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GASEOUS DISCHARGE SYSTEM

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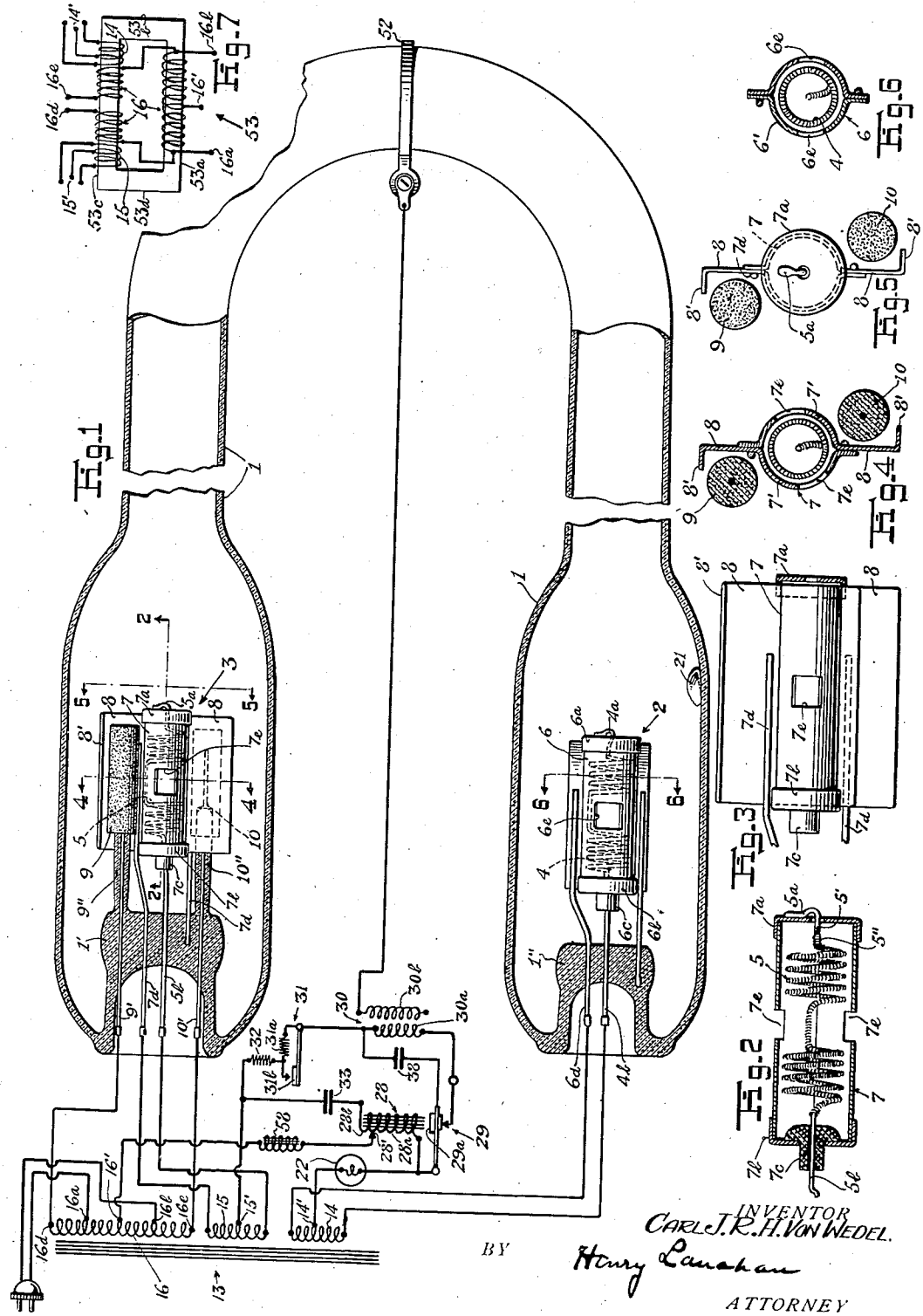


Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

INVENTOR
CARL J. R. H. VON WEDEL.

BY Henry Lanahan

ATTORNEY

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GASEOUS DISCHARGE SYSTEM

Carl J. R. H. von Wedel, West Orange, N. J., assignor to Thomas A. Edison, Incorporated, West Orange, N. J., a corporation of New Jersey

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The present invention relates to gaseous discharge systems, and especially to systems operating from alternating current to provide a luminous arc discharge. It will be understood, however, that various sub-combinational features of the invention may be useful in other than such particular discharge systems.

An important object of the invention is to provide a system of the type described which operates with a very high efficiency of light output from the luminous column relative to power input.

An allied object is the reduction of the ballasting means normally required in such a system.

Another important object is the reduction of the flicker of the luminous column ordinarily occurring in such systems.

Still another object is the extension of the range of supply voltage over which the system will satisfactorily operate.

Yet another object is the improvement of the color of the light emitted by the luminous column.

A more detailed object of my invention is the provision of a small cathode requiring a minimum of heating power and characterized by an improved life.

Another such object is the provision of an improved rectifier structure wherein the anodes and cathode are relatively closely spaced.

Still another such object is the provision of improved and more dependable means for starting the arc discharge.

Other and allied objects will more fully appear from the following description and the appended claims.

In the description reference is had to the accompanying drawing, of which:

Figure 1 is a view of a discharge device and an associated circuit according to my invention, the discharge device appearing principally in section and the circuit schematically;

Figure 2 is a cross-sectional view taken along the line 2—2 of Figure 1, illustrating the interior of one of the electrode structures;

Figure 3 is an enlarged elevational view of a portion of the electrode structure 3;

Figures 4, 5, and 6 are cross-sectional views taken along the lines 4—4, 5—5, and 6—6 of Figure 1; and

Figure 7 is a schematic view of a special form of transformer which may advantageously be employed in the circuit of Figure 1.

