Sept. 12, 1939. C. J. R. H. VON WEDEL 2,172,630

ELECTRIC DISCHARGE SYSTEM

Filed July 19, 1935

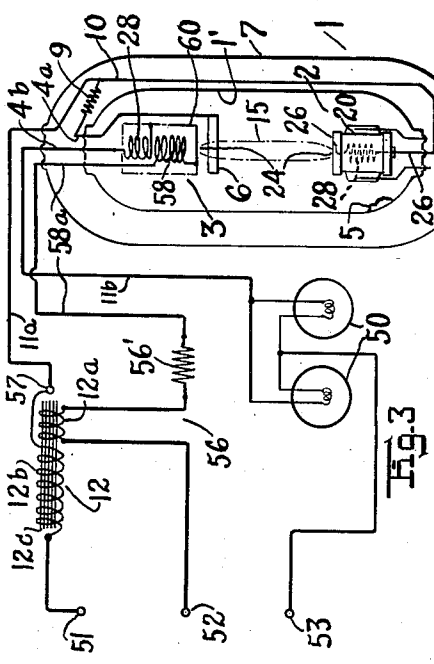


Fig. 3

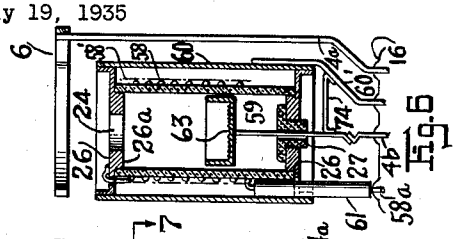


Fig. 6

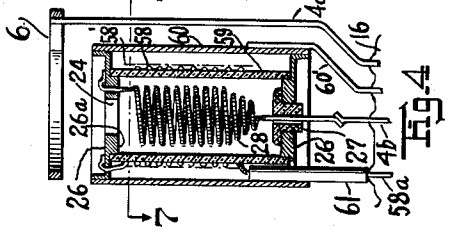


Fig. 4

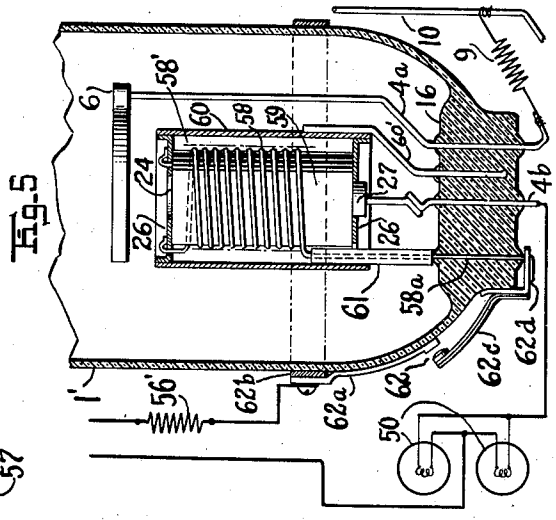


Fig. 5

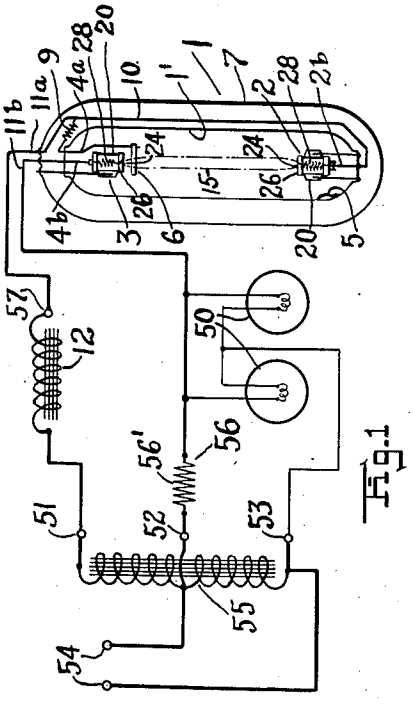


Fig. 1

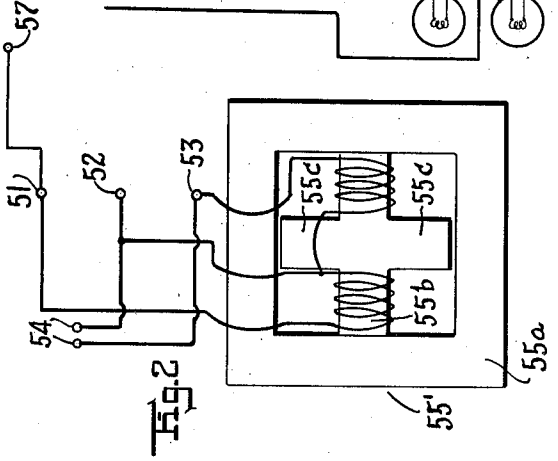


Fig. 2

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ELECTRIC DISCHARGE SYSTEM

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Application July 19, 1935, Serial No. 32,175

10 Claims. (Cl. 176—9)

This invention relates to electric discharge systems and particularly to those employing gaseous discharge devices. While various features of the invention have utility in broader connections, the invention has especial reference to improved circuits for operation of devices of that character. Throughout the specification the term "gaseous" is employed as an adjective relating to either a gas or a vapor or a combination thereof, while the terms "gas" and "vapor" are each used in a more specific sense.

