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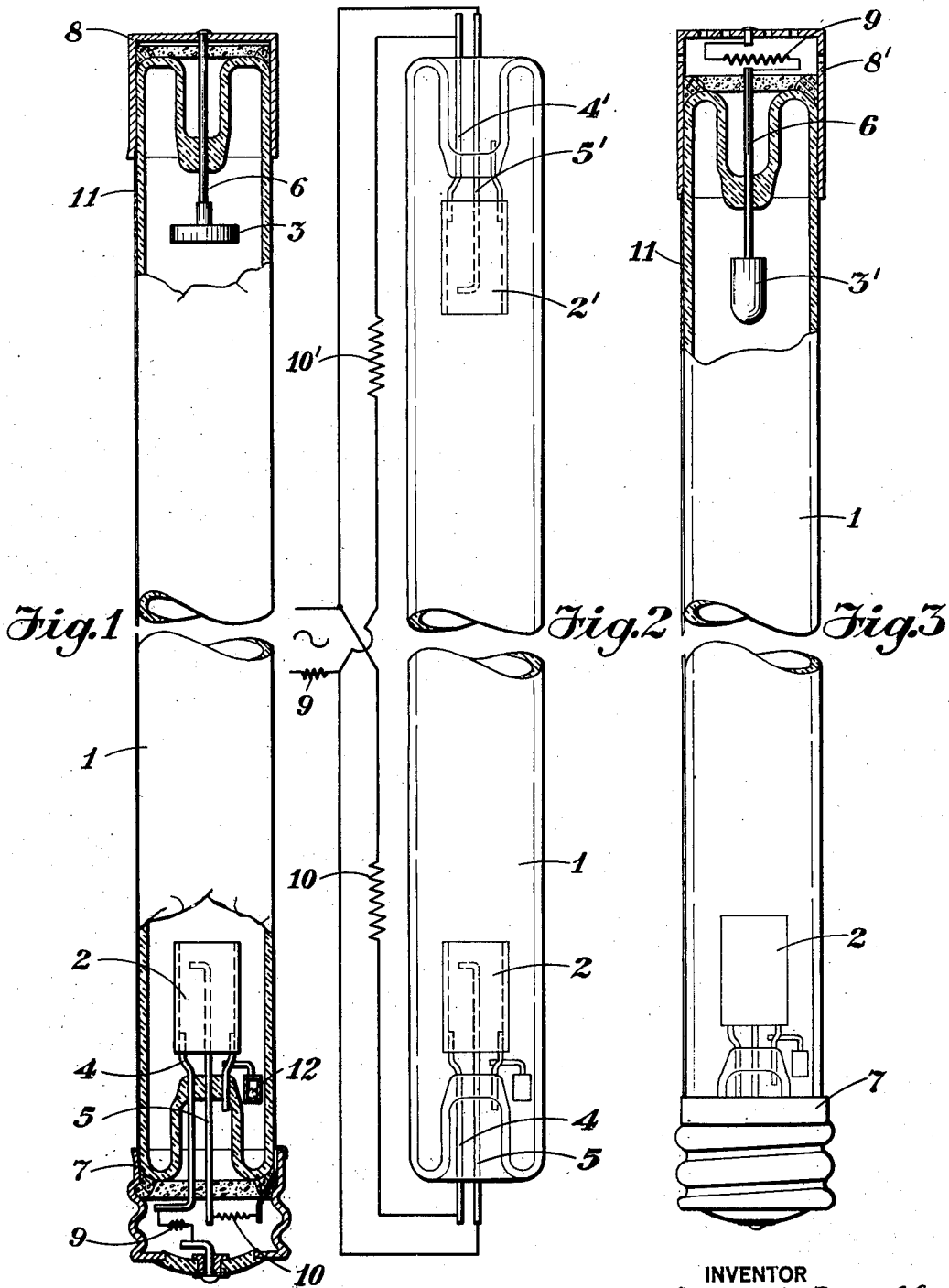
T. E. FOULKE

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GASEOUS ELECTRIC DISCHARGE DEVICE

