and potassium in said reservoir, a resistance-type heating element adjacent said insulating bushing, a grid interposed in spaced insulated relation between said anode and cathode, said grid having a thermal reflecting surface presented to said cathode and a thermal radiating surface presented to said anode, a closure plate having said heating elements mounted thereon, said closure plate being mounted to close

the opening in said cathode in a substantially gas-tight manner, a source of substantially constant potential connected to the heating element adjacent the insulating bushing and a source of variable potential connected to the heating element adjacent the cathode portion having the enlarged surface area, a blower delivering cooling fluid about said anode, a motor driving said blower, a source of potential connected to said motor and a variable reactor controlling the potential applied to said motor.

38. A vapor-electric device comprising a hollow cathode-body, a heating device in said hollow body, an anode spaced from said cathode-body, a vitreous seal joining said anode to said cathode-body to provide a vacuum-tight container, said seal including a base metal and a vitreous composition having a substantially similar coefficient of expansion, a relatively thin layer of bonding metal having an oxide inert to alkali metal vapor interposed between the base metal and the vitreous composition, a quantity of alkali metal selected from the group consisting of cesium, rubidium and potassium in said container, and a control electrode interposed between said anode and cathode and insulated therefrom, said electrode having an active surface of metal having a low work function in regard to the aforesaid alkali metals.

39. A seal for an alkali metal container comprising a pair of annular metal bodies composed of an alloy of iron, nickel and cobalt separated by a collar of borosilicate glass, said collar and said annular bodies having suastantially the same thermal coefficient of expansion, a thin layer of a metal having an oxide inert to alkali metal diffused into the surface of the annular bodies at the junction with the glass collar, said glass being sealed to the oxidized surface of said thin layer.

40. A cathode-structure comprising a hollow body, a plurality of fins arranged in spaced-apart relation on a portion of said body, an opening into said hollow body, a cover for said opening, a substantially gas-tight seal between said cover and said body, a heater in said body in proximity to the portion thereof having the fins, connections for said heater extending through said cover and substantially gas-tight seals between said connections and said cover, and an expansible reservoir connected in communication with the interior of said hollow body.

41. The invention as defined in claim 40, characterized by said cathode-body and said cathode-fins being made of nickel.

42. A cathode-structure comprising a hollow body, a plurality of fins arranged in spaced-apart relation on a portion of said body, an opening into said hollow body, a cover for said opening, a substantially gas-tight seal between said cover and said body, a heater in said body in proximity to the portion thereof having the fins, connections for said heater extending through said cover, substantially gas-tight seals between said connections and said cover, and a filling of inert atmospheric gas in said hollow body.

43. The invention as defined in claim 42, characterized by said cathode-body and said cathode-fins being made of nickel.

44. A cathode-structure comprising a hollow body, a plurality of fins arranged in spaced-apart relation on a portion of said body, an opening into said hollow body, a cover for said opening, a substantially gas-tight seal between said cover

and said body, a heater in said body in proximity to the portion thereof having the fins, connections for said heater extending through said cover and substantially gas-tight seals between said connections and said cover, and a valved passage controlling the admission of atmosphere to said hollow body.

45. The invention as defined in claim 44, characterized by said cathode-body and said cathode-fins being made of nickel.

46. A glass-metal seal resistant to alkali metals comprising a metal body composed of an alloy of iron, nickel and cobalt, a thin layer of beryllium diffused into the surface of the metal body, an oxidized surface on said beryllium layer and a body of borosilicate glass sealed to said beryllium layer.

47. A vapor-electric device comprising a substantially tubular cathode-body, means on a portion of said body increasing the surface area per unit length thereof, means for heating, from the inside, at least said portion of said cathode-body, a substantially tubular anode spaced from said cathode, a glass insulating bushing between said anode and cathode, said bushing being sealed vacuum tight to said anode and cathode by a metal having an oxide inert to the vapors of cesium, rubidium or potassium, a quantity of discharge metal selected from the group consisting of cesium, rubidium and potassium in said device, means for maintaining said insulating bushing at a temperature higher than the coolest point in the device, a grid interposed in spaced insulated relation between said anode and cathode, said grid having a thermal reflecting surface presented to said cathode and a thermal radiating surface presented to said anode, and means for cooling said anode.

48. A vapor-electric device comprising spaced electrodes between which an electric current can flow, and an enclosure-means including an insulator-to-metal seal, said device including a quantity of a vaporizable discharge-carrying stable alkali metal having more than three shells in its atomic structure, and further characterized by the metal part of said insulator-to-metal seal having a lightly oxidized vapor-resistant surface composed of a metal having a sufficiently high melting point to enable the formation of said seal, and having an oxidized surface, said seal-metal being one of the chemical group of metals whose oxides have a relatively high negative free-energy, as compared to the negative free-energy of the oxide of said vaporizable metal.