Reference is first invited to Figure 1. Herein appears an elongated glass vessel or other envelope 1, adapted to contain a gaseous filling—i. e., a filling of gas and/or vapor—in which to create a luminous arc discharge of any desired intensity and for any desired purpose. The presence of desired vapor in the filling may be effected by the vaporization of a small amount of appropriate metal placed within the envelope, such metal being shown by way of example in Figure 1 as the globule 21 of mercury. Main discharge electrode structures 2 and 3 are suitably positioned within the envelope, for example at its respectively opposite extremities, the arc discharge being intended to take place between these structures.

The electrode structure 2 comprises the main cathode 4 of the device together with a shield can 6 therefor, while the structure 3 comprises the two anodes 9 and 10, a second or auxiliary cathode 5 whose function is hereinafter more particularly set forth, and a shield can 7 about the cathode 5. Both the cathodes 4 and 5 comprise thermionic elements—i. e., elements favorably adapted to emit electrons when heated—and have been illustrated as coiled filaments. These have been shown arranged to be at least partially heated by currents from the heating windings 14 and 15 of the transformer 13, but it will be understood that many of the features of my invention are adapted for employment as well with other forms of cathodes, such as normally cold cathodes adapted to be heated substantially wholly by ionic bombardment attendant upon the main arc discharge, or indirectly heated cathodes of well known structure wherein activated metal surfaces are heated by adjacent heating coils.

The electrode structure 3 may conveniently be first described, reference being had to the cross-sectional Figures 2, 4, and 5 and to the enlarged fragmentary Figure 3, as well as to Figure 1. The cathode element 5 is preferably made from a heater wire 5′ onto which has been wound and welded a fine wire 5″. The wire 5′ is coiled into the form of a helix, the turns of which are relatively close to one another, excepting that they are divided into two groups by a spacing, at about the longitudinal center of the helix, of the order of 2 to 2½ times the side dimension of apertures 7e hereinafter referred to. The cathode 5 is coated with a rather heavy Wehnelt type oxide coating.

The cathode 5 is supported within and shielded by a cylindrical can or thimble 7, which is made of an internal diameter only slightly exceeding the external diameter of the cathode 5. The can 7 is provided with anode-shielding vanes 8, and

may conveniently be formed, as appears in Figure 4, of two similar metal plates 7', each in the form of a semi-cylinder from which extends in an axial plane one of the vanes 8, the plates being appropriately assembled and welded together. Each vane 8 may be provided with a right-angular flange 8' at its outer extremity. The ends of the cylinder may be closed by the cup-shaped metallic top and bottom members 7a and 7b respectively. A first extremity 5a of the cathode 5 may be led through the top member 7a and welded to the outside of the top member (thereby rendering the shield can 7 at the potential of one extremity of the cathode), while the other cathode extremity 5b may be led outwardly of the can 7 through an isolantite or other insulating bushing 7c inserted centrally in the bottom member 7b, and outwardly of the envelope 1 through the stem or seal 1' to be electrically connected to one extremity of the heating winding 15 of the supply transformer 13. The can 7 is supported to the seal 1' by small rods 7d welded to the can, one of these rods extending through the seal to be electrically connected to the other extremity of the heating winding 15. The cathode is arranged to operate at a relatively low voltage—of the order of 2 to 3 volts—and the coated fine spiral wire 5'' on the wire 5' insures sufficient insulation from the can 7 should the cathode sag or warp into contact with the can. It also prevents shorting between adjacent turns of the helix.

The anodes 9 and 10 are disposed on opposite sides of the shield can 7, preferably very closely spaced from the vanes 8 and generally within the L's formed by the vanes 8 and their flanges 8'. The anodes are supported on the rods 9' and 10', these passing outwardly through the envelope seal 1'. This seal is shown provided with the beads or extensions 9'' and 10'', these extensions surrounding the respective rods 9' and 10' to within the respective anodes. The rods 9' and 10' are electrically connected to the respective extremities 16d and 16e of the high voltage winding 16 of the transformer 13. This high voltage winding may be tapped at points 16a and 16b, symmetrically located about its centerpoint, to form a primary for connection to the alternating current supply. On this transformer 13 are also wound the separate heating windings 14 and 15 elsewhere mentioned.

The cylindrical portion of the can 7 is provided with two apertures 7e. These may be square, and of a size hereinafter more fully specified. Longitudinally of the cylinder, these apertures are approximately centralized with the central spacing of the helix above mentioned; in the other dimension they are approximately centralized in a plane passing through the cylinder axis normal to the plane containing the axes of the two anodes—in other words they are situated on opposite sides of the cylinder in each case approximately midway between the anodes.

The electrode structure 2, comprising the main cathode 4 of the device and a shield can 6 therefor, may be formed of components quite similar and similarly arranged to the components of the electrode structure 3, excepting that the vanes 8 and the anodes 9 and 10 with their supporting means are omitted from the structure 2. The components of the structure 2 are supported to the seal 1'', located at the opposite extremity of the device from the seal 1', and in each case are designated in the figures by numerals less by 1 than those provided for the respectively analogous components of the structure 3. The shield can 6 (and thus the extremity 4a of the cathode 4) and the other extremity 4b of the cathode 4 are connected to the respective extremities of the heating winding 14.

In the case of either of the cathodes 4 and 5, the internal radius of the helix formed by the cathode should be materially greater than the mean free path of the gas molecules at operating temperature and several times greater than that of the electrons which in the operation of the cathode leave the cathode surface and travel perpendicularly toward the axis of the helix. The reason for this specification is that the electronic current leaving the cathode surface and proceeding toward the helix axis must be able to build up a region of positive space charge about the axis, otherwise the discharge will take place only to the portions of the cathode immediately adjacent the shield can apertures. This positive space charge can of course not be created at a region nearer to the cathode than the mean free path of the electrons. This mean free path is of course dependent on the density and molecular weight of the gaseous filling which exists within the shield can under operating conditions. In a discharge device operating with a gaseous filling comprising both rare gas and metal vapor, the gaseous filling within both the shield can and the rest of the device when the discharge is first started is of course of substantially pure gas. As the temperature of the device rises, however, increasing densities of metal vapor are formed in the device. The vapor molecules, being preferredly ionized, then enter the shield can, and by virtue of their greater mass largely displace from out of the can the gas molecules; thus when the device has reached full operating temperature the gaseous filling within the shield can is largely of metal vapor. The mean free path of the electrons will vary with these varying conditions of the gaseous filling in the shield can, and it is desirable that the longest mean free path attained by the electrons under any of these conditions be appreciably exceeded by the radius of the cathode. At the same time this radius is preferably not permitted to attain an unnecessarily large value. As a specific example, a cathode internal radius of 2 to 2½ millimeters has been found satisfactory in a discharge device having a gaseous filling of krypton or argon at a pressure of 2 to 2½ mm. Hg together (when the device has reached full operating temperature) with mercury vapor at a pressure corresponding to a wall temperature of 60 to 90 degrees C., the cathode then operating at a temperature of 800 to 900 degrees C.