Filed May 29, 1931

3 Sheets-Sheet 1



INVENTOR
Ted E. Foulke
BY
H. O. Brown
ATTORNEY

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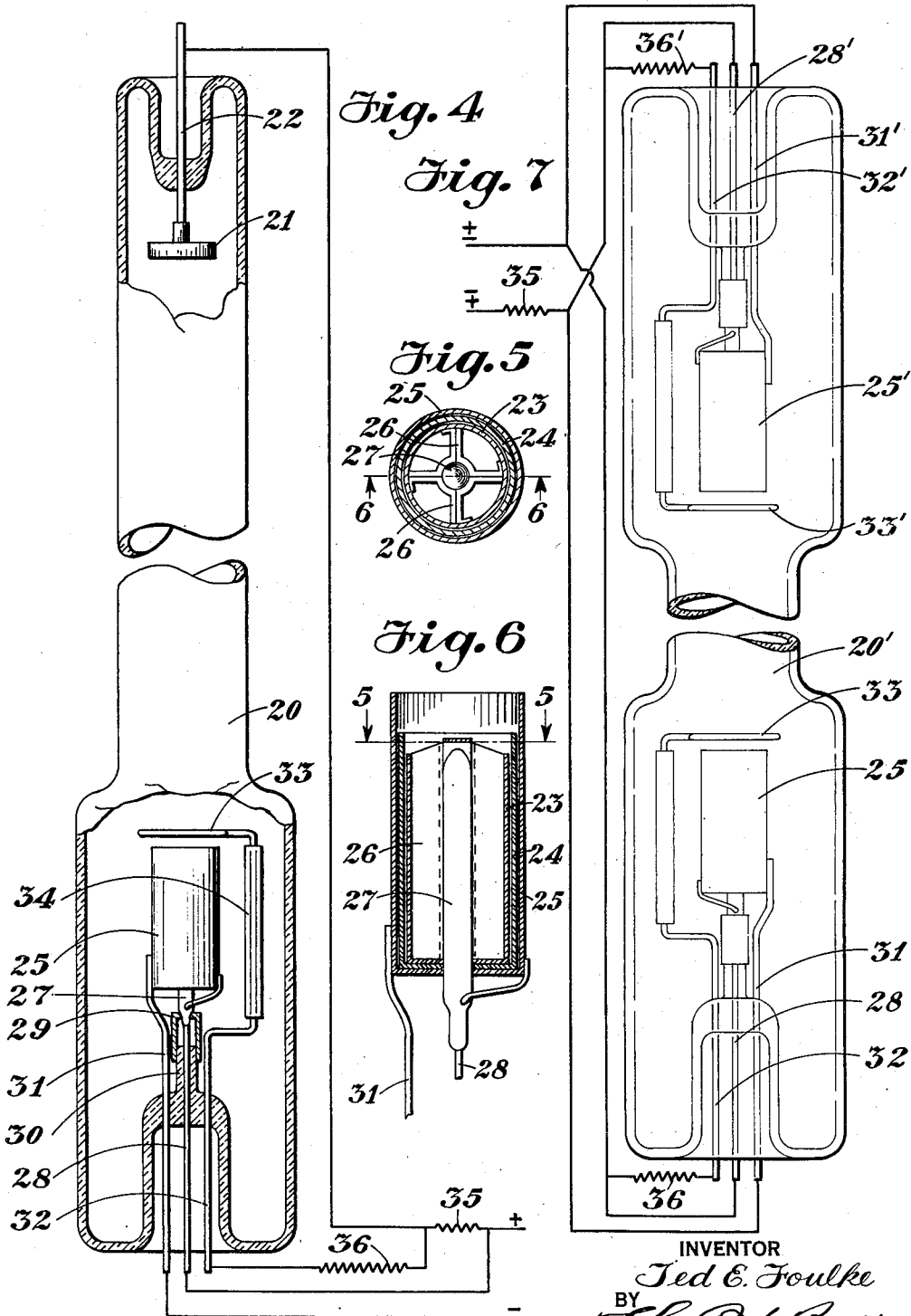
T. E. FOULKE

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3 Sheets-Sheet 2



INVENTOR

Ted E. Foulke

BY

Thos. A. Brown
ATTORNEY

Feb. 5, 1935.