In my co-pending application, Serial No. 6,612, filed February 15, 1935, now Patent No. 2,084,751, I described an improved luminous discharge device adapted to operate with high vapor pressures; and an important aspect of the instant invention comprises a novel and useful combination of a device of that general character with one or more incandescent lamps. This combination according to my invention results in improvements in the operating characteristics and efficiencies both of the discharge device and incandescent lamps, has a very excellent power factor, increases the range over which the supply voltage may fluctuate without causing extinction of the discharge in the device, provides illumination from the incandescent lamps during the preliminary and starting discharge periods and during any period of discharge extinction resulting from very abnormal supply voltage fluctuation, and has other advantages as will hereinafter more fully appear.

It is an object of my invention to provide an improved combination of a discharge device with one or more incandescent lamps.

It is another object to provide improved methods of operating combinations of discharge devices with incandescent lamps.

It is another object to provide such a combination wherein the light efficiency of the incandescent lamps is maintained high throughout normal operation of the discharge device, without danger of lamp burn-out during starting periods when the discharge device may require extra-high current.

It is another object to provide considerable equalization of the total light output from the combination during the several successive operational periods of the discharge, from the moment of first supplying current to the combination.

It is another object to provide such a combination having a high tolerance to supply voltage fluctuations.

It is another object to provide such a combination wherein the cathode means of the discharge device may be pre-heated by novel arrangements useful for performing other objects of the invention.

It is another object to automatically heat the cathode means in a gaseous discharge system to proper degree in the successive stages of operation of the system.

It is another object to facilitate the introduction of an initial auxiliary discharge in a gaseous discharge system.

It is another object to provide improved heating means for a gaseous discharge device cathode.

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

In the detailed description of my invention, hereinafter set forth, reference is had to the accompanying drawing, of which:

Figure 1 is a diagrammatic view of a high pressure gaseous discharge device, a pair of incandescent lamps, and an associated circuit, illustrating one form of my invention;

Figure 2 is a schematic view of a constant current transformer which may be substituted for the auto-transformer and choke of Figure 1;

Figure 3 is a view similar to Figure 1, but additionally illustrating certain optional features;

Figure 4 is an enlarged cross-sectional view of a representative form of electrode structure for the device of Figure 3;

Figure 5 is an enlarged cross-sectional view of one extremity of the device of Figure 3, including the representative electrode structure in partly sectional form; and

Figure 6 is a view similar to Figure 4 but illustrating a modified form of electrode structure.

Reference being had to Figure 1, there will be seen the discharge device 1, which may be in general of the type shown and described in the prior patent to me abovementioned. It may comprise the sealed glass vessel or tubular envelope 1' evacuated of air and containing a filling of a monatomic gas at a pressure of a few mm. Hg. as well as some source 5 of metal vapor. This source for example may be mercury or alkaline metal or a mixture of the two, may cling to the wall of the envelope 1 when cold, and is adapted upon heating of the envelope to vaporize and to develop a vapor pressure within the envelope. Closely adjacent the respective ends of the envelope are the main electrodes 2 and 3, supported on appropriate lead-in wires; these main electrodes may be similar, and each may comprise in general a cylindrical nickel or other metallic shield can 20 terminally closed excepting for a discharge admitting hole

24 in its end member 26 facing the other electrode, and a generally helical cathode element 28 within and co-axial with the shield can and only slightly spaced therefrom. The cathode element is coated with a mixture which may include alkaline earth metals; preferably this mixture also includes oxides of metals of the iron group, and the coating after application to the cathode element is reduced to a strongly metallized or partially alloyed form—all of which details of the electrodes and their cathode elements may desirably conform to those more fully set forth in the prior patent to me above-mentioned. The extremity of each cathode nearest the hole 24 in the surrounding shield can may be welded to that shield can, and the other extremity is led insulatedly through the can and connected with the lead-in wire 2*b* or 4*b* (for electrodes 2 and 3, respectively). Close to one of the main electrodes—e. g., electrode 3—is shown a starting ring 6 in the form of a metal ring supported to and electrically conductive with a lead-in wire 4*a*. The device 1 further comprises an outer glass bulb 7 of tubular form, in which the envelope 1 is placed, the space between bulb and envelope being evacuated or filled with gas; this arrangement serves to reduce cooling of the envelope 1. Outside the envelope 1 but within the bulb 7 the lead-in wire 2*b* may be extended to the opposite end of the bulb by means of the wire 10. The starting electrode lead-in wire 4*a* is connected to the wire 10 through a resistance 9. The wire 10 and the lead-in wire 4*b* are brought out through bulb 7 to form two main device leads 11*a*, 11*b* respectively.

Some series impedance such as the choke 12 is serially included in the gaseous discharge means, for example in the lead 11*a* to the discharge device. When voltage is first applied across the leads 11*a*—11*b* an auxiliary glow discharge in the low pressure gas atmosphere within the device takes place in alternate half cycles from the starting electrode 6 to the cathode element 28 in electrode 3. This glow discharge is made of sufficient magnitude, by proper choice of resistance 9, so that the cathode resistance to glow discharge presently breaks down, hot spots are formed on the cathode, and the main discharge strikes between the main electrodes.

This main arc discharge will be understood to take place from electrode 2 to electrode 3 in one half cycle, from 3 to 2 in the next, then from 2 to 3, and so on, each of the electrodes 2 and 3 acting alternately as cathode and anode. It will be appreciated that the arc discharge when first initiated has widely different characteristics from those final ones which obtain during its later and normal continuance; and the period through which its characteristics change to the final ones I have herein termed the starting period.

