Oct. 3, 1933. C. G. SMITH 1,929,122

VAPOR SPACE CURRENT DEVICE

Original Filed March 1, 1924 2 Sheets-Sheet. 1

Fig. 1

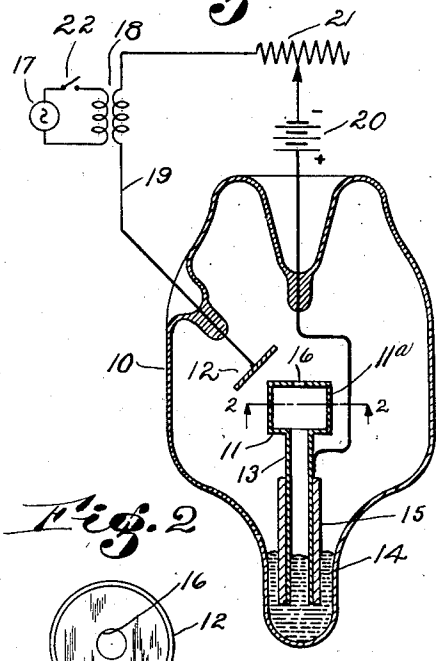


Fig. 2

Fig. 3

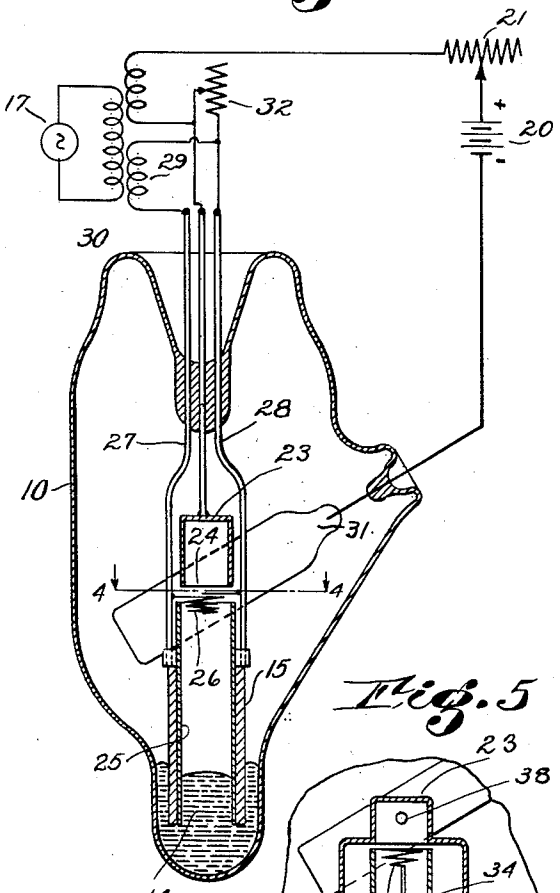


Fig. 5

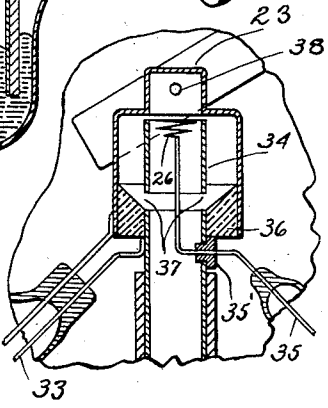
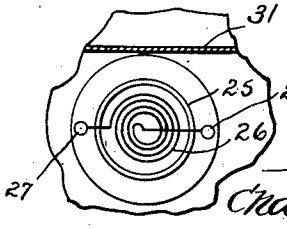


Fig. 4



Inventor
Charles G. Smith
By Roberts, Roberts & Cushman,
Attys.

Oct. 3, 1933. C. G. SMITH 1,929,122

VAPOR SPACE CURRENT DEVICE

Original Filed March 1. 1924 2 Sheets-Sheet. 2

Fig. 6

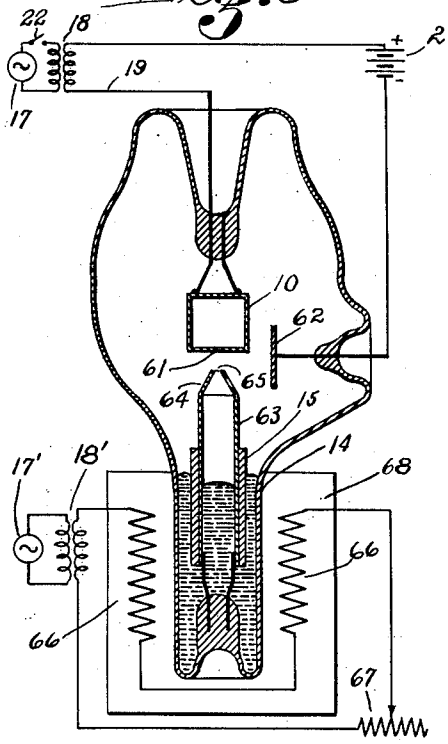
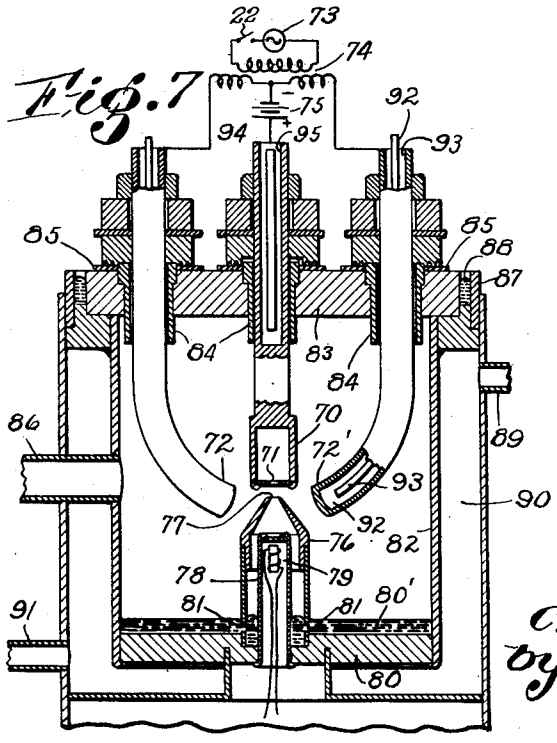


Fig. 7



Inventor
Charles G. Smith,
By Roberts, Roberts & Cushman
Attys.