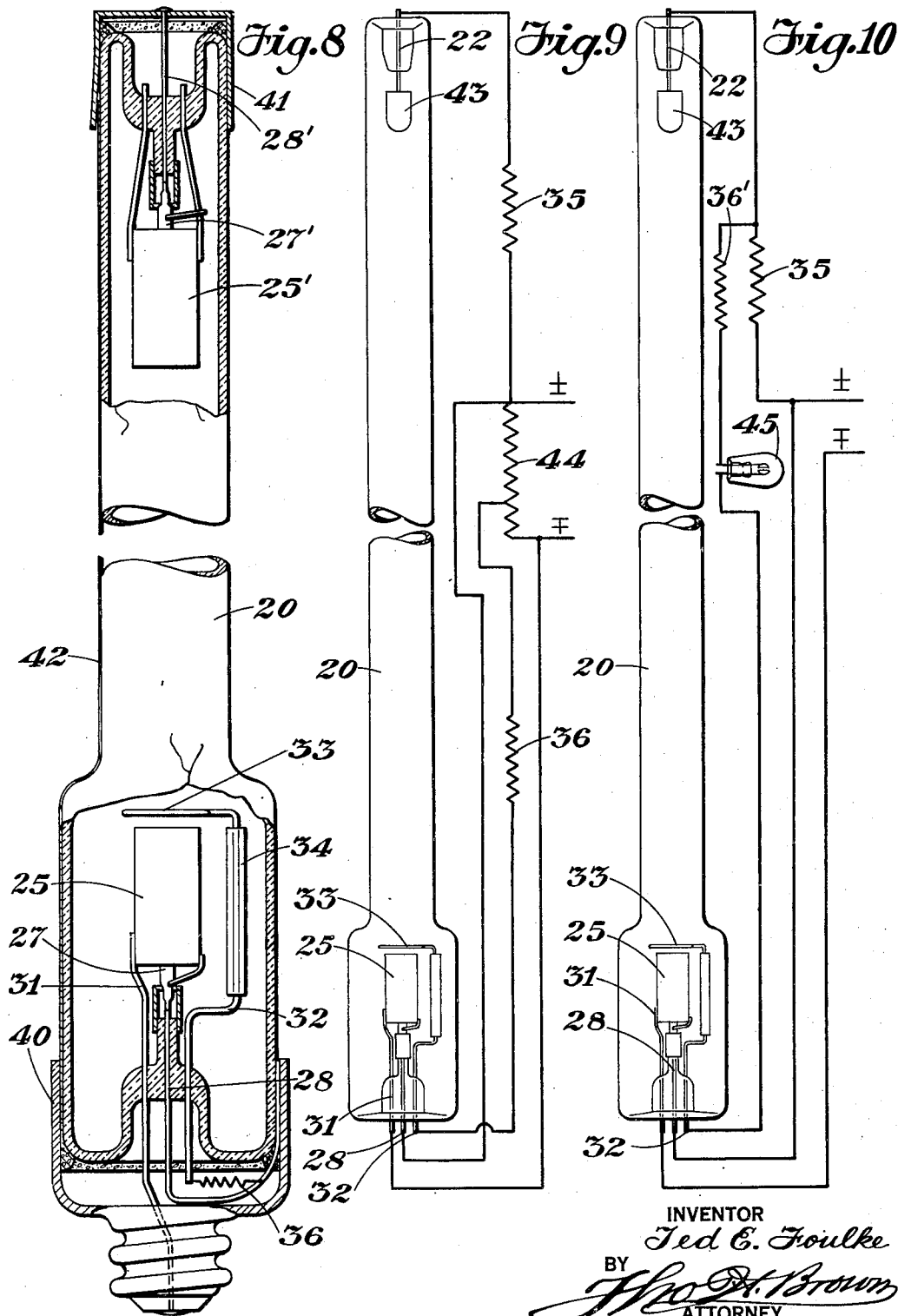
T. E. FOULKE

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GASEOUS ELECTRIC DISCHARGE DEVICE