At the beginning of the starting period the discharge spreads in the low gas pressure throughout the cross-section of the envelope 1, passing through the hole 24 of the electrode momentarily acting as cathode to reach the cathode element proper therein. The device is already warming up and progressively vaporizing the metal 5. At first the potential gradient and voltage drop in the device do not change materially because, while the vapor has a lower ionization potential than the gas, the total gaseous density is increasing. Typically the voltage drop in the tube during this early portion of the starting period may be of the order of 22 volts; the current must be limited, by means such as choke coil 12 external to the tube, to a value capable of being withstood by the electrodes (which may for example be 4.25 amperes), but nevertheless large enough to heat the envelope in a reasonable time. Presently a point is reached where gaseous pressure and density increases, attendant upon the continued heating of the envelope 1' by the discharge, are no longer counterbalanced by a lowering ionization potential; this point may be approximately arrived at when the envelope temperature reaches 125 degrees centigrade and the vapor pressure 1 mm. Hg. in the typical devices above-mentioned, with the ratio of vapor to gas densities of the order of 1:4.

As the starting period progresses from this point the vapor density increase rather rapidly increases the potential gradient within device, decreasing the mobility of the gaseous molecules and ions by increased collisions. This leads in turn to further increase of temperature; but this increase now exhibits a selectivity between the cross-sectional portions of the envelope, occuring to the greatest extent in the central such portion. Accordingly the total gaseous density becomes selectively distributed, the central cross-section portion being one of relatively low density and being surrounded by a gaseous shell of relatively high density. The mean free path of the electrons and ions is then of course much greater in the central portion than in the surrounding gaseous shell, and the discharge tends to concentrate in the central portion. As the vaporization of metal 5 continues the gaseous shell surrounding the central cross-sectional portion becomes so dense that it acts as a discharge path wall. Intercepting ions straying from the now central discharge path and causing recombination thereof with slow electrons diffusing in the gaseous shell. This shell then performs the same function as the walls of the envelope 1 performed before at low total gaseous densities, and the effect of the shell is similar to that which would be produced by constricting the walls of the envelope to a very small radius. A high temperature gradient will be established in the gaseous shell, so that the arc pencil heat may become of the order of 1800 to 2000 degrees centigrade while the envelope temperature remains only of the order of 250 degrees; such typical temperatures may be reached with vapor pressures of the order of 100 mm. Hg. At some such typical temperatures the radiation losses from the device will have risen to equal the heat generation within the device, further temperatures and density rise will cease, and the starting period may be considered at an end, the device having acquired its normal operating characteristics. These may for example comprise a potential drop of 80 volts and a discharge current of the order of 2.5 amperes.

The voltage drop hereinabove referred to is an average drop across the discharge path. The instantaneous drop in the final arc discharge path and the instantaneous discharge current therethrough are interrelated with the instantaneous temperature of this discharge path, which temperature is capable of rapid and material fluctuation. This path, finally in the form of a narrow light pencil designated as 15 in Figure 1, has as above noted a low gaseous density relative to the surrounding gaseous shell, and because of its low density and small size has small heat storage

capacity or thermal inertia. This contrasts with the relatively high thermal inertia of the balance of the device—i. e., the gaseous shell, the envelope 1, etc. The temperature of the pencil 15 is very high at instants of high current, but reduces materially as the current stops flowing each half cycle. This reduction increases the instantaneous potential gradient, and thus increases the restarting voltage of the device—i. e., the voltage required for starting the discharge in the next half cycle. The restarting voltage is therefore materially higher than the average voltage drop in the device.

The small thermal inertia of the pencil is significant not only as to instantaneous current changes, but also as to average current changes. Thus if the supply voltage is suddenly reduced, the attendant current reduction causes the average heat in the arc pencil to reduce forthwith; this causes an increase in gaseous density within the pencil, increasing the potential gradient in the pencil and further reducing the current. Unless the series impedance (e. g. choke 12) is very generously apportioned so as to raise the voltage available across the leads 11a—11b very materially in response to the decreased current, the discharge will be extinguished. When this happens the gaseous density within the entire envelope equalizes rapidly and the discharge can thereupon be restarted only with very high voltages which many times exceed the available supply voltage. The discharge can restart with the normal supply voltage only after the whole device has cooled down and the total gaseous density reduced to the order of that of the original rare gas filling—for example, only after the device has cooled down to the order of 125 degrees centigrade, which cooling requires several minutes.

If incandescent lamps be employed as a part of the series or ballast impedance in a conventional series arrangement with the discharge path, they must be apportioned to withstand the high current and absorb a high voltage during the starting period, and therefore operate with very poor light efficiency throughout the normal discharge. In other words were the lamps apportioned to operate efficiently throughout the normal discharge they would be seriously overloaded and burned out during the starting period.

According to my invention incandescent lamps are employed with the discharge device in such an arrangement that they are efficiently operated during the normal discharge, but without danger of serious overload or burn-out during the starting period. My arrangement further is one in which there exists only very modest requirements for inductive series impedance (e. g., for the choke 12), in consequence of which an excellent power factor is readily obtained without the introduction of expensive and large condensers. The arrangement provides good illumination from the incandescent lamps immediately upon the supply of current to the system, so that considerable illumination is available during the auxiliary discharge period abovementioned. Finally the incandescent lamps and discharge device co-act with one another to improve the operating characteristics and stability of each, rendering the system highly tolerant to supply voltage fluctuations. These general advantages and subdivisions thereof, as well as others, will be apparent in the light of the detailed description of the circuit, to which I shall now proceed with references to Figure 1.