Patented Oct. 3, 1933 1,929,122

UNITED STATES PATENT OFFICE

1,929,122

VAPOR SPACE CURRENT DEVICE

Charles G. Smith, Medford, Mass., assignor to Raytheon Inc., Cambridge, Mass., a corporation of Massachusetts

Application March 1, 1924, Serial No. 696,337
Renewed May 20, 1933

37 Claims. (Cl. 250—27.5)

This invention relates to gaseous space current devices of the kind utilizing a gaseous body as a source of space current carriers.

Heretofore in the operation of mercury vapor arc-discharge apparatus or similar vapor-discharge devices, it has been considered necessary to produce a "hot spot" or flame at the surface of the liquid being vaporized and to use this spot as the cathode. As a result of this method of operation a large potential drop is produced at the cathode, giving a correspondingly large loss of energy within the apparatus and undesirably limiting the efficiency of operation.

In vapor electric arc-discharge apparatus as used heretofore, there is a large evolution of heat at the cathode causing the liquid of the cathode to vaporize so rapidly that a large vessel is required in order to condense the hot vapor and return the liquid to the cathode. Only a small fraction of the total vapor produced is actually utilized for conveying space current between the cathode and the anode, hence the large loss of energy in the form of heat dissipated through the walls of the tube represents a loss without any compensating advantage. It is highly desirable to eliminate this waste of energy within the tube, not only for the purpose of increasing the efficiency of operation, but also to avoid the use of a bulky tube of complicated construction for dissipating the heat involved.

A further difficulty encountered in the operation of ordinary vapor electric apparatus results from the effect of the load current in varying the impedance of the device. The stability of operation of the device and the regulation of the load is objectionably affected by the load current varying the impedance of the tube.

In prior single phase mercury-vapor arc tubes it has been considerably essential to maintain the cathode excited by means of a secondary or separate heating source when the main source of electromotive force for producing space current is alternating in character, as, for example, in rectifiers utilizing alternating current of commercial frequencies. The separate excitation of the cathode is necessary because the space current arc goes out at the end of each half cycle and will not start again without special starting means. This difficulty makes it necessary in prior tubes to provide more complicated construction in the tube, and additional apparatus external to the tube.

Objects of the present invention are to overcome the above difficulties; to provide efficient space current apparatus of low internal impedance and of simple construction; to reduce the loss of energy within a space current tube resulting from inefficient vaporization of the source of vapor; to provide a simple arrangement whereby a space current tube may be efficiently cooled; to reduce the size of tubes capable of handling a given amount of power; to provide improved methods of and means for efficiently producing and ionizing vapor; to provide improved forms of cathodes; to provide an efficient form of rectifier of low resistance; to efficiently excite the emission of electrons from a cathode utilizing gas or vapor as a promoter of emission without depending upon a continuous passage of current therethrough; to provide improved methods of controlling tubes utilizing ionized gas or vapor; and generally to improve the construction and operation of space current apparatus.

In the arc-discharge devices according to the invention, the cathode is not made of a vaporizable material, but of a solid, refractory body with an extended electrode surface that remains intact while serving as a cathode terminal for the arc discharge. Adjacent the solid cathode surface is formed an enclosure, preferably by making the cathode in the form of a hollow, solid body with an extended interior cathode surface. A gaseous conducting body, such as vapor of mercury, potassium, sodium, gallium, but preferably, cæsium, is held in the enclosure adjacent the solid cathode surface, there being no vaporizable conducting body in the enclosure upon which a cathode terminal could form. The enclosed gas with the associated cathode surface are heated by means of the discharge current or by independent means, or both, to a high temperature and maintained in a state of intense excitation, at which the gas is highly ionized, the cathode enclosure preserving and intensifying the ionization. Under such conditions there is no loss of energy due to excessive vaporization, and the device will operate with an arc or arc-like discharge by which is meant a discharge at a voltage of the order of the ionization voltage of the gas or less. A relatively high pressure is maintained in the cathode enclosure, and the pressure is preferably made substantially independent of the load by supplying the vapor into the cathode enclosure from a vaporizable body that is vaporized by an auxiliary heater.

The invention is described more fully hereinafter in connection with the accompanying diagrammatic drawings of exemplifications thereof, in which

Fig. 1 is a vertical section of a rectifier;

Fig. 2 is a cross-section on line 2—2 of Fig. 1;

Fig. 3 is a vertical section of a modified form of rectifier;

Fig. 4 is a cross-section on line 4—4 of Fig. 3;

Fig. 5 is a modification of a portion of Fig. 3; and

Figs. 6 and 7 are vertical sections of modified forms of rectifiers.