49. The invention as defined in claim 48, characterized by said seal-metal being beryllium.

50. The invention as defined in claim 48, characterized by said seal comprising a pair of annular metal bodies, each composed of an alloy of iron, nickel and cobalt, separated by a collar of borosilicate glass, said collar and said annular bodies having substantially the same thermal coefficient of expansion, a thin layer of a metal having an oxide inert to alkali metal diffused into the surface of the annular bodies at the junction with the glass collar, said glass being sealed to the oxidized surface of said thin layer.

51. The invention as defined in claim 48, characterized by said seal comprising a metal body composed of an alloy of iron, nickel and cobalt, a thin layer of beryllium diffused into the surface of the metal body, an oxidized surface of said beryllium layer and a body of borosilicate glass sealed to said beryllium layer.

52. A vapor-electric arc-discharge device as defined in claim 48, including therein a substantially non-emitting solid-metal member having at least a portion of its surface selected from the group of metals having a work function lower than the ionization potential of the vaporizable metal, and having a melting point higher than the maximum operating temperature of said substantially non-emitting electrode.

53. The invention as defined in claim 52, characterized by at least a portion of the surface-metal of the substantially non-emitting member being zirconium.

54. The invention as defined in claim 52, characterized by said discharge-metal being cesium.

55. The invention as defined in claim 54, characterized by at least a portion of the surface-metal of the substantially non-emitting member being selected from the group of metals consisting of zirconium, hafnium, thorium, and beryllium.

56. The invention as defined in claim 52, characterized by said discharge-metal being potassium.

57. The invention as defined in claim 56, characterized by at least a portion of the surface-metal of the substantially non-emitting member being selected from the group of metals consisting of molybdenum, cobalt, tantalum, vanadium, titanium, columbium, zirconium, hafnium, thorium, and beryllium.

58. The invention as defined in claim 52, characterized by said discharge-metal being rubidium.

59. The invention as defined in claim 58, characterized by at least a portion of the surface-metal of the substantially non-emitting member being selected from the group of metals consisting of tantalum, vanadium, titanium, columbium, zirconium, hafnium, thorium, and beryllium.

60. A hot-cathode vapor-electric arc-discharge device as defined in claim 48, characterized by said spaced electrodes comprising a finned cathode having a large electron-emitting surface within a relatively small volume, and a spaced anode, said cathode having an electron-emitting surface selected from the group of metals having a work function higher than the ionization potential of the discharge-metal, and also having a melting point higher than the maximum operating temperature of the cathode, in combination with heating-means for predeterminedly heating the cathode to a suitable electron-emitting temperature, cooling-means for predeterminedly cooling the anode to a substantially non-emitting temperature and for providing a condensing-surface which determines the working vapor-pressure of the discharge-metal, and means for maintaining the seal at an intermediate working-temperature.

61. The invention as defined in claim 60, characterized by said discharge-metal being cesium.

62. The invention as defined in claim 60, characterized by said discharge-metal being potassium.

63. The invention as defined in claim 60, characterized by said discharge-metal being rubidium.

64. The invention as defined in claim 60, characterized by the surface-metal of said cathode being iron.

65. The invention as defined in claim 60, characterized by the surface-metal of said cathode being nickel.

66. The invention as defined in claim 60, characterized by the surface-metal of said cathode also having an adsorbed surface-layer of oxygen.

67. The invention as defined in claim 66, characterized by the surface-metal of said cathode being iron.

68. The invention as defined in claim 66, characterized by the surface-metal of said cathode being nickel.

69. The invention as defined in claim 60, characterized by the surface-metal of said cathode also having a vapor-pressure sufficiently low to avoid objectionable deposits thereof on other surfaces within the device when said metal is operated at a temperature in excess of 800° C., said device being further characterized by said heating-means maintaining a substantial portion of said cathode at an operating temperature in excess of 700° C.

70. The invention as defined in claim 60, characterized by the surface-metal of said cathode also having a work function higher than the ionization potential of the discharge-metal by an amount between the limits of zero and about 0.6 electron-volts, considering the values of work function and ionization potential to the nearest tenth of an electron-volt.

71. The invention as defined in claim 70, characterized by said discharge-metal being cesium.

72. The invention as defined in claim 71, characterized by the surface-metal of said cathode being selected from the group of metals consisting of columbium, titanium, vanadium, tantalum, cobalt, molybdenum, iron, tungsten, ruthenium and osmium.