The length of the cathode should not be too great relative to the cathode diameter; a ratio of length to diameter of the order of 2 or 2½ to 1 is however permissible. The reason for this specification is that if the cathode is excessively long relative to its diameter there will develop along the cathode axis a significant potential gradient, which will cause the discharge to take place quite predominately to the portions of the cathode immediately adjacent the shield apertures. In the case of the typical device above mentioned, a satisfactory cathode length was of the order of 10 millimeters.

The most desirable size of the apertures in the shield can varies with the value of the discharge current which is to take place to the cathode. The apertures must be made small enough to produce an appreciable potential gradient in the dis-

charge passing therethrough, otherwise the discharge will be found to pass through only one of the two apertures, to some extent impairing the uniformity with which the discharge proceeds to the several cathode portions. Of course extremely small apertures which would produce excessive potential losses are to be avoided. For currents of the order of 2 amperes, which is the approximate discharge current in the luminous column of the typical device above mentioned, the apertures may satisfactorily be approximately 2 by 2 millimeters.

The structure of the cathodes having thus been described, some of the advantages of this structure generic to the two cathodes may be set forth. In the first place a cathode of this form may be heated most efficiently—e. g., a very low value of heating current may be employed—because the shield can tremendously reduces the gaseous convection currents between the immediate neighborhood of the cathode and other and cooler portions of the discharge device. Thus a cathode of this form to support a 2 ampere discharge may be satisfactorily heated by only 15 watts and may be correspondingly small, as compared with a larger cathode operating with 30 or 40 watts required to perform the same function when exposed to the mentioned gaseous convection currents. For the same reason a short length of time for the initial heating of the cathode is assured. Again, the high current density in the shield can apertures enforces ionization of alkaline earth material disintegrating from the cathode surface, so that the field of the tube transports this material back to the cathode, improving the cathode life and avoiding discoloration of the glass walls of the envelope 1. Further, in the particular case of devices operating with a filling including metal vapor, the extra high vapor density within the shield can relative to other space within the device, above explained, reduces the vaporization of cathode material, providing a longer cathode life and/or permitting a smaller cathode for given discharge current thereto. Finally, and independently of the nature of the gaseous filling, the discharge, entering the shield can through its two apertures, is thereby forced to enter into the axial space within the helix, and therefrom diffuses in a most even manner over the entire inner cathode surface, eliminating the danger of uneven or spot-heating of the cathode.

In devices operating with a filling of rare gas and metal vapor, the use of the described cathode structure for the main cathode of the device has an additional advantage. In the operation immediately following the starting of such devices the potential gradient of the luminous column increases with the steadily increasing metal vapor density until the device reaches its normal operating temperature. In such tubes with the described form of cathode structure, however, there is a tendency for the potential gradient in the shield can apertures to be initially higher than after the device has reached normal operating temperature, this offsetting to some extent the change of potential gradient of the luminous column, reducing the net potential change across the entire device and permitting the reduction of the usual series ballasting means and of the power consumed therein. This action may be assisted to some extent, or produced to some extent in devices having this cathode structure but operating without metal vapor in the filling, by an initially extra high cathode drop brought about by employing for the cathode a heating current somewhat less than required for full emissivity of the cathode. This I have found it permissible to do because this cathode structure has proven well adapted for some additional heating by ionic currents, without danger of puncturing by spot-heating of the cathode surface

Certain advantages exist particularly with relation to the electrode structure 3 as above described. In the first place, the vanes 8 provide good shielding of the anode surfaces, preventing cross-arcing therebetween and undue ionic bombardment thereof. Further, by virtue of the relative disposition of the anodes and the apertures 7e, disintegrating anode material is substantially prevented from flying to and contaminating the cathode surface; with carbon anodes this minimizes the deposit of carbon on the cathode and the attendant formation of undesired gases in the discharge path. Again, such disintegrating cathode material as may not be ionized in the apertures 7e and transported back to the cathode is flung from the apertures toward the envelope walls, preventing contamination of the anodes thereby.

The discharge device proper having been thus described, attention may now be directed to appropriate circuit arrangements for its operation. Without the employment of the cathode 5, the device may of course be operated, as the usual double anode alternating current discharge device, by a wholly conventional circuit. In the preferred embodiment of my invention, however, the cathode 5 is employed in a circuit arrangement which I shall now proceed to explain.

In conventional circuit systems for double anode alternating current discharge devices it is customary to connect the center-tap of the high voltage supply to the cathode of the device through a choke coil and a series ballasting resistance or lamp. The choke coil both limits the peak discharge currents and also slightly prolongs each successive discharge so that it extends to an instant at which the succeeding discharge (to the other anode) can begin. Viewing the choke coil action in another light, it reduces the pulsations in the voltage between cathode and the instantaneously most positive anodic element (i. e., the voltage across the luminous column), both limiting the peaks and raising the valleys in this voltage. A strong pulsation or ripple component having a fundamental or main frequency of twice the supply frequency still remains in this voltage, however, and in the current through the choke coil and is responsible for the flicker of the light produced by the luminous column.

An important feature of my invention is the reduction of this ripple component, whereby the light flicker is reduced. This reduction I accomplish by inducing into the choke coil a ripple voltage appropriate to oppose the ripple voltage between the cathode and the instantaneously most positive anodic element. The ripple voltage induced may be otherwise defined as one appropriate to cause the potential of the cathode extremity of the luminous column to fluctuate similarly in phase, amplitude and waveform to the potential of the anode extremity of the column (though of course remaining at a definite direct potential difference therefrom). Still otherwise, the ripple voltage induced may be defined as one appropriate to oppose current fluctuations in the choke coil; this definition is synonymous with the others, since the current through the choke coil is the same as the current through the lumi-

nous column, and if voltage fluctuations across the luminous column are opposed the current fluctuations are opposed, and vice versa.