In the device shown in Fig. 1, envelope 10 of impervious material, such as glass, encloses the cathode 11 and the anode 12. The anode may be a disk, or may have any other well-known form. The cathode 11 consists of a cylindrical chamber 11*a* having the conduit 13 of smaller diameter depending therefrom and dipping into a pool of mercury, gallium, cæsium, or other suitable vaporizable substance 14, the conduit 13 being surrounded by a jacket or sleeve of heat insulating material 15 such as porcelain for preventing rapid loss of heat through the walls of conduit 13. The upper end of cathode chamber 11*a* is closed except for the restricted opening 16 through which space current passes to the anode. A source of alternating current 17 is coupled by means of transformer 18 to the rectifier circuit 19 including the storage battery or other load 20 to be charged or supplied with rectified current from the source 17. Rheostat 21 permits of adjusting the current supplied to load 20. The tube permits flow of current only in the direction from the anode to the cathode.

The rectifier is started by closure of switch 22 one or more times to cause a transient high potential to be transferred to cathode 11 and anode 12 to start the flow of space current between the cathode and the anode. The heat evolved within cathode 11 is conducted down the conduit 13 to the vaporizable substance 14 which is vaporized by the heat and passes upward into the chamber 11*a* wherein the heat evolved by the drop of potential in the vapor rapidly increases the temperature of the vapor and the cathode until the increase of temperature reduces the impedance of the vapor by ionizing the vapor or by exciting the vapor to a prepared state in which it is readily ionized by low voltage collisions of electrons with molecules. Thus it will be seen that the temperature of the vapor will be at a higher value than the temperature of the vaporizable substance and the vapor immediately adjacent to it. When gallium is employed the heat from the cathode or other suitable source of heat should maintain the gallium at a temperature of at least 30 degrees centigrade in order to maintain the gallium in liquid form.

The reduced impedance within the cathode caused by the increase of temperature and the increased ionization of the vapor automatically sets a limit to the heating of the cathode, so that a relatively fixed temperature is quickly established, the heat evolved within the cathode being dissipated by the external cathode surface which is free to radiate the heat in substantially all directions from the cathode to surrounding heat-absorbing media. By making envelope 10 transparent to the radiations of the cathode 11 the envelope is only slightly heated in the presence of the intense radiations of the cathode. On the other hand, if it is desired, the envelope may be chosen to absorb appreciable heat radiated from the cathode, the envelope being cooled by convection of air or other cooling fluid around the tube.

The intense heating of the chamber 11*a* and of the gas or vapor within chamber 11*a* produces a strong emission of electrons, the heat and intense radiation within the chamber photo-electrically and otherwise ionizing the vapor or exciting it to a prepared state as mentioned before. Since the electron emission is produced in the interior of the chamber and the radiation of heat occurs from the exterior of said chamber, it will be seen that the heat radiation takes place from a surface which is different from that from which the electron emission occurs. When mercury vapor is employed, the cathode is preferably raised to white heat and at this temperature adequate ionization of the mercury vapor is readily produced.

In the arrangement shown in the drawings, thermal ionization and ionization resulting from exciting the atoms to a prepared state in which slight further excitation produces ionization, is produced by feeding the vapor to be ionized into a conducting chamber having a restricted opening through which electrons are transmitted to the anode under the influence of the potential gradient between the cathode and anode. The conducting chamber functions as an electrostatic shield around the ionized gas within the chamber. The opening through which electrons are transmitted is large enough to permit withdrawal of electrons by the electric field but is small enough so that the relatively heavy ions are afforded little opportunity to escape through the opening during the short interval when they register with the opening.

The slight drop of potential within the chamber caused by space current flowing through the opening, causes the chamber and the vapor in the chamber to rise to a much higher temperature thereby maintaining a copious supply of electrons, so that at all times more electrons are available than are required for transmission of the space current. The heating of the gas in the chamber maintains the vapor thermally excited during slight intervals when the space current ceases, as between half cycles of an alternating current, or when the current becomes relatively small. This form of cathode is therefore adapted, without additional heating means, to provide a continuous supply of electrons for transmission to the anode, and is of particular utility in rectifier tubes wherein the space current periodically passes through a zero value.

The chamber form of cathode is particularly adapted for the use of sodium-potassium alloy, cæsium, or other alkali metal as well as for mercury, gallium, or other vaporizable substance, the advantage in employing the alkali materials being in part due to the very low voltage drop at the cathode when thermal ionization or ionization employing the prepared state of the atom is used. Another advantage in using alkali vapor results from the fact that such vapor is readily excited by radiation of relatively long wave length. In general, when a gas or vapor is to be excited by radiation, it is preferred to employ a gas or vapor capable of excitation by a longer wave length than that required to excite mercury vapor.

The cathode chamber may be made of any suitable conducting material which is refractory at the temeprature utilized. By employing highly refractory material in the cathode and providing a relatively large external surface, the outer cathode wall presents an efficient radiating surface for radiating the heat losses within the chamber. It is advantageous to utilize a cathode chamber, the inside walls of which are capable

of efficient reflection. The form of cathode described may be placed relatively close to the anode, the heat being evolved largely within the cathode chamber, although it is evolved to some extent at the anode. When mercury vapor is employed, the cathode is preferably raised to a white heat and at this temperature the discharge produces adequate ionization of the mercury vapor.

By utilizing high temperature in the cathode, the ionization of vapor is not only facilitated, but the temperature of the cathode tends to remain more constant when the space current fluctuates between wide limits for the reason that heat is radiated from the cathode at a rate which is enormously greater than the proportional increase in temperature above that utilized in ordinary tubes, owing to the tendency of the radiation to increase according to the fourth power of absolute temperature. When the space current increases, a very slight increase in the temperature of the cathode results in a greatly increased radiation of heat, so that the temperature tends to remain relatively constant. As a result of the high temperature used, efficient ionization is produced and the voltage drop in the tube is very small, thereby producing very small loss of energy and a relatively small amount of heat to be dissipated as compared to prior tubes, this heat being concentrated by the cathode chamber so that a suitably high temperature is produced.