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3 Sheets-Sheet 3



INVENTOR

Ted E. Foulke

BY

Attorney

UNITED STATES PATENT OFFICE

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GASEOUS ELECTRIC DISCHARGE DEVICE

Ted E. Foulke, Nutley, N. J., assignor to General Electric Vapor Lamp Company, Hoboken, N. J., a corporation of New Jersey

Application May 29, 1931, Serial No. 541,021

17 Claims. (Cl. 176-124)

The present invention relates to gaseous electric discharge devices generally, and more particularly to discharge devices operating with a long positive column discharge.

5 A particular object of the invention is to provide a gaseous electric discharge device of the positive column type in which a discharge may be initiated by the application of a potential of less than 110 volts D. C. between the electrodes thereof. A further object of my invention is to provide a novel method of operating an electric gaseous discharge device. Still other objects and advantages of the invention will appear from the following detailed description thereof, or from an inspection of the accompanying drawings.

10 The invention consists in a new and novel electric gaseous discharge device, and in a novel method of operation thereof, as hereinafter set forth and claimed.

20 As is well known, electric gaseous discharge tubes in their normal unionized state offer a very considerable resistance to the passage of an electric discharge therethrough, it being necessary to ionize the gas or vapor before a normal positive column discharge can take place there-
25 through at low voltage. To attain this ionization it is obviously necessary to provide means for producing ions at a rate which exceeds the loss of ions through recombination with electrons in space and at the walls of the device. In the past this has involved either the application of an extremely high potential to produce the required ionization, or the production of ions by means
30 of a discharge to an auxiliary electrode across a gap which is sufficiently short to permit the initiation of a discharge at the line potential. The first expedient is obviously undesirable, since it involves the use of auxiliary apparatus such as a high voltage transformer of poor regulation or the equivalent thereof; or a high frequency, high voltage mechanism such as a conventional vibrator coil; or means to produce an inductive surge of the required potential. Hence the use
35 of the auxiliary discharge, avoiding as it does the use of auxiliary apparatus, has theoretically been the more desirable of these expedients. In practice, however, it has been found impossible to start positive column discharges of any appreciable length on the usual commercial circuits having potentials of the order of 110 volts A. C. or D. C., for the reason that the auxiliary discharge is necessarily localized at one end of the tube, diffusion of the ions being relied upon to reduce the potential required to initiate the posi-

tive column in the tube. This diffusion, however, falls off rapidly with the distance, the number of ions which reach a distance of but three tube diameters from the discharge being insignificant. Thus this method still required the use of potentials of the order of 220 volts or more, except where the length of the positive column was less than three tube diameters. This mode of ionizing the gas has, therefore, never gone into commercial use, due to the obvious limitations inherent therein.

5 I have now discovered, however, that by introducing into the main gas a small quantity, usually less than one per cent, of a gas or vapor having an ionizing potential which is less than the potential of the metastable atoms of the main gas the radiations from such an auxiliary discharge may be utilized in a novel manner to produce ionization at relatively large distances from the auxiliary discharge, provided certain
10 other conditions hereinafter set forth are fulfilled. This ionization supplements the ionization heretofore present in the immediate vicinity of the auxiliary discharge, and makes possible for the first time the starting of positive column discharges of appreciable length on potentials of less than 100 volts D. C. For instance, the potential of metastable atoms of neon is about 16.5 volts, hence any gas or vapor having a lower ionizing potential, such as argon, krypton, xenon or mercury, may be used therewith as the auxiliary gas. In practice, however, it has been found that the best results are obtained when the difference between the metastable potential of the main gas and the ionizing potential of the auxiliary gas is relatively small, say of the order of about 5 volts or less, hence I prefer to use argon, whose ionizing potential is about 15.7 volts, as the auxiliary gas in a neon lamp. Other combinations which work very effectively are helium-argon, helium-krypton, argon-mercury, xenon-caesium, and mercury-caesium, the last mentioned gas or vapor being the auxiliary gas in each case.