A circuit appropriate for addition to the conventional system to effect the required ripple induction might theoretically be formed of an auxiliary coil, tightly coupled to the choke coil in proper polarity and an appropriate condenser in series with the auxiliary coil, this series circuit being connected between the input extremity of the choke coil and the instantaneously more positive anode. Practically, of course, it is impossible to make a direct connection to the instantaneously more positive anode, since this would require a connection which automatically shifted cyclicly from one anode to the other and back again. I have found, however, that such a series circuit may advantageously be connected between the input extremity of the choke coil and an emissive cathode located closely adjacent the two anodes. Such a cathode forms with the two anodes an auxiliary discharge device or rectifier in which, by virtue of the close spacing of its elements, the voltage drop when the device is discharging is extremely low.

Reference may be conveniently had at this point to Figure 1, which may be considered for the present with the choke coil **58** omitted (i. e., short-circuited). The center-tap **16'** of the high voltage winding **16** is then connected to the tap **28'** on the choke coil **28**. This tap divides the total coil into two sections: one **28*a***, which is preferably the larger of the two and which forms the choke coil as discussed in the preceding paragraphs; and the other **28*b***, which is preferably the smaller, which forms the auxiliary coil discussed above, and which is of course tightly coupled to the section **28*a***. The tap **28'** forms the "input" extremity of the section **28*a***, the other or output extremity of which is connected, through the series ballasting resistance or tungsten lamp **22** to the main cathode **4** (the connection to the cathode being made if desired through the medium of a center-tap **14'** on the heating winding **14** for this cathode). The outer extremity of the section **28*b*** is connected through the condenser **33**, which comprises the condenser discussed in the preceding paragraph, to the rectifier cathode **5** (the connection to this cathode being made if desired through the medium of a center-tap **15'** on the heating winding **15** for this cathode). The preferred physical formation of the cathode **5** and its disposition relative to the anodes **9** and **10** have already been outlined.

For the ripple inducing circuit to function properly, there must be at least very approximately established a proper inter-relationship between its parameters—i. e., between the constants of the choke coil **28** and the capacity of the condenser **33**. It seems that theoretically the capacity of the condenser **33** should be of the order of magnitude of the capacity required for resonance, to the ripple frequency, with the mutual inductance between the auxiliary choke section **28*b*** and the entire choke coil. (This mutual inductance is the same as the sum of the self-inductance of the auxiliary section **28*b*** and the mutual inductance between the two sections **28*a*** and **28*b***.) This capacity value I have not found sharply critical, however, and I have satisfactorily employed for **33** a condenser of a fraction of the value indicated above. More broadly, then, the capacity value may be specified as one of the order required for resonance to the ripple frequency with the total inductance of the choke coil **28**—i. e., of the sections **28*a*** and **28*b*** when mutually aidingly coupled.

The explanation of beneficial result from the connection of the ripple inducing circuit **33—28*b*** to the rectifier cathode **5** appears to be that the potential of this cathode in a very general sense approximates that of the most positive anodic element. This is because if its potential rises above that of the instantaneously more positive anode, the rectifier cathode (and its shield **7**) will itself become the most positive anodic element (under which conditions it will support at least a portion of the main arc discharge, thus lowering the charge in condenser **33** and reducing the rectifier cathode potential); while whenever the rectifier cathode potential is several volts lower than the instantaneously more positive anode potential, current is passed in the rectifier, charging the condenser **33** and raising the rectifier cathode potential.

The rectifier supports a ripple current flow through the circuit **33—28*b***, by virtue of which flow the circuit performs its function of ripple voltage induction into the choke section **28*a***. This ripple current flow, however, is strongly displaced in phase from the instantaneously more positive anode potential; it appears that it tends to lead the latter by very roundly 90 degrees in a ripple cycle. (The circuit **33—28*b*** is of course by itself capacitive, and would cause the ripple current flowing through it to be advanced by something less than 90 degrees; its coupling to the choke section **28*b*** and the ripple current through the latter, however, are responsible for the additional phase displacement.) Apparently this displaced phase condition of the ripple current through the circuit **33—28*b*** causes the approximation of the potential of the instantaneously most positive anodic element by the rectifier cathode potential to be only fair—a condition which reacts on the ripple current in question to affect its characteristics unfavorably to its function of proper ripple voltage induction. However, with this circuit arrangement (i. e., without the choke coil **58**) I have been able approximately to halve the ripple current through the choke section **28*a***, and hence markedly to reduce the ripple voltage across the luminous column and the light flicker; this is by comparison to a simple circuit in which the choke coil employed was identical with the entire choke coil **28** of the described circuit.

I have found that if, in the circuit as described, I insert the additional choke coil **58** between the center-tap of the high voltage winding **16** and the tap **28'** on the choke coil **28**, I reduce to substantially zero the ripple current through the choke section **28*a***, the ripple voltage across the luminous column, and the light flicker. The inductance of the choke coil **58** must be materially greater than that value which, when added to the inductance value of the auxiliary choke section **28*b***, will resonate with condenser **33** to the ripple frequency. This is first necessary to avoid dangerously high ripple voltages across the condenser **33** which might cause its break-down, and secondly is desirable for the function of flicker elimination. Thus the value of the choke coil **58** may be of the order of that of the choke section **28*a***, and may even be larger.