73. The invention as defined in claim 70, characterized by said discharge-metal being potassium.

74. The invention as defined in claim 73, characterized by the surface-metal of said cathode being selected from the group of metals consisting of iron, tungsten, ruthenium, osmium, iridium, rhodium, palladium and nickel.

75. The invention as defined in claim 70, characterized by said discharge-metal being rubidium.

76. The invention as defined in claim 75, characterized by the surface-metal of said cathode being selected from the group of metals consisting of cobalt, molybdenum, iron, tungsten, ruthenium, osmium, iridium, rhodium, palladium and nickel.

77. A hot-cathode vapor-electric arc-discharge device as defined in claim 60, having one or more perforated heat-shields interposed between the relatively hot cathode and the relatively cool anode, at least one of said heat-shields being in relatively poor heat-transfer relation to the cathode and having a relatively poor heat-absorbent surface on the side toward the cathode and a relatively good heat-radiating surface on the side toward the anode.

78. A hot-cathode vapor-electric arc-discharge device as defined in claim 60, having a grid interposed between the cathode and the anode, and having one or more perforated heat-shields interposed between the cathode and the grid.

79. A hot-cathode vapor-electric arc-discharge device as defined in claim 60, having a grid interposed between said cathode and said anode, the surface of at least the hottest portions of said grid being selected from the group of metals having a work function lower than the ionization potential of the discharge-metal, and having a melting point higher than the maximum operating temperature of the grid.

80. The invention as defined in claim 79, characterized by said discharge-metal being cesium.

81. The invention as defined in claim 79, characterized by said discharge-metal being potassium.

82. The invention as defined in claim 79, characterized by said discharge-metal being rubidium.

83. A hot-cathode vapor-electric arc-discharge device as defined in claim 60, having a grid interposed between said cathode and said anode, at least the hottest portions of the grid having a relatively poor heat-absorbent surface on the side toward the cathode and a relatively good heat-radiating surface on the side toward the anode.

84. A hot-cathode vapor-electric arc-discharge device as defined in claim 60, having a grid interposed between said cathode and said anode, characterized by the anode being substantially cylindrical, the cathode being a hollow cathode-body inside of and spaced from said anode, the seal being a vitreous seal joining said anode to said cathode, said seal consisting of sealing strips of an alloy of iron, nickel and cobalt separated by a body of borosilicate glass with a thin layer of beryllium interposed between the glass and the alloy, a removable heater element in said cathode body, and that surface of the grid exposed to the cathode being finished as a thermal reflector and that surface exposed to the anode being finished as a thermal radiator.

85. The invention as defined in claim 84, characterized by at least the active surface of the grid being cobalt.

86. The invention as defined in claim 85, characterized by the surface-metal of said cathode being nickel.

87. The invention as defined in claim 86, characterized by said discharge-metal being cesium.

88. A hot-cathode vapor-electric arc-discharge device as defined in claim 60, characterized by the anode being a cylindrical anode-member closed at one end, the cathode including a cylindrical cathode-member closed at one end, the closed end of the cylindrical cathode-member being spaced from the closed end of the cylindrical anode-member, and a plurality of axially spaced cathode-fins encircling said cathode-member near its closed end, the peripheries of the cathode-fins being spaced from the cylindrical portion of the anode-member, and said seal being disposed between the open-end portions of said cylindrical anode-member and said cylindrical cathode-member to provide a vacuum-tight enclosure-means for the device.

89. A hot-cathode vapor-electric arc-discharge device as defined in claim 60, characterized by the anode being a cylindrical anode-member closed at one end, the cathode including a cylindrical cathode-member closed at one end, the closed end of the cylindrical cathode-member being spaced from the closed end of the cylindrical anode-member, the cylindrical cathode-member having a plurality of electron-emitting fins near its closed end, the peripheries of the cathode-fins being spaced from the cylindrical portion of the anode-member, said seal being disposed between the open-end portions of said cylindrical anode-member and said cylindrical cathode-member to provide a vacuum-tight enclosure-means for the device, and the heating-means for the cathode being a removable heater disposed within said cylindrical cathode-member.

90. The invention as defined in claim 89, in combination with an approximately gas-tight removable end-closure for the open end of the cylindrical cathode-member.