The incandescent lamps 50, of which I have illustrated two in parallel, are connected in series with the main lead 11b to the discharge device. These lamps may for example be designed for normal efficient operation on a voltage somewhat in excess of the voltage drop taking place across the device 1 during its normal operation, and with a total current intermediate the discharge currents through the device during the starting and normal operating periods, respectively. Illustratively, with the 200 watt discharge device above described I may employ two lamps in parallel each designed to consume 200 watts when 120 volts is impressed across their terminals; at this impressed voltage it will be understood that the two lamps together pass approximately 3.33 amperes. This apportionment of power in the device 1 and lamps 50 in the ratio of approximately 1:2 is a very favorable one for approximation of daylight by the combined light emission spectrum.

The entire series system comprising choke coil 12, device 1 and lamps 50, is connected across a current supply of voltage of the order of double the mentioned voltage of the incandescent lamps. Thus in Figure 1 I have shown the series system connected across the terminals 51 and 53, between which for the sake of example it is convenient to postulate a voltage of 230; this voltage may for example be obtained from the two outside leads of a 3-wire 230-volt supply system, or from the terminals 54 of a 115-volt supply system through a 2:1 step-up transformer or auto-transformer 55 as shown in Figure 1. A terminal 52 is provided, either as the center lead of the 3-wire system or as an intermediate tap—for example a center-tap—on auto-transformer 55.

The system as thus described (and without connection of any element to the center terminal 52) will be recognized as one having an unusually high magnitude of series resistive ballast. Inherently therefore it tends to have excellent characteristics in respect of tolerance to supply voltage fluctuation and of small requirement for inductive ballast. Were there employed, however, the lamp parameters above mentioned, the lamps would be burned out in short order by the heavy starting period current; and in turn were their filaments to be more generously apportioned to avoid burn-out, the light efficiency of the system during normal operation would be relatively low. I avoid danger of starting period lamp burn-out without appreciably impairing the light efficiency, and at the same time retain to a high degree the inherent tolerance to supply voltage fluctuation and the small inductive ballast requirement, by significantly stabilizing the potential at the junction between incandescent lamps and discharge device (i. e., at the device lead 11b). This I do by connecting between this junction and the center terminal 52 above mentioned a circuit 56 comprising a relatively low impedance, which may be the resistance 56'. With system parameters as above set forth this resistance for example may be of the order of 6 ohms. Attention may now be directed to the operation of this circuit during the several successive periods after connection of the power supply.

The instant the supply is first connected current begins to flow between the terminals 52 and 53 through the circuit 56 and lamps 50 in series and the lamps are lighted, providing immediate light output. The resistance of the lamps, then cold, may be of the order of only 3 ohms (as

distinguished from the normal thirty-odd ohms), and consequently at this initial instant only about ⅓ of 115 volts is dropped in the lamps; some 190 volts is therefore available across choke **12** and the discharge device to start the glow discharge, which is highly advantageous for dependability of this action. Very rapidly, however, the filaments of the lamps heat and approach their normal resistance, so that some 98 volts may drop in the lamp; this however will provide the choke and discharge device with a voltage still some 15% above that of the 115 volt supply, the potential at the lamp-device junction being below the center terminal potential by that percentage of 115 volts. This excess facilitates initiation of the main discharge. It arises, of course, by virtue of a substantial current flow through the circuit **56**—a flow which with the typical parameters mentioned may be of the order of 3 amperes; this current is being supplied by the circuit **56** to the lamps additionally to the very small current through the discharge device attendant on the glow discharge.

It is also to be pointed out that the inclusion of the circuit **56** not only provides immediate light output, but also insures the thorough heating of the filaments of the lamps **50** before the time of initiation of the main or arc discharge, so that the lamps **50** then have a substantial resistance and not their small cold resistance. It is apparent that if at this time the lamps were cold—as would result from omission of the circuit **56**—the initial starting period current through the system would be excessive, causing serious overloading of the electrodes at a most precarious instant when the discharge changes from a glow to an arc discharge, with the cathode elements not yet fully heated; the effect of such overload would of course be serious sputtering and pitting and disintegration of the cathode surface, impairing its useful life.

When the starting period of the main discharge begins, the voltage across the device **I** dropping to some 22 volts and the current therethrough rising to some 4.25 amperes as above mentioned, the potential at the lamp-device junction will rise above the center terminal potential by several volts—for example with the parameters mentioned, to provide some 121 volts across the lamps. About 1 ampere flows through the circuit **56**, this being the excess of the discharge current over the current through the lamps; the diversion of this excess during the early part of the starting period is an important contribution to the avoidance of burn-out of lamps which are yet able to operate efficiently during the normal discharge. While the inclusion of the circuit **56** somewhat reduces the effective magnitude of the resistive ballast of the system, yet the necessary starting period current limitation (e. g., to the exemplary 4.25 amperes) may be effected with a materially smaller inductive ballast then is required in the complete absence of resistive ballast; and preferably the choke coil **12** will be apportioned to the minimum required for the necessary current restriction. In view of the relatively small series inductance and of the appreciable series resistance the power factor of the system is readily kept high without the use of condensers.