Apparently an important function of this choke coil **58** is a substantial retardation of the ripple current through the circuit **33—28*b***, bringing this current more closely into phase with the instantaneously more positive anode potential

and improving the approximation by the rectifier cathode potential of the potential of the instantaneously most positive anodic element. The choke coil 58 of course renders inductive the simple circuit 33—28b; because of the coupling of this circuit to the choke section 28a, however, the current retardation may not be wholly sufficient to render the ripple current through the circuit in phase with the instantaneously more positive anode potential unless the choke coil 58 be made of very high inductance. In any event it appears that a choke coil of the order mentioned is sufficient to provide ample retardation of the ripple current. Another function which it is possible for the choke coil 58 to perform, in cooperation with the succeeding circuit elements 28 and 33, is the actual filtration of the ripple current flowing between the high voltage winding 16 and the main cathode 4. This function is only significantly performed as to the main ripple frequency with relatively high inductance values for the choke coil 58, which I have found it unnecessary to employ; as to ripple components at harmonics of the main ripple frequency, however, this function is probably always more or less significantly performed. The choke coil 58 of course exerts a retarding influence not only on the ripple current through the circuit 33—28b, but also on other ripple currents in the system; because of similarity of these retarding influences, however, the relationships between the parameters of the choke coil 28 and the condenser 33 as above outlined remain satisfactory when the choke coil 58 is inserted in the circuit.

With the circuit constructed and properly apportioned as thus described the voltage across the luminous column is substantially free of fluctuation and the discharge current is substantially pure direct current. The absence of appreciable peaks facilitates the use of a small cathode 4, it being well known that the capacity of the cathode must be in conformity with the peak maximum discharge current thereto. The cathode 5, passing only the current required for the ripple inducing circuit 33—28b, operates under less current stress than the cathode 4, and therefore need obviously be no larger.

The system must not be confused with one wherein the current for a D. C. discharge device is rectified and smoothed by a rectifier and filter external to the device. Not only is its structure and mode of operation obviously distinct therefrom, but it has important operational advantages thereover. In the separate rectifier system the rectifier would be called on to pass the entire discharge current for the device. Consequently, such an external rectifier having to pass much more current than the rectifier in my improved system, the power losses would be materially higher, the cathode of the external rectifier would have to be much larger than my cathode 5 or even my cathode 4, since it would have to withstand not only the full device discharge current but also large peaks therein; a second anode fall would have to be accounted for, which is absent in my system in view of the employment of only one pair of anodes; etc. Even though I employed for my rectifier a full-wave rectifier external to the discharge device with anodes respectively connected with the device anodes, which I might less preferredly do, practically all of these distinctions would still obtain.

The important advantages of the circuit arrangement which I have described do not stop with the substantial elimination of discharge current ripple and of light flicker. Another most important advantage, assuming the device to be employed with a given value of ballasting means (e. g., lamp 22), is a tremendous increase in the range of supply voltage over which the device will operate without extinguishment of the discharge or other undesirable effect. The principal reason for this may be simply outlined as follows:

In the operation of a discharge device the instantaneous discharge current in each cycle will fluctuate over a range which is very roughly proportional to the fluctuation of voltage in each cycle across the luminous column. There is, as is well known, a lower limit of discharge current through a given discharge device below which the minimum instantaneous current cannot be permitted to fall without discharge extinguishment. Likewise there is an upper limit above which the instantaneous current should not be permitted to rise, this upper limit being very critical as to discharge extinguishment in the case of tubes operating with a filling including metal vapor. When the voltage fluctuation across the luminous column is appreciable the minimum and maximum current values may approach respectively the lower and upper current limits just mentioned. If now the mean supply voltage varies appreciably, either the minimum or maximum instantaneous current value (as the case may be) may pass its respective limit. Indeed, the way in which a reasonable tolerance to varying supply voltage is normally obtained is by the use of a very substantial value of ballasting means, which of course has a stalbilizing effect on the current. In my improved circuit arrangement the voltage fluctuation across the luminous column is substantially zero, the minimum and maximum instantaneous current values are therefore practically coincident, and therefore the minimum current value is much larger and the maximum current value much smaller than the corresponding values with conventional circuits. Accordingly the supply voltage must vary very much more widely before either current value may pass its respective limit.

The vast increase therein renders the permissible range of supply voltage variation quite unnecessarily large, and accordingly I am able greatly to reduce the value of the ballasting means. This in turn enables me to make any one of several advantageous readjustments of the parameters of the circuit and/or device proper, while retaining a satisfactory permissible supply voltage range. Three particular such readjustments may be mentioned, any one of which may be effected to a large extent alone, or to a reduced extent in combination with one or both of the others. First, I may reduce the size of the high voltage winding 16 appropriately to the reduction of the ballasting means, thereby reducing the power consumed by the system; the light output remaining constant, however, the efficiency of the system is improved. Secondly, I may increase the length of the luminous column appropriately to the reduction of ballast, increasing the light output of the system without increasing its power consumption. Thirdly, I may operate the discharge device with a higher discharge current; this, at least in the case of a device operating with a filling including metal vapor, improves the color of the light emitted by the luminous column. For example, with a device employing mercury as a vaporizable metal and having envelope walls of a yellow uranium

glass, the color of the emitted light becomes more whitish-green in character and more pleasing to the eye. It may be mentioned that the character of the light can be further improved, when operated with this greater current density, by including in small quantities with the mercury, as further metal adapted for vaporization, alkaline metals and metals such as cadmium, zinc, thallium and other metals whose vapors are of lower ionization potential than mercury vapor.

That portion of the circuit directed to the maintenance of the discharge having thus been described, attention may be directed to the further circuit components which, in cooperation with those already described, serve to start the discharge. These components are comprised in a "starting" circuit connected between the two cathodes **4** and **5** (for example through the media of the center-taps **14'** and **15'** of the respective heating windings for these cathodes). Connected to the cathode **4** is the interrupter **29** and thereto the coil **30***a*, in parallel with which two elements is a condenser **38**. The coil **30***a* with the condenser **38** may form a circuit resonant to a high frequency. The interrupter **29** is closed when the system is inoperative, and carries an armature **29***a* positioned for attraction by the core of the choke coil **28**, so that when the choke section **28***b* becomes loaded with sufficient direct current the interrupter will open. From the coil **30***a* the starting circuit passes through the thermostat **31**, which comprises a heatable resistance **31***a* and a switch **31***b* which is open except when the resistance **31***a* is hot. From the thermostat **31** the starting circuit passes through the current limiting resistance **32** to the cathode **5**. The starting operation may be outlined as follows:—