In the rectifier modification shown in Fig. 3 the envelope 10 encloses the cylindrical cathode 23 supported from its upper closed end and having its open end 24 disposed close to the upper end of the conduit 25, the lower end of which dips into the vaporizable liquid 14 such as mercury, alkali metal, or other suitable substance. The filamentary heating element 26 is connected by supporting leads 27, 28 to winding 29 of transformer 30 which is supplied with power from the source of alternating current 17. Filament 26 is preferably constructed to operate at a high temperature, such as at a bluish white heat, when a relatively low voltage is applied thereto, thus affording a minimum tendency for the transmission of space current to the filament as a result of the voltage drop therein. The filament is wound to have a spiral concave shape which causes intense radiation to fall upon the inner walls of cathode 23, the filament being spaced close to the opening 24 in the chamber in order to transmit its radiations most efficiently to the cathode. The heat from filament 26 causes the mercury to evaporize and fill conduit 25 and cathode chamber 23 wherein the intensified radiation from the filament helps to ionize the vapor without requiring an excessively high temperature in the material of the chamber. By means of this construction it is possible to utilize a material for cathode 23 which may be photo-electrically excited by radiation from filament 26, producing additional photo-electric emission. Since the cathode is not raised to as high a temperature as that corresponding to the radiation exciting the photo-electric effect and the ionization of the vapor, a material of relatively low melting point, such as calcium for example, or other substance, may be utilized for the cathode, as contrasted with the form of cathode utilized in the rectifier tube of Fig. 1 wherein the emission of ions is excited in part by high temperature within the vapor in the cathode and high temperature in the cathode material.

By using the filament 26, space current is readily established between the cathode 23 and the anode 31 positioned close to the cathode adjacent the open end 24. When cercury or other material requiring high temperatures for ionization is employed in the tube the variable resistance 32 is connected between the filament and cathode 23. This resistance is preferably adjusted to a high value to prevent flow of excessive space current to filament 26.

Fig. 5 shows a modified arrangement of cathode 23 in conjunction with filament 26. In this case cathode 23 is supported by a depending cylindrical portion of larger diameter than the cathode. The filament is heated by current passing through lead 33, conduit 34, filament 26, and lead 35, lead 35 being insulated from conduit 34 by insulator 35'. Cathode 23 is electrically and thermally insulated from conduit 34 by means of the insulating annulus 36, the upper end of which is bevelled to slope downwardly toward conduit 34 to direct condensed vapor through openings 37 in the walls of conduit 34. The opening 38 in cathode 23 adjacent anode 31 provides a passage for space current to the anode from within the cathode.

In Fig. 6, the cylindrical cathode 60 is provided with the opening 61 for space current which is transmitted to anode 62. The conduit 63 at its lower end dips into the pool 14 of vaporizable liquid and is surrounded by heat insulation 15, the upper end converging to form a nozzle 64 having the orifice 65 through which mercury vapor is projected from within conduit 63, the vapor stream being directed toward the opening 61 in cathode 60 to hold a volume of vapor under pressure inside the cathode. The source of current 17 transmits current through transformer 18 to the rectifier circuit 19 wherein the current is rectified between cathode 60 and anode 62 and transmitted to the load 20.

In order to maintain a supply of vapor for the cathode independent of the load current, mercury is evaporized in the interior of conduit 63, as by a suitable heater, and the produced vapor is projected through nozzle 65 against the opening 61 in the hollow cathode 60.

The pressure of vapor in cathode 60 due to the high temperature therein, is counteracted by the vapor stream from nozzle 64 projected against opening 61. In this manner the hot ionized gas is conserved within the cathode chamber.

In Fig. 7, the cathode chamber 70 of refractory material such as tungsten is provided with the aperture 71 through which space current is transmitted to anodes 72 and 72', the current being supplied from the source of alternating current 73 through transformer 74, successive half waves of the alternating current passing alternately through anodes 72 and 72' to supply rectified current to the load 75. The vapor nozzle 76 having the opening 77 for spouting vapor toward opening 71 in the cathode is heated by the cylindrical chamber 78 concentrically disposed within nozzle 76 and containing the removable electrical heating unit 79. Nozzle 76 is supported from the base 80 above which is located the vaporizable liquid 80' which is transmitted through holes 81 into the nozzle to be vaporized. The action of nozzle 76 in conjunction with cathode 70 is similar to that described in connection with nozzle 64 and cathode 60.

The walls 80, 82 and 83 of the tube are preferably of metal of high conductivity, and not easily amalgamated by the liquid being used, for ex-

ample, iron is suitable for the walls when mercury is used as the liquid.

Electrodes 70, 72 and 72' are insulated from the upper wall 83 by bushings 84 of porcelain, or other suitable material and by insulating washers 85. In order to maintain the proper degree of vacuum within the tube an evacuating pump (not shown) is connected in the usual manner to conduit 86 leading from the interior of the tube. All of the walls of the tubes are joined in a gas tight manner except the joint between wall 82 and wall 83 which is ground plane and wetted by a suitable plastic sealing compound to permit of ready removal of wall 83 and the electrodes from the remainder of the tube. This joint is still further sealed by the dam 87 gas tight to wall 82 for retaining the seal 88 of mercury between walls 82 and 83.

The walls of the tube are cooled by circulation of a cooling medium such as water through conduit 89, jacket 90 and conduit 91. The anodes 72 and 72' and insulation 84 therefor, are cooled by the circulation of cooling fluid through concentric conduits 92 and 93 in series. The insulation 84 for cathode 70 is cooled by circulation of cooling fluid through concentric conduits 94 and 95 in series.