15 The auxiliary discharge in any of the above cases emits radiations characteristic of the main gas, with the result that the resonance lines of that gas are made available. While the core of these lines is absorbed within a very short distance by the main gas, the fringes or edges of these lines have been found to penetrate the gas for a considerable distance before they are absorbed. The atoms of the main gas which absorb these radiations are put in an excited state thereby, this excited state being normally of very
20 25 30 35 40 45 50 55

short duration and therefore relatively ineffective. An appreciable portion of the excited atoms, however, gain or lose enough energy through collisions to get into a metastable condition, the life of these metastable atoms being relatively long, so that there is plenty of opportunity for these atoms to collide with an atom of the auxiliary gas. Upon such a collision the energy of the metastable atom is transferred to the latter, causing ionization of this atom of the auxiliary gas. It will thus be seen that if the gas in the space between the main electrodes is irradiated with the radiations of this auxiliary discharge a considerable amount of ionization will be set up throughout the path of the positive column, with the result that the conductivity of the tube is so increased that a positive column discharge may be initiated therethrough at a potential but little above the arc maintaining voltage. Once the arc is started the main gas, of course, is ionized and thereafter the auxiliary gas takes but a minor part in the transfer of energy through the tube.

From the above it will be apparent that the amount of the auxiliary gas employed is determined by two considerations: It must be present in a sufficient concentration to yield the ionization necessary to permit the starting of the positive column discharge; and it must not be present in so large an amount as to appreciably change the radiation characteristic of the auxiliary discharge from that of the main gas. For example, in a neon lamp I find argon concentrations of .01% to 1% to be effective, although greater or lesser percentages may be used in some cases.

The pressure of the gas is also very important, since in a neon-argon lamp this effect virtually disappears when pressures as high as 10 m. m. of mercury are employed. In practice I employ pressures as low as are consistent with the initiation of the auxiliary discharge in the device, since not only is the desired ionization throughout the tube increased in an amount greatly out of proportion to the decrease in pressure, but the efficiency of the positive column discharge is also enhanced thereby. For example, in a neon lamp using a cold cathode I employ a pressure of the order of 4 m. m. of mercury, and with a thermionic cathode a pressure of 1 to 3 m. m. of mercury is desirable. When other gases are used, correspondingly low pressures are, of course, necessarily employed.

In any case the pressure employed is necessarily a compromise between the low pressure at which the positive column discharge will be the most efficient, and the somewhat higher pressure at which the production of ionization by resonance radiation and collision phenomena is most effective. In the case of the cold cathode device consideration must also be given to the somewhat higher pressure at which the initial breakdown of the auxiliary gap most easily occurs. Since it is thus essential that the pressure should be as low as possible it is of the utmost importance that the geometry of the auxiliary gap should be as favorable to low voltage breakdown as possible, and that the cathode surface should have a minimum work function, so that the breakdown potential of this auxiliary gap may be kept below the available line potential despite the unfavorably low pressure of the gas. When cold cathodes are used I find that a coating of cesium, preferably intermixed with the oxide thereof, gives a very satisfactory surface for this purpose, per-

mitting breakdown in neon at less than 100 volts D. C., even when the pressure of the gas is as low as 3 m. m. of mercury. Where the cathode of the auxiliary discharge is also the cathode of the main discharge, as is usual, this coating of low work function also serves to materially reduce the cathode fall, thus releasing a very considerable portion of the available potential for use in the positive column, a cathode coated as above described, for example, having a cathode fall of but 40 volts D. C. Where a thermionic cathode is employed, of course, breakdown may be secured at the available line potential at even lower pressures, and the maintaining voltage is also materially reduced, so that considerably longer positive columns may be started and operated, due both to the more efficient use of the resonance radiations and to the decrease voltage consumption at the cathode.