As soon as the terminals **16***a* and **16***b* are connected to the alternating current supply source, the cathodes **4** and **5** are provided with heating current and the anodes **9** and **10** with high alternating potentials. By virtue of the voltage of the high voltage winding **16**, the full-wave rectifier formed by the anodes and the cathode **5** starts immediately with a glow discharge to pass a current. This current charges the condenser **33** to the peak voltage of half the high voltage winding **16**. The current also flows through the starting circuit, the choke section **28***a*, and the choke **58**. The resistance **31***a* of the thermostat (together with the resistance **32**) limits the current to a very small value until it has become hot, whereupon it is shorted out by the closing of switch **31***b*. The heating period of the thermostat is arranged to give the cathodes an opportunity to become fairly well heated by their heating currents; this period may be made relatively low, however, because of the relatively rapid heating of the cathodes. When the thermostat resistance is shorted out a sudden increase of course occurs in the current through the rectifier, the starting circuit, the choke section **28***a* and the choke coil **58**. The heavier current is now sufficient so that its flow through the choke section **28***a* causes the attraction by the choke core of the armature **29***a*, opening the interrupter **29** and abruptly breaking the flow of this heavier current through the choke section **28***a* and the coil **30***a*. The breaking of the current flow through the choke section causes the production thereacross of a high voltage kick, and the breaking of the current flow through the coil **30***a* causes the superimposition on this kick of a high frequency oscillation. By virtue of the circuit position of the choke section **28***a* this kick (together with the superimposed high frequency oscillation) is applied between the anodes and the rectifier **5** (with its shield can **7**) on the one hand, and the cathode **4** on the other hand. This causes ionization of the gas path and starting of the arc discharge; the flow of the discharge current through the choke section **28***a* then maintains open the interrupter **29** and hence the starting circuit, and the thermostat resistance **31***a* cools down and sets the thermostat for another operation.

While I prefer to utilize the high frequency oscillation in addition to the kick across the choke section **28***a*, it is in many cases dispensable and the circuit may then be operated without the high frequency oscillation; in this event the coil **30***a* would be omitted (i. e., short-circuited) and the condenser **38** would be omitted (i. e., open-circuited). When the high frequency oscillation is employed, and with discharge devices in the form of tubes of over about 60" in length, it may be desirable to aid the high frequency ionization of the discharge path by surrounding the tube at an intermediate point by an external electrode **52**, this being connected to an extremity of the secondary **30***b* of a high frequency transformer or Tesla coil **30** of which the coil **30***a* forms the primary.

Starting circuits have heretofore been connected from the main cathode of a discharge device to one of its anodes, or to some point in the high voltage winding supplying the anodes. Such circuit arrangements are not to be confused with my improved arrangement. In the latter the rectifier formed by the anodes and the cathode **5**, in association with the condenser **33**, provides a source of substantially pure direct current for the starting circuit, insuring against the opening of the interrupter **29** at an instant of low current flow with resulting feeble kick. Still more significantly the rectifier and the condenser **33** cooperate to provide, up to and including the instant of the kick no matter when in a supply cycle the kick may occur, an anodic element at the maximum available positive potential relative to the main cathode **4**—i. e., at the potential of the peak voltage of half the high voltage winding **16**. This anodic element is the cathode **5** together with its shield can **7**; and the effect of its certain high positive potential relative to the main cathode at the instant of kick is to insure against failure of the kick (and high frequency oscillation if employed) to start the main discharge. In previous starting circuit arrangements the kick is as likely as not to occur at an instant when no anodic element is at a high positive potential relative to the cathode. Thus I provide improved and more dependable starting of the discharge; furthermore I do this principally by means of components—i. e., the rectifier and the condenser **33**—which already are adapted to perform other highly important circuit functions as set forth in detail hereinabove. It may be noted that the condenser **33** is so positioned in the circuit that it is not affected by either the starting kick or the high frequency oscillation, so that its function in the starting operation does not increase the requirements for dielectric strength in the condenser.

The transformer **13** has been illustrated in a wholly schematic manner in Figure 1. While it may be of entirely simple and conventional design, I have found it advantageous, particularly in connection with discharge devices operating with a filling including metal vapor, to make the transformer structurally of a "constant current"

type, for example as illustrated in Figure 7. Herein the various windings and extremities and taps have been designated as in Figure 1. Figure 7 shows a core 53 having the four legs 53a, 53b, 53c, and 53d. A portion only of the high voltage winding 16—i. e., that portion, between taps 16a and 16b, which forms the primary—is wound on a first leg 53a. The remaining portions of the winding 16 are wound on the opposite leg 53c, on which may also be wound the heating windings 14 and 15. By proper apportionment of the core, as is well understood, the stray field lines between the core legs 53b and 53d may be made significantly to increase with the current loading of the core, and consequently the voltages induced in the windings on the core leg 53c reduce as the current demands thereon increase.

This arrangement as to the heating windings is always advantageous because the initial heating currents (when no main arc discharge is taking place and hence no heavy current is being drawn from the winding 16) may be made relatively high for quick cathode heating; as soon as the main arc discharge starts and becomes available to aid in the cathode heating by recombination of ions on the cathode surface, the heating currents from the transformer are automatically reduced. The arrangement is also advantageous as to the high voltage winding 16, particularly with devices operating with a filling including metal vapor, since it largely counteracts the tendency for excess current to flow in the early portion of the main arc discharge (as a result of the then lower potential gradient of the luminous column discussed hereinabove). In this connection it will be apparent that a transformer of this type will further facilitate the reduction of the value of the ballasting means (e. g., lamp 22), which has already been shown to be capable of great reduction in connection with other features of my invention.

I have above recited certain typical parameters of a discharge device proper according to my invention. I may here augment those recitations by setting forth certain further typical parameters of a system incorporating such a device. These are derived from observations made upon a particular system actually constructed and satisfactorily operated, but in which the choke coil 58 was not employed; accordingly appreciable discharge current fluctuation remained and compelled the use of a higher value of ballast means (with correspondingly greater high voltage winding 16 and/or less luminous column length) than necessary in the preferred embodiment of my invention wherein the choke coil 58 is employed.