As the starting period progresses the voltage drop in the device **I** increases and the discharge current decreases; this reduces the excess of discharge current over current tending to flow through the lamps. The circuit **56**, the current through which represents the diversion of this excess, automatically responds with decreasing current. While the parameters might be so apportioned that this decreasing current in circuit **56** would just reach zero when the discharge current is finally stabilized at its normal value, I prefer to permit the value of the diverted current in circuit **56** to pass through zero to a small value of opposite phase—i. e., to make circuit **56** respond to low discharge currents by passing through the lamps **50** a current additional to the discharge current. In this way I am able to increase the lamp current over the normal operating discharge current, to maintain the lamps at good efficiency during normal operation. The combination of this second action of increasing the lamp current over the discharge current during normal operation, with the first action of reducing of the lamp current below the starting period discharge current above discussed, enables me in practical cases to hold the lamp voltage to within a few per cent of a mean voltage from the beginning of the starting period onward. While I prefer the combination of both actions, and as second choice prefer the first action alone, it will be obvious that I may if desired rearrange the operating values or parameters to obtain the second action only, and that even this alone will be beneficial. It will further be obvious that in any of these events I by circuit **56** maintain the change of lamp current at materially less than the change of current through the device **I**. With the parameters above mentioned I rely on both actions, the voltage across the lamps when the discharge has finally stabilized being for example of the order of 111 volts, and an excess current (flowing through the lamps but not through the discharge device) of some ⅔ ampere flowing through the circuit **56** to produce a few volts drop therein.

While the tolerance of the system to supply voltage fluctuations during the normal discharge may not be as great as would characterize the system with the specified lamps **50** but with the circuit **56** omitted, it nevertheless remains materially better than the tolerance which would be obtained by the use of a resistance of the magnitude of **56'** as the sole resistive ballast. Thus when a supply voltage drop suddenly decreases the discharge current, raising the voltage drop across the device **I** as above set forth, the current through the lamps is reduced; this reduces their resistance roughly as quickly as the device voltage drop rises, in view of their high temperature coefficient and low thermal inertia. The voltage across the lamps is reduced and the available device voltage drop raised, not only by virtue of those lamp current and resistance reductions in themselves, but also by the potentiometric action across the terminals **52**—**53** produced by the reducing lamp resistance and the constant resistance **56'**. Sudden supply increases are of course stabilized in a converse manner.

A reduction in supply voltage which persists for a prolonged period of course will eventually permit the device **I** to cool, reducing its total gaseous density, largely restoring its normal discharge current, and reducing its voltage drop to less than normal. Under these circumstances, however, the potential at the lamp-device junction—normally a few volts lower than that of terminal **52** in the case of the exemplary parameters above mentioned—will rise relative to that terminal potential, and may even exceed it, providing considerable stabilization of total light

output. A voltage increase persisting for a prolonged period will of course produce a converse stabilizing effect on light output. With these supply voltage fluctuations, the voltage across and efficiency of the incandescent lamps will remain more constant than had they been connected directly across the fluctuating voltage supply.

I prefer to leave the circuit **56** permanently connected, thus avoiding complications and wasting during normal operation an amount of power which is obviously wholly negligible. If desired, however, the circuit **56** may be disconnected (open-circuited) at an appropriate time—for example automatically late in, or shortly after the end of, the starting period. (A typical means for effecting such disconnection has been illustrated in and will be described in connection with one of the later figures). Of course upon disconnection of this circuit some readjustment of currents and voltages would occur—and lamps **50** having typical parameters such as above set forth would not operate quite as efficiently.

It will be appreciated that the typical currents and voltages above detailed are necessarily based on the employment of some particular choke **12**. With the values as above detailed it will be observed that during the early portion of the starting period a voltage drop of some **87** volts effective will be occurring across the choke at the current of approximately 4.25 amperes, while during normal operation a drop of some 39 volts effective will be occurring at the current of approximately 2.5 amperes. The decrease of apparent impedance from the former to the latter condition will be understood as a natural function of the lower amplitude of alternating current, the change in waveform of the current, the inherent shift of power factor of the system, etc.

It will be obvious that the fundamental system I have disclosed, including the circuit **56**, may be employed to advantage in connection with direct current supplies. In this case the inductive ballast should be replaced with a resistive ballast—preferably incandescent lamp ballast so that the above mentioned and desirable change of apparent impedance at different currents may be approximated. Such a ballast substitution having been effected, it is obvious that the terminals **53**, **52**, **51** might be connected (instead of to transformer **55**) to a direct current supply yielding relative voltages at those respective terminals of −115, 0, and +115 respectively. In spite of the loss during normal operation of almost 100 watts in the substituted ballast, the system would remain a very efficient one in terms of light output per watt, and would have the advantages of high stability analogous to those above set forth for the alternating current operation.

Reference again being had to alternating current operation, the auto-transformer **55** may be considered a true transformer arranged to provide current only for the discharge device (and at times for resistance **56**), so that it can be made rather small and inexpensive. In connection with the transformer, a variation is shown in Figure 2. This comprises a "constant current" type of transformer **55'** having outer core **55***a*, core leg **55***b* connecting with **55***a* and carrying the windings, and leakage core legs **55***c* extending from leg **55***b* at right angles thereto into close adjacency with the outer core **55***a*. The action of such a transformer is that of by-passing through the legs **55***c* that portion of its flux which exceeds its core saturating value, thus limiting the voltage of the transformer in accordance with current flow. By employing a properly apportioned transformer of this type to provide current for the discharge device, the choke coil **12** may be omitted. The manner of its substitution for auto-transformer **55** and choke **12** of Figure 1 is indicated by the correspondingly numbered terminals, the terminal **57** appearing in Figure 1 as the discharge device end of choke **12**, and the terminals **51** and **57** being shorted in Figure 2.