I claim:

1. An electrical space discharge device comprising a gas tight vessel containing an anode and a hollow cathode constituting an enclosure around a part of the space in said vessel and having an extended interior solid electron-emitting electrode surface constructed and arranged to be heated during operation to thermionic emission, said cathode having a discharge opening for passing a space discharge between the interior electrode surface thereof and said anode, means associated with said cathode for pumping during operation an ionizable gas into said cathode enclosure at a pressure sufficient to secure a space-current discharge between said interior electron emitting surface and said anode at a voltage of the order of the ionization voltage of the gas or less, and means hindering outflow of gas from said cathode enclosure during the discharge.

2. An electrical space discharge device comprising a gas tight vessel containing an anode and a hollow cathode constituting an enclosure around a part of the space in said vessel and having an extended interior solid electron-emitting surface constructed and arranged to be heated during operation to thermionic electron emission, said cathode having a discharge opening for passing a space discharge between the interior electron-emitting surface thereof and said anode, an ionizable gas in said vessel which has during operation a pressure at which sufficient positive ions are supplied to the discharge to neutralize the space charge, and means including an incandescent element energized independently of the space discharge for heating the interior electrode surface of said cathode to temperature of thermionic emission required to maintain the space discharge during operation of the device and simultaneously maintaining the gas sufficently excited within said enclosure to secure a space current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the gas or less.

3. An electrical space discharge device comprising a gas tight vessel containing an anode and a hollow cathode constituting an enclosure around a part of the space in said vessel and having an extended interior solid electron-emitting wall surface constructed and arranged to be heated during operation to thermionic electron emission, said cathode having a discharge opening for passing a space discharge between the interior electron-emitting surface thereof and said anode, means deriving heat from said cathode for supplying during operation an ionizable gas into said cathode enclosure at a pressure at which sufficient positive ions will be supplied to the discharge to neutralize the space charge, and means including an incandescent element energized independently of the space discharge but exposed to irradiate the same for heating the interior of said cathode to thermionic emission required to maintain the space discharge during operation of the device and simultaneously maintaining the gas sufficiently excited at a high temperature in said enclosure to secure a space current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the gas or less.

4. A gaseous arc-discharge tube comprising a gas tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior, solid, electrode surface, a vaporizable conducting substance positioned and arranged in said vessel to prevent formation of a cathode spot thereon during normal operation of the device, and means for heating the interior of said cathode to high temperature during operation of the device, and simultaneously maintaining vapor from said vaporizable substance excited at sufficiently high temperature and sufficient pressure within said enclosure to secure an arc-like discharge between said interior electrode surface and said anode.

5. An electrical space discharge device comprising a gas tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior, solid, electron-emitting surface constructed and arranged to be heated during operation to provide electron emission sufficient for the space discharge, a vaporizable liquid conducting substance positioned and arranged in said vessel to prevent formation of a cathode spot thereon during operation of the device, means for vaporizing said substance during operation and supplying the vapor therefrom at substantial pressure into said cathode enclosure, maintain the vapor sufficiently excited within said enclosure to secure a space-current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the vapor or less.

6. A gaseous arc-discharge tube comprising a gas tight vessel containing an anode and a cathode structure having an extended solid electron-emitting electrode surface constructed and arranged to be heated to thermionic emission during operation, said cathode structure constituting an enclosure confining a part of the space in front of said emitting surface and shielding the interior against loss of heat and radiation but permitting space current flow between said emitting surface and said anode, and means for maintaining during operation of the device an ionizable gas heated and excited inside said enclosure at a pressure sufficient to produce an arc-like discharge between said anode and said emitting surface.

7. An electrical space discharge device com-

prising a gas tight vessel containing an anode and a cathode structure having an extended solid electron-emitting electrode surface constructed and arranged to be heated during operation to emit more electrons than required for the space discharge, said cathode structure constituting an enclosure confining a part of the space in front of said emitting surface and shielding the interior against loss of heat and radiation but permitting space current flow between said electrode surface and said anode, and means for maintaining during operation an ionizable gas heated and excited within said enclosure at a pressure sufficient to secure a space current discharge between said anode and said emitting surface at a voltage of the order of the ionization voltage of said gas or less.

8. An electrical space discharge device comprising a gas tight vessel containing an anode and a cathode structure having an extended solid electron-emitting electrode surface constructed and arranged to be heated during operation to emit more electrons than required for the space discharge, said cathode structure constituting an enclosure confining a part of the space in front of said emitting surface and shielding the interior against loss of heat and radiation but permitting space current flow between said electrode surface and said anode, and means for maintaining during operation an ionizable gas heated and excited within said enclosure at a pressure sufficient to supply the number of positive ions necessary to secure a space current discharge between said anode and said emitting surface at a voltage of the order of the ionization voltage of said gas or less, said cathode structure being shaped to make the major part of the heat radiation therefrom emanate from a different effective surface than the electron emission.

9. An electrical space discharge device comprising a gas tight vessel containing an anode and a cathode structure having an extended solid electron-emitting electrode surface constructed and arranged to be heated during operation to thermionic emission, said cathode structure constituting an enclosure confining a part of the space in front of said emitting surface and having a discharge opening permitting space current flow between said emitting surface and said anode, means associated with said cathode structure for supplying during operation an ionizable gas in said enclosure at a pressure sufficient to secure a space-current discharge between said anode and said cathode emitting surface at a voltage of the order of the ionization voltage of said gas or less, while maintaining a steep pressure-gradient at said discharge opening to secure low pressure conditions in the space outside said enclosure adjacent said anode.