In this system the discharge device was filled with krypton gas at 2 to 3 mm. Hg pressure, and was provided with a supply (e. g., globule 21) of mercury adapted for vaporization. The cathodes 4 and 5 were similar and consumed (in the absence of discharge) approximately 7 amperes of current at 2.5 volts. The voltage of each half of the high voltage winding 16 was approximately 110 volts. The main arc discharge current was measured at 2.2 amperes D. C., representing a current density of about 1 ampere per square centimeter of cross-section in the positive column. The column length was 108 centimeters (measured from cathode shield 6 to cathode shield 7), and the D. C. voltage drop in the column was measured at 60 to 65 volts. The D. C. voltage drop across the tungsten ballast lamp 22 measured 20 volts. The inductance of the choke coil section 28a under load was of the order of 1/15th henry; the choke coil section 28b had approximately ⅓ as many turns as had the section 28a. Accordingly the sum of the self inductance of the section 28b and the mutual inductance between the sections would be of the order of 1/33rd henry, and for resonance therewith to the main ripple frequency of 120 cycles a condenser of about 60 microfarads would be indicated. Actually I satisfactorily employed for condenser 33 a capacity of 25 to 30 microfarads, the alternating current through the condenser 33 was of the order of 1.4 amperes, corresponding to an alternating voltage thereacross of the order of 100 volts peak; accordingly I have found it possible to use for condenser 33 an inexpensive electrolytic capacity.

It will be understood that these values are not recited with a limiting intention, nor indeed as examples of the best possible apportionment of parameters for the device in question. They are simply directed to the further specification of one particular embodiment of my invention, which however is obviously capable of embodiment in a wide variety of discharge devices and systems. Likewise it will be understood that many modifications of the structures herein disclosed may be made without departure from the true spirit and scope of my invention.

In the claims hereto appended I intend to claim not only the entire combination which I have disclosed, but also all its various novel elements and sub-combinations, in each case as broadly as the state of the art will permit.

I claim:—

1. In combination in a gaseous discharge device, a pair of relatively closely spaced anodes, a thermionic cathode substantially spaced from said anodes and adapted to receive therefrom an arc discharge, means for applying to said anodes opposed alternating potentials, and a second thermionic cathode closely adjacent said anodes and forming therewith a full-wave rectifier.

2. In combination, a gaseous discharge device comprising anode means and a thermionic cathode adapted to receive therefrom an arc discharge, an inductance and an alternating voltage source serially interposed between said anode means and said cathode, and means inductively coupled to said inductance for opposing current fluctuations therein.

3. In combination, a gaseous discharge device and therein a pair of relatively closely spaced anodes and a thermionic cathode substantially spaced from said anodes and adapted to receive therefrom an arc discharge, means for raising the potentials of said anodes alternately above the potential of said cathode, a second thermionic cathode closely adjacent said anodes, and means connected to said second cathode for opposing fluctuations in said discharge.

4. In combination, a gaseous discharge device and therein a pair of relatively closely spaced anodes and a thermionic cathode substantially spaced from said anodes and adapted to receive therefrom an arc discharge; means for applying opposed alternating potentials to said anodes; a rectifier comprising anodes respectively connected to said opposed potential applying means, and a cathode; and circuit means connected to said rectifier cathode for opposing fluctuations in said discharge.

5. In combination, a gaseous discharge device and therein a pair of anodes and a thermionic

cathode adapted to receive therefrom an arc discharge, means for alternately raising the potentials of said anodes, an element adapted to approximate in potential the potential of the instantaneously more positive said anode, and circuit means connected to said element for opposing fluctuations in said discharge.

6. In combination, a gaseous discharge device and therein a pair of anodes and a thermionic cathode adapted to receive therefrom an arc discharge, means for alternately raising the potentials of said anodes, choke means between said cathode and said potential raising means, an element adapted to approximate in potential the potential of the instantaneously more positive said anode, and means, connected to said element and inductively coupled to said choke means, for inducing in said choke means ripple voltages to oppose voltage fluctuations between said cathode and the instantaneously more positive said anode.

7. In combination, a gaseous discharge device and therein a pair of anodes and a thermionic cathode adapted to receive therefrom an arc discharge; means for applying opposed alternating potentials to said anodes; choke means between said cathode and said potential applying means; a rectifier comprising anodes respectively connected to said opposed potential applying means, and a cathode; and means, connected to said rectifier cathode and inductively coupled to said choke means, for inducing in said choke means ripple voltages to oppose current fluctuations therein.

8. In combination, a gaseous discharge device and therein a pair of anodes and a thermionic cathode adapted to receive therefrom an arc discharge; sources of opposed alternating potentials respectively connected to said anodes; a choke coil between said cathode and said sources; a second thermionic cathode closely adjacent said anodes; and a circuit connected between said second cathode and said choke coil, comprising serially a condenser and an auxiliary coil tightly coupled to said choke coil.

9. In combination, a gaseous discharge device and therein a pair of anodes and a thermionic cathode adapted to receive therefrom an arc discharge; sources of opposed alternating potentials respectively connected to said anodes; a choke coil between said cathode and said sources; a second thermionic cathode closely adjacent said anodes; a circuit connected between said second cathode and said choke coil, comprising serially a condenser and an auxiliary coil tightly coupled to said choke coil; and a second choke coil, interposed between said first choke coil and said sources, of a value substantially greater than required for resonance with said auxiliary coil and said condenser to twice the frequency of said alternating potentials.

10. A discharge system comprising, in combination, a gaseous discharge device and therein a pair of anodes and a thermionic cathode adapted to receive therefrom an arc discharge; sources of opposed alternating potentials respectively connected to said anodes; a choke coil between said cathode and said sources; a second thermionic cathode closely adjacent said anodes; a circuit for inducing in said choke coil a ripple voltage whereby to oppose ripple currents therein, comprising an auxiliary coil tightly coupled to said choke coil and a condenser, and serially connected between said second cathode and said choke coil; and means for retarding the phase of ripple currents in the system, whereby to bring the ripple current through said circuit more nearly into phase with said anode potentials.