91. A hot-cathode vapor-electric arc-discharge device as defined in claim 60, characterized by the anode being a cylindrical anode-member closed at one end, the cathode including a cylindrical cathode-member closed at one end, the closed end of the cylindrical cathode-member being spaced from the closed end of the cylindrical anode-member, the cylindrical cathode-member having a plurality of electron-emitting fins near its closed end, the peripheries of the cathode-fins being spaced from the cylindrical portion of the anode-member, the cylindrical cathode-member being longer than the cylindrical anode-member so that the open end of the cylindrical cathode-member extends beyond the open end of the cylindrical anode-member, said seal being disposed between the open-end portions of said cylindrical anode-member and said cylindrical cathode-member to provide a vacuum-tight enclosure-means for the device, and the heating-means for the cathode and the temperature-maintaining means for the seal jointly including a heating-means disposed within said cylindrical cathode-member for differently controllably heating the finned portion of the cathode-member and the portion of the cathode-member near said seal.

92. A hot-cathode vapor-electric arc-discharge device as defined in claim 48, characterized by said spaced electrodes comprising a hollow cathode-body and an anode spaced from said cathode-body, said cathode-body and said anode constituting portions of the enclosure-means of said device, said seal being a vitreous seal joining said anode to said cathode-body to provide a vacuum-tight enclosure-means for the device, said seal including a base metal and a vitreous composition having a substantially similar coefficient of expansion, the lightly oxidized surface of said seal comprising a relatively thin layer of bonding-metal interposed between said base metal and said vitreous composition, a heating device in said hollow cathode-body, and a control-electrode interposed between said cathode-body and said anode and insulated therefrom, said control-electrode having an active surface of a metal having a low work function in regard to the discharge-metal.

93. The invention as defined in claim 92, characterized by said discharge-metal being cesium.

94. The invention as defined in claim 92, characterized by said discharge-metal being potassium.

95. The invention as defined in claim 92, characterized by said discharge-metal being rubidium.

96. A hot-cathode vapor-electric arc-discharge device as defined in claim 48, characterized by said spaced electrodes comprising a cathode having a substantially tubular cathode-body and a means on an emitting portion of said cathode-body for increasing the surface area per unit length thereof, and a substantially tubular anode spaced from said cathode, said cathode and said anode constituting portions of the enclosure-means of said device, said seal including a glass insulating bushing disposed between said cathode and said anode, a means for heating, from the inside, at least said emitting portion of the cathode, a means for maintaining said insulating bushing at a temperature higher than the coolest point in the device, a grid interposed in spaced insulated relation between said anode and said

cathode, said grid having a thermal reflecting surface presented to said cathode and a thermal radiating surface presented to said anode, and a means for cooling said anode.

97. A hot-cathode vapor-electric arc-discharge device as defined in claim 48, characterized by said spaced electrodes comprising a cathode having a substantially tubular cathode-body and a means on an emitting portion of said cathode-body for increasing the surface area per unit length thereof, and a substantially tubular anode spaced from said cathode, said cathode and said anode constituting portions of the enclosure-means of said device, said seal including a glass insulating bushing disposed between said cathode and said anode, the anode portion of said enclosure-means including a reservoir for receiving the discharge-carrying alkali metal, a resistance-type heating-element in said cathode adjacent to said emitting portion, a resistance-type heating-element adjacent to said seal, a grid interposed in spaced insulated relation between said anode and said cathode, said grid having a thermal reflecting surface presented to said cathode and a thermal radiating surface presented to said anode, a closure-plate having said heating-elements mounted thereon, said closure-plate being mounted to close the opening in said cathode in a substantially gas-tight manner, a source of substantially constant potential connected to the heating-element adjacent to the seal, and a source of variable potental connected to the heating-element adjacent to said emitting portion, a blower delivering cooling fluid about said anode, a motor driving said blower, a source of potential connected to said motor and a variable reactor controlling the potential applied to said motor.

98. A hot-cathode vapor-electric arc-discharge device as defined in claim 48, characterized by said spaced electrodes comprising a cathode and an anode, said cathode comprising a hollow body, a plurality of fins arranged in spaced-apart relation on a portion of said hollow body, an opening into said hollow body, a cover for said opening, a closable connection-means between the interior of said hollow body and the external atmosphere, said connection-means comprising a substantially gas-tight seal between said cover and said body, a heater in said body in proximity to the portion thereof having the fins, connections for said heater extending through said cover and substantially gas-tight seals between said connections and said cover.

99. The invention as defined in claim 98, characterized by said cathode-body and said cathode-fins being made of nickel.

100. The invention as defined in claim 98, characterized by an expansible reservoir connected in communication with the interior of said hollow body.

101. The invention as defined in claim 100, characterized by said cathode-body and said cathode-fins being made of nickel.

102. The invention as defined in claim 98, characterized by a filling of inert atmospheric gas in said hollow body.

103. The invention as defined in claim 102, characterized by said cathode-body and said cathode-fins being made of nickel.

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