The current through the junction potential stabilizing circuit **56** is in general very high (i. e., of large amperage) at the initial instant of the auxiliary discharge, and remains much higher during the rest of the auxiliary discharge period than during either the starting or normal operating periods. This has already been seen to be responsible for a desirable increased voltage across the device **1** during the auxiliary discharge period; but by special circuit arrangements I may take further advantage of this then high current. Reference is invited to the left-hand portion of Figure 3 for an illustration of one of these arrangements. Herein it will be seen that in the circuit **56**—i. e., in the connection from the resistance **56'** to the center terminal **52**—has been inserted a small auxiliary winding **12***a* on the core **12***c* of, and coupled to the coil **12***b* of, choke **12**. This auxiliary winding **12***a* may be of few turns relative to the coil **12***b*, and forms a primary which when traversed by the high circuit current during the auxiliary discharge will induce a considerable voltage in the coil **12***b*. The winding **12***a* is of course so poled or phased that this voltage induced in **12***b* will add to the voltage across the device **1** from the supply terminals. This voltage increase is of material value in securing the dependable starting of the auxiliary discharge particularly after long periods of idleness, which apparently cause the cathode element coatings to become less active and more stringent in their demands for glow discharge starting voltage.

During the earlier portion of the starting period the current flow through the circuit **56** and hence winding **12***a* is of course much lower and much less voltage will be induced in coil **12***b*; but such flow as occurs is in opposite phase to that obtaining throughout the auxiliary discharge, and the induced voltage will therefore tend to reduce the voltage impressed across the device **1**—a desirable action in view of the then very low voltage drop within the device. At the end of the starting period and throughout the normal discharge the current through the circuit **56** and winding **12***a* is also relatively low, but normally in the same phase as during the auxiliary discharge period. Accordingly the tendency is again to boost the voltage impressed across the device **1**; this occurring when the voltage drop within the device has risen, it will be seen that a desirable stabilizing effect between starting and normal operating periods is achieved by the combination of the junction potential stabilizing circuit **56** and the winding **12***a* included therein. The winding **12***a* may also have a simple inductive ballasting effect, additive to that of the simple choke **12**. It will be understood that, while Figure 3 illustrates other variations from the circuit of Figure 1 which I am about to describe, the insertion of the winding **12***a* may be

effected in the circuit of Figure 1 without other variation thereof.

In Figure 3 another arrangement has been illustrated for taking advantage of the extra high current through the circuit 56 during the auxiliary discharge period. This comprises a heater winding 58, appropriately located in heating relationship to the cathode element 28 in electrode 3 as hereinafter more particularly set forth, and serially connected in the circuit 56. In general the value of resistance 56' should be reduced by the value of resistance of the heater winding 58; and the latter may in appropriate cases be apportioned to have the full resistance value desired in this circuit, so that the resistance 56' may then be reduced in value to zero (e. g., short-circuited). The heater winding 58 being of course disposed within the device 1, the external portion of the circuit 56 is led into the device 1 through a new lead-in wire 58*a* connected to a first extremity of the heater winding. While for complete equivalence of the connection of the circuit 56 to its connection in Figure 1 the second extremity of the heater winding should be electrically connected to the lead-in wire 4*b*, I find it entirely satisfactory and mechanically simpler to connect the second heater extremity to the surrounding can (60, to which one extremity of the cathode element 28 is connected); this differs only in the rather immaterial respect that the very small resistance of the cathode element 28 becomes moved from a position in series with discharge column of the device 1 to a position in series with the lamps 50.

Obviously when the current through the circuit 56 is high the greatest cathode element heating effect is produced by the heater winding 58; this of course is during the auxiliary discharge, before the main discharge has been initiated. Accordingly a strong pre-heating effect may be obtained for the cathode elements, which will be understood to be desirable for the minimization of tendencies to cathode element sputtering upon initiation of the initially very strong main discharge. Since the current through the circuit 56 automatically reduces upon initiation of the main discharge (typically to less than ⅓ of its value during the auxiliary discharge period), the heating effect of the heater winding is then substantially eliminated (typically reduced to less than 1/9 of its former value), avoiding overheating of the cathode element when the main discharge itself is capable of heating them.

While in Figure 3 I have shown, as heater windings connected in the junction potential stabilizing circuit 56, only a single heater winding disposed within the electrode 3, it is obvious that I am not limited thereto but may connect in the circuit 56 a plurality of heater windings mutually in series or parallel and respectively disposed within the several electrodes of the device.

In Figures 4 and 7 I have illustrated a typical structure for the electrode 3 when equipped with the heater winding 58; an adjacent starting electrode 6 also appears in Figure 4 by way of illustration. The cathode element 28 appears centrally of the electrode. This element may be a helix formed with small pitch from a relatively heavy wire (nickel for example) having an indentured or corrugated surface (provided for example by plating or welding thereon a continuous fine wire spiral), and coated with a suitable oxide mixture as above mentioned and as more fully set forth in my said co-pending application; preferably the diameter of the helix is reduced toward its end nearer the adjacent seal 16 of the envelope 1'. Closely spaced about the helical cathode element 28 is the cylinder 59 slightly overhanging each axial extremity of the element 28. Across each end of the cylinder 59 is placed a circular end member 26, for example of nickel; these may be provided with the central bosses 26*a* registering with the ends of the cylinder 59, and with the central apertures 24. In this aperture in the end member 26 nearer the envelope seal 16 is placed the insulating ceramic bushing 27; and outwardly through this bushing is led the cathode element wire from the reduced diameter end of the helix, to connect to the lead 4*b*. The other extremity of the cathode element wire is welded to the other end member 26, the aperture 24 in which serves to admit the discharge to the cathode element. Were the cylinder 59 of nickel or other metal, it might itself be employed as shield can 20, producing with the other so far described structure an electrode without a heater winding adapted for use as either the electrode 2 or 3 illustrated in Figure 1, or electrode 2 as illustrated in Figure 2.