10. A gaseous arc-discharge device comprising a gas tight vessel containing an anode, a partially open hollow cathode structure having an extended interior electrode surface constructed and arranged to be heated to thermionic emission during operation, and a gas sufficient in amount to constitute during operation a gaseous filling maintained in ionized and excited condition within the hollow cathode structure at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure an arc-like discharge between said anode and the interior of said cathode.

11. An electrical space discharge device comprising a gas tight vessel containing an anode and a hollow cathode constituting an enclosure around a part of the space in said vessel and having an extended interior solid electron-emitting electrode surface constructed and arranged to be heated to thermionic emission during operation, said cathode having a discharge opening for passing a space discharge between the interior electrode surface thereof and said anode, means associated with said cathode for supplying during operation an ionizable gas into said cathode enclosure through said discharge opening at a pressure sufficient to secure a space-current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the gas or less, while maintaining the exterior space adjacent said anode substantially free from ionizable gas molecules and holding the gas excited at sufficient temperature and pressure in said enclosure.

12. An electrical space discharge device comprising a gas tight vessel containing an anode and a hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior solid electron-emitting surface constructed and arranged to be heated during operation to provide thermionic emission greater than required for maintenance of the space discharge, said cathode structure having a discharge opening for passing a space discharge between the interior electron-emitting surface thereof and said anode, a vaporizable substance positioned and arranged in said vessel outside said cathode enclosure to prevent formation of a cathode spot thereon during operation of the device, means for vaporizing said substance during operation and supplying the vapor therefrom to said cathode enclosure at sufficient pressure to secure a space-current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the vapor or less, while holding the exterior space adjacent said anode at substantially lower pressure, said cathode structure being shaped to make the heat radiation therefrom emanate from an effective heat radiating surface thereof different from the surface supplying the major part of electron emission.

13. An electrical space discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface constructed and arranged to be heated during operation to thermionic emission, and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface, to cause a discharge between the anode and the emitting surface inside said cathode enclosure, and shielding the interior of said enclosure against loss of heat and radiation, means for heating the interior of said cathode enclosure during operation, and means for maintaining ionizable vapor heated and excited in said enclosure at a pressure sufficient to secure a space discharge between said anode and said interior cathode emitting surface at a voltage of the order of the ionization voltage of the gas or less.

14. An electrical space discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface constructed and arranged to be heated during operation to thermionic emission, and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure con-

fining a part of the space in front of said emitting surface, to cause a discharge between the anode and the emitting surface inside said cathode enclosure, and shielding the interior of said enclosure against loss of heat and radiation, means including an incandescent element energized independently from the discharge for heating the interior of said cathode enclosure during operation, and means for maintaining ionizable gas heated and excited in said enclosure at a pressure sufficient to secure a space discharge between said anode and said interior cathode emitting surface at a voltage of the order of the ionization voltage of the gas or less.

15. An electrical space discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface constructed and arranged to be heated during operation to thermionic emission, and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface, to cause a discharge between the anode and the emitting surface inside said cathode enclosure, and shielding the interior of said enclosure against loss of heat and radiation, means including an incandescent element energized independently from the discharge for irradiating and heating the interior of said cathode enclosure during operation, and means for maintaining ionizable gas heated and excited in said enclosure at a pressure sufficient to secure a space discharge between said anode and said interior cathode emitting surface at a voltage of the order of the ionization voltage of the gas or less.

16. An electrical space discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface, to cause a discharge between the anode and the emitting surface inside said cathode enclosure, and shielding the interior of said enclosure against loss of heat and radiation, and means for maintaining ionizable gas heated and excited in said enclosure at a pressure sufficient to secure a space discharge between said anode and said interior cathode emitting surface at a voltage of the order of the ionization voltage of the gas or less, while maintaining substantially lower pressure in the space outside said enclosure adjacent said anode.

17. An electrical arc-discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface, to cause a discharge between the anode and the emitting surface inside said cathode enclosure, and shielding the interior of said enclosure against loss of heat and radiation, and means including heating means for maintaining ionizable vapor heated and excited in said enclosure at a pressure sufficient to secure an arc-like discharge between said anode and said interior cathode emitting surface, while maintaining substantially lower pressure in the space outside said enclosure adjacent said anode.

18. An electrical space discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface, to cause a discharge between the anode and the emitting surface inside said cathode enclosure, and shielding the interior of said enclosure against loss of heat and radiation, a vaporizable substance in said vessel outside said cathode enclosure, and means including heating means for supplying ionizable vapor from said substance heated and excited to the interior of said enclosure at a pressure sufficient to secure a space discharge between said anode and said interior cathode emitting surface at a voltage of the order of the ionization voltage of the gas or less.

19. An electrical space discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface constructed and arranged to be heated during operation to thermionic emission, and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface, to cause a discharge between the anode and the emitting surface inside said cathode enclosure. and shielding the interior of said enclosure against loss of heat and radiation, means for maintaining ionizable gas heated and excited in said enclosure at a pressure sufficient to secure a space discharge between said anode and said interior cathode emitting surface at a voltage of the order of the ionization voltage of the gas or less, and means for controlling the pressure in said enclosure independently of the discharge.

20. An electrical space discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface constructed and arranged to be heated during operation to thermionic emission, and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface, to cause a discharge between the anode and the emitting surface inside said cathode enclosure, and shielding the interior of said enclosure against loss of heat and radiation, and means including independently energized electrical heating means for supplying ionizable vapor to the interior of said enclosure and maintaining the vapor heated and excited therein at a pressure sufficient to secure a discharge between said anode at a voltage of the order of the ionization voltage of the vapor or less, while hindering outflow of the vapor from the enclosure and maintaining the exterior space adjacent the anode at low pressure.