11. In combination, a gaseous discharge device and therein anode means and a thermionic cathode substantially spaced from said anode means and adapted to receive therefrom an arc discharge; an alternating voltage source connected to said anode means; a choke coil between said source and said cathode; a second thermionic cathode closely adjacent said anode means and forming therewith a rectifier; and means for producing an inductive kick across said choke coil, comprising a conductive circuit serially including circuit-breaking means responsive to a predetermined circuit current, said circuit being adapted to conduct current from said source through said rectifier and said choke coil, and being connected between said two cathodes.

12. In combination, a gaseous discharge device and therein a filling of gas, anode means, and a thermionic cathode substantially spaced from said anode means and adapted to receive therefrom an arc discharge; an alternating voltage source between said anode means and said cathode; a second thermionic cathode closely adjacent said anode means; means, operative at a time interval after said source is rendered operative, for ionizing said gas whereby to start said luminous discharge; and a condenser, connected between said second cathode and a point intermediate said source and said first cathode, whereby to maintain said second cathode at a high positive potential at the instant of said gas ionization.

13. In combination, a gaseous discharge device and therein anode means and a thermionic cathode substantially spaced from said anode means and adapted to receive therefrom an arc discharge; an alternating voltage source connected to said anode means; a choke coil between said source and said cathode; a second thermionic cathode closely adjacent said anode means and forming therewith a rectifier; a circuit connected between said two cathodes and adapted to conduct current from said source through said rectifier and said choke coil; means for increasing the current through said circuit at a time interval after said source is rendered operative; means responsive to said increased current for breaking said circuit, whereby to produce across said choke coil an inductive kick; and a condenser connected from said second cathode to said choke coil, whereby to render said current substantially smooth and to maintain said second cathode at a high positive potential at the instant of said kick.

14. In combination, a gaseous discharge device and therein a filling of gas, a pair of anodes, and a thermionic cathode substantially spaced from said anodes and adapted to receive therefrom an arc discharge; sources of opposed alternating potentials respectively connected to said anodes; a choke coil between said cathode and said sources; an auxiliary coil tightly coupled to said choke coil and connected thereto; a second cathode closely adjacent said anodes; means, operative at a time interval after said sources are rendered operative, for ionizing said gas whereby to start said luminous discharge; and a condenser, connected between said second cathode and said auxiliary coil, whereby to maintain said second cathode at a high positive potential at the instant of said gas ionization and thereafter to oppose current fluctuations in said choke coil.

15. The combination according to claim 1, fur-

ther including a shield can surrounding said second cathode, provided with discharge-conducting apertures, and electrically connected to said second cathode.

16. In a gaseous discharge device, a rectifying structure comprising a thermionic cathode; a cylindrical shield can surrounding said cathode and provided on respectively opposite sides with two discharge conducting apertures; and a pair of anodes adjacent said can on opposite sides thereof, in a plane axial of said can and at right angles to the axial plane containing said apertures.

17. In a gaseous discharge device, a rectifying structure comprising a thermionic cathode; a cylindrical shield can surrounding said cathode and provided on respectively opposite sides with two discharge conducting apertures; a pair of anodes adjacent said can on opposite sides thereof, in a plane axial of said can and at right angles to the axial plane containing said apertures; and anode shielding vanes extending from said can in substantially a single axial plane, each vane being closely spaced from a respective said anode.

18. In a gaseous discharge device, anode means and an electron-emissive cathode adapted to receive therefrom an arc discharge, said cathode being of hollow formation and being both internally and externally emissive; and means for forcing substantially the entire said discharge into the space bounded by interior surface of said cathode, comprising apertured shielding means in close spaced relationship to the exterior surface of said cathode.

19. In a gaseous discharge device, anode means and an electron-emissive cathode adapted to receive therefrom an arc discharge, said cathode being an open-walled hollow body; and apertured shielding means in sufficiently close spaced relationship to the outside of said body to force substantially the entire said discharge into the space within said body.

20. In a gaseous discharge device, anode means and an electron-emissive cathode adapted to receive therefrom an arc discharge, said cathode comprising a thermionic helix wound in two spaced sections; and shielding means surrounding and close to said helix and provided with discharge-conducting apertures intermediate said sections and adapted to guide the discharge internally of said helix, the internal radius of said helix being several times greater than the mean free path length of the electrons emitted by said cathode during said discharge.

21. In a gaseous discharge device, anode means and an electron-emissive cathode adapted to receive therefrom an arc discharge, said cathode comprising a heater wire in the form of a helix wound in several sections spaced apart, a fine wire wound about and in intimate contact with said heater wire, and an oxide coating over said wound heater wire; means for passing a heating current through said heater wire; and shielding means surrounding and close to said helix and provided with discharge-conducting apertures adapted to guide the discharge intermediate of said sections and internally of said helix.

22. In a gaseous discharge device, anode means and an electron-emissive cathode adapted to receive therefrom an arc discharge, said cathode comprising a thermionic helix; and shielding means surrounding and close to said helix and provided with discharge-conducting apertures intermediate the extremities of said helix; said apertures being sufficiently small to produce an appreciable potential gradient in the discharge passing therethrough, said helix being provided with a longitudinal spacing adjacent to and of substantially greater length than said apertures, and the radius of said helix being several times greater than the mean free path length of the electrons emitted by said cathode during said discharge.

23. In a gaseous discharge device, anode means and an electron-emissive cathode adapted to receive therefrom an arc discharge, said cathode comprising a thermionic helix; shielding means surrounding and close to said helix and provided with relatively small discharge-conducting apertures adapted to guide the discharge internally of said helix; a constant-current transformer having a heating secondary connected across said helix and having a discharge-supporting secondary connected between said cathode and said anode means; and means for delaying the starting of said discharge for a time interval after said transformer is energized.

24. In a gaseous discharge device, anode means and an electron-emissive cathode adapted to receive therefrom an arc discharge, said cathode comprising a pair of axially aligned hollow bodies; and shielding means in close spaced relationship to the outside of said bodies, said means being apertured between said bodies for the admission of said discharge to their interiors.

CARL J. R. H. VON WEDEL.