For the inclusion of the heater winding 58 in the electrode, I form the cylinder 59 of refractory insulating material, such for example as magnesium oxide or "steatite", and wind thereabout over most of its length the heater winding 58. Preferably over this heater winding is coated and dried a solution of some refractory insulating material, for example similar to that of the cylinder 59, to form an insulating layer 58' in which the heater winding is imbedded. Surrounding the heater winding 58 in spaced relation thereto is the metal shield can 60, for example of nickel; this may be welded at each end to the peripheries of end members 26, which are accordingly made of appropriate diameter and peripherally flanged. The can 60 may be supported on a wire 60' extending inwardly from the seal 16. The end of heater winding further from the seal 16 is welded to the adjacent end member 26; the end of the heater nearer the shield is led, within a ceramic insulating tube 61, through the adjacent end member 26 and to the seal 16, passing outwardly through the seal to form the lead 58*a*.

The shield can 60 of course isolates the heater winding 58 from the gaseous discharge path. Within the space between can and heater winding, however, cross-arcing might occur between those two elements or between portions of the heater when the peak voltage across the heater exceeds the ionization potential of the gaseous atmosphere within the device (which it will be understood will permeate the space between shield can and heater, this enclosure not being hermetically tight). I have found that the danger of this cross-arcing is minimized by spacing the shield can from the heater by a distance of the order of the mean free path length of electrons in the gaseous atmosphere within the enclosure at operating temperatures; in the system which I have described the heater winding voltage and danger of cross-arcing will of course be greatest during the auxiliary discharge or pre-heating period, before the metal vapor has formed and when the heater winding is at maximum temperature, and accordingly the spacing specification just laid down will be referred to the rare gas atmosphere and the temperature within the enclosure during the pre-heating period.

It will of course be understood that this rela-

tive arrangement of heater winding and cathode element is not a thermally efficient one from the standpoint of heater watts required for given cathode element heating, in view of the considerable loss of heater winding heat via the shield can **60** to the gaseous atmosphere within the device. When the heater winding is required, however, to perform preheating functions for short periods only, the matter of this efficiency is not an important one—particularly when the heater winding is connected in a circuit such as **56** wherein considerable power is in any event to be consumed during the auxiliary discharge period. This relative arrangement, on the other hand, is very efficient from the standpoint of conservation of cathode heat, so that during normal operation the cathode requires for maintenance at proper temperature only a relatively small heating energy which is readily supplied as ionic heating energy by the normal discharge.

In the electrodes comprising the helical cathode element **28** and the adjacent cylinder **59**, whether or not the heater winding be employed, it is desirable that the enclosure, bounded by the interior cathode element surface and the end member **26** having the discharge-admitting aperture **24**, be of a diameter of several times the mean free path length of the electrons in the gaseous atmosphere within the enclosure at operating temperatures, and of a length preferably still somewhat greater. This apportionment permits the electrons leaving the cathode surface to develop within the enclosure, by ionization of the atmosphere, a field of intense positive space charge or an ion cloud. This permits the cathode element to be heated by recombination on its surface produced by ions falling from the ion cloud to the surface through only a short distance and with a low velocity. If these dimensions are made too small relative to the electronic means free path length, then the ion cloud is formed outside the enclosure; thereupon heavy ion losses occur on the end-member **26**, heating it and the can connected to it, but not the cathode surface; furthermore the now reduced number of ions falling from the cloud to the cathode surface fall with higher velocity along a longer path, producing disintegrating impacts on the cathode surface. Favorably, particularly in full wave devices such as herein illustrated, the diameter of the aperture **24** is made somewhat smaller than the internal cathode helix diameter to produce a slightly increased potential gradient and current density in the discharge passing therethrough.

In Figure 5 I have illustrated the electrode structure of Figure 4 in only partial cross-section and in position in the end of the envelope *l'*, with portions of the circuit of Figure 3 connected thereto (the outer bulb **7** being omitted for the sake of illustration simplification). An optional feature shown herein is the thermostatic switch **62** comprising the stationary contact **62***a* strapped by strap **62***b* to the envelope *l'* and the bimetallic strip **62***c* secured as by bracket **62***d* to the lead-in wire **58***a*. This switch is serially interposed in the junction potential stabilizing circuit **56**, is closed when cold, and is responsive to the heat of the envelope *l'* so that it opens late in or after the termination of the starting period and remains open throughout the normal operation of the device. This switch then serves automatically to disconnect the circuit **56**, and of course the heater winding **58** when included in that circuit, at some time after the auxiliary discharge and pre-heating period; I have above called attention, however, to the fact that in the system as described I do not consider such a circuit and heater disconnection essential, and rather prefer to omit the switch **62**.

It is not essential, particularly when pre-heating means are employed, that the cathode elements be in the specific form thus far described. A desirable alternative form of cathode element for use when the cathode element is to be pre-heated, and pre-heating means therefor, have been illustrated in the electrode which appears in cross-section in Figure 6. This electrode is quite similar to that of Figure 4, excepting for the different cathode element **63**, and for the addition of a jumper **74** welded between the supporting wire **60'** and the lead-in wire **4***b*, which provides the connection between the can **60** and the cathode element. The cathode element **63** is in the form of a nickel or other metal cup having a rough or pitted interior surface directed toward the discharge-admitting aperture **24** and coated with active material similarly to the coating of the cathode element **28** of other figures. The cathode element **63** is relatively further from the discharge-admitting aperture **24** than from the other end of the cylinder **59**, providing a spacing to the aperture of several times the mean free path length of the electrons in the atmosphere within the enclosure at operating temperatures; this, and a cylinder diameter of the same general order of dimension, permits the ion cloud or region of intense positive ionization to form within the enclosure and hence near the cathode element. Of course from this cloud many ions diffuse to and recombine on the interior wall of the cylinder **59**, heating this wall, but this heat is principally confined within the enclosure and by convection and radiation aids in heating the cathode element. Accordingly the discharge still efficiently heats the cathode element, and disintegration of the latter remains low by virtue of the short distance of fall thereon of ions from the ion cloud. Preferably the aperture **24** will be made of appreciably smaller diameter than the cylinder **59** to provide some increased potential gradient and current density in the discharge passing through the aperture; and any material which does disintegrate from the cathode and having a lower ionization potential than the gaseous atmosphere will be strongly deterred from leaving the enclosure, thereby minimizing discoloration of the walls of envelope *l'*.