21. A gaseous arc-discharge device comprising a gas-tight vessel containing an anode, a partially open hollow cathode structure having an extended interior electrode surface and an outer heat radiating surface, said interior electrode surface being constructed and arranged to be heated to thermionic emission during operation, and a gas sufficient in amount to constitute during operation a gaseous filling maintained in ionized and excited condition within the hollow cathode structure at a pressure high enough to supply the requisite number of positive ions

to neutralize the space charge and secure an arc-like discharge between said anode and the interior of said cathode.

22. A gaseous arc-discharge device comprising a gas-tight vessel containing an anode, a partially open hollow cathode structure having an extended interior electrode surface constructed and arranged to be heated to thermionic emission during operation, and a source of alkali metal vapor within said vessel for supplying during operation to said enclosure alkali metal vapor maintained in ionized and excited condition within the hollow cathode structure at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure an arc-like discharge between said anode and the interior of said cathode.

23. A gaseous arc-discharge device comprising a gas-tight vessel containing an anode, a partially open hollow cathode structure having an extended interior electrode surface constructed and arranged to be heated to thermionic emission during operation, a source of alkali metal vapor within said vessel, and means for heating said emissive surface to temperatures of electron emission during operation of the device and for maintaining alkali vapor from said source in ionized and excited condition within the hollow cathode structure at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure an arc-like discharge between said anode and the interior of said cathode.

24. An electrical arc-discharge device comprising a gas-tight vessel containing a hollow cathode structure having an extended interior solid electron-emitting electrode surface and an anode disposed outside said cathode structure, said cathode structure constituting a partially open enclosure confining a part of the space in front of said emitting surface to cause a discharge between the anode and the emitting surface inside said cathode enclosure, and shielding the interior of said enclosure against loss of heat and radiation, a source of alkali metal vapor within said vessel, and means including heating means for maintaining ionizable vapor from said source heated and excited in said enclosure at a pressure sufficient to secure an arc-like discharge between said anode and said interior cathode-emitting surface, while maintaining substantially lower pressure in the space outside said enclosure.

25. A gaseous arc-discharge device comprising a gas-tight vessel containing an anode, a partially open hollow cathode structure having an extended interior electrode surface constructed and arranged to be heated to thermionic emission during operation, and a source of cæsium within said vessel for supplying during operation to said enclosure cæsium vapor maintained in ionized and excited condition within the hollow cathode structure at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure an arc-like discharge between said anode and the interior of said cathode.

26. A gaseous arc-discharge device comprising a gas-tight vessel containing an anode, a partially open hollow cathode structure having an extended interior electrode surface constructed and arranged to be heated to thermionic emission during operation, and alkali metal vapor within said hollow cathode structure, the alkali metal vapor within said hollow cathode structure during operation being maintained in ionized and excited condition within the hollow cathode structure at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure an arc-like discharge between said anode and the interior of said cathode, the pressure of vapor within said vessel outside of said hollow cathode structure during operation being at a considerably lower value.

27. An electrical space discharge device comprising a gas-tight vessel containing an anode and a hollow cathode constituting an enclosure around a part of the space in said vessel and having an extended interior solid electron-emitting surface constructed and arranged to be heated during operation to thermionic electron emission, said cathode having a discharge opening for passing a space discharge between the interior electron-emitting surface thereof and said anode, an ionizable gas in said vessel which has during operation a pressure at which sufficient positive ions are supplied to the discharge to neutralize the space charge, and means including an incandescent element exposed to the inside of said hollow cathode and energized independently of the space discharge for heating the interior electrode surface of said cathode to thermionic emission required to maintain the space discharge during operation of the device and simultaneously maintaining the gas sufficiently excited within said enclosure to secure a space current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the gas or less.

28. An electrical space discharge device comprising a gas-tight vessel containing an anode and a hollow cathode constituting an enclosure around a part of the space in said vessel and having an extended interior solid electron-emitting surface constructed and arranged to be heated during operation to thermionic electron emission, said cathode having a restricted discharge opening for passing a space discharge between the interior electron-emitting surface thereof and said anode, an ionizable gas in said vessel which has during operation a pressure at which sufficient positive ions are supplied to the discharge to neutralize the space charge, and means including an incandescent element energized independently of the space discharge for heating the interior electrode surface of said cathode to thermionic emission required to maintain the space discharge during operation of the device and simultaneously maintaining the gas sufficiently excited within said enclosure to secure a space current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the gas or less.

29. A gaseous arc-discharge device comprising a gas-tight vessel containing an anode, a partially open hollow cathode structure having an extended interior electrode surface constructed and arranged to be heated to thermionic emission during operation, cæsium vapor within said vessel, and a member exposed to the interior of said hollow cathode member and arranged to be heated during operation to a temperature of incandescence at which it emits radiation that excites the confined vapor, said vapor being sufficient in amount to constitute during operation a gaseous filling maintained in ionized and excited condition within the hollow cathode structure at a pressure high enough to supply the requisite number of positive ions to neutralize the space charge and secure an arc-like discharge between

said anode and the interior of said cathode.

30. An electrical space discharge device comprising a gas-tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior, solid, electron-emitting surface constructed and arranged to be heated during operation to provide electron emission sufficient for the space discharge, a body of mercury positioned and arranged in said vessel to prevent formation of a cathode spot thereon during the operation of the device, means for vaporizing said mercury during operation and supplying the vapor therefrom at substantial pressure into said cathode enclosure to maintain the vapor sufficiently excited within said enclosure to secure a space-current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the vapor or less.

31. A gaseous arc-discharge tube comprising a gas-tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the said vessel and having an extended interior, solid, electrode surface, a vaporizable conducting substance positioned and arranged in said vessel to prevent formation of a cathode spot thereon during normal operation of the device, means for vaporizing said substance and supplying the vapor therefrom at substantial pressure into said cathode enclosure, means for heating the interior of said cathode to high temperature during operation of the device, and simultaneously maintaining vapor from said vaporizable substance excited at sufficiently high temperature and sufficient pressure within said enclosure to secure an arc-like discharge between said interior electrode surface and said anode, and means for controlling the vaporization of said substance independently of the discharge.

32. A gaseous arc-discharge tube comprising a gas-tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior, solid, electrode surface, a vaporizable conducting substance outside of said enclosure positioned and arranged in said vessel to prevent formation of a cathode spot thereon during normal operation of the device, a conduit for conveying vapor from said source to said enclosure, and means for heating the interior of said cathode to high temperature during operation of the device, and simultaneously maintaining vapor from said vaporizable substance excited at sufficiently high temperature and sufficient pressure within said enclosure to secure an arc-like discharge between said interior electrode surface and said anode.

33. An electrical space discharge device comprising a gas-tight vessel containing an anode and a cathode structure having an extended solid electron-emitting electrode surface constructed and arranged to be heated during operation to emit more electrons than required for the space discharge, said cathode structure constituting an enclosure confining a part of the space in front of said emitting surface and shielding the interior against loss of heat and radiation but permitting space current flow between said electrode surface and said anode, a vaporizable substance so arranged in said vessel outside said cathode enclosure as to prevent formation of a cathode spot thereon during operation of the device, means including a conduit extending from said enclosure to said substance for supplying the vapor therefrom at substantial pressure into said cathode enclosure, and means for heating the interior of said cathode to temperature of electron emission during operation of the device and simultaneously maintaining the vapor heated and excited within said enclosure at a pressure sufficient to supply the number of positive ions necessary to secure a space current discharge between said anode and said emitting surface at a voltage of the order of the ionization voltage of said vapor or less, said cathode structure being shaped to make the major part of the heat radiation therefrom emanate from a different effective surface than the electron emission, said conduit being arranged to carry heat from said cathode to said substance to vaporize the same.

34. A gaseous arc-discharge tube comprising a gas-tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior, solid, electrode surface, a vaporizable conducting substance positioned and arranged in said vessel to prevent formation of a cathode spot thereon during normal operation of the device, means for vaporizing said substance and supplying the vapor therefrom at substantial pressure into said cathode enclosure, means for heating the interior of said cathode to high temperature during operation of the device, and simultaneously maintaining vapor from said vaporizable substance excited at sufficiently high temperature and sufficient pressure within said enclosure to secure an arc-like discharge between said interior electrode surface and said anode, and heat insulating means around said vaporizing means.

35. A gaseous arc-discharge tube comprising a gas-tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior, solid, electrode surface, a vaporizable conducting substance positioned and arranged in said vessel to prevent formation of a cathode spot thereon during normal operation of the device, means including a conduit extending from said enclosure to said substance for vaporizing said substance and supplying the vapor therefrom at substantial pressure into said cathode enclosure, means for heating the interior of said cathode to high temperature during operation of the device, and simultaneously maintaining vapor from said vaporizable substance excited at sufficiently high temperature and sufficient pressure within said enclosure to secure an arc-like discharge between said interior electrode surface and said anode, said conduit being arranged to carry heat from said cathode to said substance to vaporize the same, and heat insulating means around said conduit for preventing loss of heat therefrom.

36. An electrical space discharge device comprising a gas-tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior, solid, electron-emitting surface constructed and arranged to be heated during operation to provide electron emission sufficient for the space discharge, a vaporizable liquid conducting substance outside of said enclosure positioned and arranged in said vessel to prevent formation of a cathode spot thereon during oper-

ation of the device, a conduit immersed at one end in said liquid conducting substance and having its opposite end connected to the interior of said enclosure, means for vaporizing said substance during operation and supplying the vapor therefrom through said conduit at substantial pressure into said cathode enclosure to maintain the vapor sufficiently excited within said enclosure to secure a space-current discharge between said interior electron-emitting surface and said anode at a voltage of the order of the ionization voltage of the vapor or less.

37. A gaseous arc-discharge tube comprising a gas-tight vessel containing an anode and a partially open hollow cathode structure constituting an enclosure around a part of the space in said vessel and having an extended interior, solid, electrode surface, a vaporizable conducting substance positioned and arranged in said vessel to prevent formation of a cathode spot thereon during normal operation of the device, a conduit extending from said enclosure to said substance, a heater in said conduit for vaporizing said substance and supplying the vapor therefrom through said conduit to said enclosure at substantial pressure higher than outside said enclosure, and means for heating the interior of said cathode to high temperature during operation of the device, and simultaneously maintaining vapor from said vaporizable substance excited at sufficiently high temperature and sufficient pressure within said enclosure to secure an arc-like discharge between said interior electrode surface and said anode.

CHARLES G. SMITH.

CERTIFICATE OF CORRECTION.

Patent No. 1,929,122. October 3, 1933.

CHARLES G. SMITH.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, line 39, for "considerably" read considered; page 3, line 78, for "cercury" read mercury; page 4, line 129, claim 5, strike out the comma and insert the word to; page 8, line 25, claim 31, after "the" insert space in; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 28th day of November, A. D. 1933.

F. M. Hopkins

(Seal) Acting Commissioner of Patents.