I do not intend that the scope of my invention be limited by the details of the particular structures shown and described, as it will be obvious that these may be modified without departure from the spirit of the invention. It is particularly to be understood that the numerical examples herein set forth are offered wholly in an illustrative and entirely non-limitative sense.

In the claims hereunto appended it is my intention to claim, as broadly as the state of the art will permit, all the various novel combinations, subcombinations and features hereinabove disclosed.

I claim:

1. In combination with a current source with three different-potential terminals, two of said terminals being outer-potential terminals and the third being an intermediate-potential terminal: gaseous discharge means arranged to pass respectively different currents in different periods of its operation; incandescent lamp means forming a series circuit with said discharge means across said outer-potential terminals; and means, con-

nected between said intermediate-potential terminal and an intermediate point in said series circuit, for reducing the range of variation of the currents through said lamp means below the range of variation of currents through said discharge means.

2. In combination with a current source with three different-potential terminals, two of said terminals being outer-potential terminals and the third being an intermediate-potential terminal: gaseous discharge means comprising a discharge device including a source of metal vapor and arranged for starting at low gaseous pressure and relatively large current and for normal operation at high vapor pressure and reduced current; incandescent lamp means adapted for efficient operation at a current within the range between said discharge device currents and at a substantial power consumption relative to that of said device during normal operation thereof, said lamp and discharge means forming a series circuit across said outer-potential terminals; and low-impedance means connected between said intermediate-potential terminal and an intermediate point in said series circuit.

3. In combination with a current source with three different-potential terminals, two of said terminals being outer-potential terminals and the third being an intermediate-potential terminal; gaseous discharge means, comprising a discharge device including a source of metal vapor and arranged for starting at low gaseous pressure and relatively large current and for normal operation at high vapor pressure and reduced current; incandescent lamp means forming a series circuit with said discharge means across said outer-potential terminals; low-impedance means connected from said intermediate-potential terminal to an intermediate point in said circuit; and means operative during said normal discharge device operation for open-circuiting said low-impedance means.

4. In combination with a source of current including two outer-potential terminals: gaseous discharge means arranged for successive operation with an auxiliary discharge of relatively small current and an arc discharge of relatively large current; incandescent lamp means forming a series circuit with said discharge means across said outer-potential terminals; an additional terminal included in said source, having a potential which is intermediate the potentials of said outer-potential terminals and which during said arc discharge is of the order of the potential of the junction between said lamp means and discharge means; and a supplemental current-passing circuit connected from said junction to said additional terminal.

5. The combination according to claim 4, further including, in said discharge means, cathode means arranged to support the discharge and heater means arranged to heat said cathode means, said heater means being connected in said current-passing circuit.

6. In combination with a current source with three different-potential terminals, two of said terminals being outer-potential terminals and the third being an intermediate-potential terminal: gaseous discharge means serially including a choke coil and a gaseous discharge device having a discharge path; resistive ballasting means forming a series circuit with said discharge means across said outer-potential terminals; a supplemental current-passing circuit connected from a point in said series circuit between said resistive ballasting means and said discharge path to said intermediate-potential terminal; and an auxiliary winding of relatively few turns connected in said circuit and coupled to said choke coil.

7. In combination with a current source with three different-potential terminals, two of said terminals being outer-potential terminals and the third being an intermediate-potential terminal; gaseous discharge means arranged for operation with different voltage drops at different periods; incandescent lamp means serially disposed with said discharge means across said outer-potential terminals; and means, connected from said intermediate-potential terminal to the junction of said lamp means and discharge means, for stabilizing the potential of said junction.

8. A gaseous discharge system having, in combination, gaseous discharge means arranged to pass respectively different currents in different periods of its operation; incandescent lamp means serially connected with said discharge means for serial current flow therethrough; and circuit means, permanently connected to the junction of said lamp means and discharge means and automatically responsive to lower currents through said discharge means, for passing through said lamp means a current additional to that passed by said discharge means.

9. A gaseous discharge system having, in combination, gaseous discharge means arranged to pass respectively different currents in different periods of its operation; incandescent lamp means serially connected with said discharge means for serial current flow therethrough; and circuit means, permanently connected to the junction of said lamp means and discharge means and responsive to the current through said discharge means, for reducing the current through said lamp means below the current through said discharge means when the latter current is relatively high and for increasing the current through said lamp means over the current through said discharge means when the latter current is relatively low.

10. In combination with a source of current: gaseous discharge means serially including a choke coil and a discharge device arranged for successive operation with a glow discharge of relatively small current and an arc discharge of relatively large current; resistive ballasting means serially connected with said discharge means for joint excitation by said source; a supplemental current-passing circuit responsive to the potential distribution between said discharge means and said resistive ballasting means to pass a maximum current during said glow discharge; and an auxiliary winding of relatively few turns connected in said circuit and coupled to said choke coil to induce therein a voltage additive to that of said source during said glow discharge.

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