For the purpose of illustrating my invention I have shown several embodiments thereof in the accompanying drawings, in which

Fig. 1 is an elevational view, in part section, of an electric gaseous discharge device of the positive column type,

Fig. 2 is an elevational view of a modification of the device shown in Fig. 1 which is especially adapted for use with alternating current,

Fig. 3 is an elevational view, in part section, of another modification of the device shown in Fig. 1, showing the use of a special anode for full wave operation,

Fig. 4 is an elevational view, in part section of an electric gaseous discharge device employing a thermionic cathode,

Figs. 5 and 6 are sectional views showing details of the cathode which is preferably used in the discharge device shown in Fig. 4,

Fig. 7 is an elevational view of a modification of the device shown in Fig. 4, this modification being especially adapted for use on alternating current systems,

Fig. 8 is an elevational view, in part section, of another modification of the device shown in Fig. 4, and

Figs. 9 and 10 are elevational views of still another modification of the device shown in Fig. 4, with two different operating circuits schematically illustrated in connection therewith.

In the drawings, with particular reference to Fig. 1, the tubular envelope 1 of glass or other vitreous material has a tubular cathode 2 which is preferably formed of nickel and an anode 3 which is conveniently made of carbon. Said cathode is supported by the inlead 4 which is sealed into the adjacent end of said envelope 1. Another inlead 5, which serves as an auxiliary anode, is also sealed into the same end of said envelope, said inlead extending for an appreciable distance within the tubular cathode 2, and preferably terminating at a point close thereto. That portion of the inlead 5 which extends within the envelope 1 preferably consists of nickel, tungsten, or other suitable electrode material. The anode 3 is supported by an inlead 6 which is sealed into the opposite end of the envelope 1. A conventional screw base 7 is cemented in place on the cathode end of the envelope 1, while a metallic cap 8 is cemented on the opposite end of said envelope. The inlead 4 is connected to the tip of said screw base 7 through a resistance 9 of a suitable value to ballast the discharge, say of the order of 500—1500 ohms., while the inlead 5 is connected to the sleeve of said screw base through a relatively large resistance 10, of the order of

25,000-100,000 ohms. Similarly the inlead 6 is connected to the cap 8, said cap being in turn connected to the sleeve of the screw base 7 by means of a conductor 11 of aluminum foil or the like

5 which extends along the surface of the envelope 1. The cathode 2 may be of a substance having a low work function, such as cesium or rubidium, or of a base metal coated therewith, but I prefer to use a cathode of a base metal, such as nickel, 10 which is coated with cesium intermixed with an oxide, since it has been found that the cesium adheres much more tenaciously to such a surface, with the result that such a cathode has a relatively long useful life. Such a cathode is conveniently 15 prepared by coating the clean nickel cathode 2 with a compound such as cesium carbonate during the manufacture of the device. While the envelope is being evacuated the cathode is heated in a suitable manner, as by means of a high 20 frequency field, to a temperature sufficient to reduce the carbonate to the oxide, the evolved gas being drawn off by the pump. Any occluded gas is, of course, also driven off during this heating. The pellet 12, which is suitably supported near 25 one end of the device, and which preferably consists of a decomposable cesium or other alkaline compound, together with a reducing agent, if necessary, a mixture of cesium dichromate and silicon being commonly used, is then heated. Pure 30 metallic cesium is thereupon produced, the vapor of which permeates every part of the device, condensing on the walls thereof. The device is then filled with a gas or vapor which gives the desired radiations, together with a small percentage of 35 another gas or vapor whose ionizing potential is less than the potential of the metastable atoms of the principal gas, at a pressure which is usually less than 10 m. m. of mercury. When red light is desired, for instance, I use neon, containing 40 about .2% of argon, at a pressure of 3 to 6 m. m. of mercury.

In the modification shown in Fig. 2 the envelope 1 has a cathode 2, supported by the inlead 4, 45 as in Fig. 1. The inlead 5 likewise extends within the cathode 2 in a similar manner. At the opposite end of the envelope 1, however, there is a similar cathode 2', supported by the inlead 4', and an inlead 5', which extends within the cathode 2', thus making opposite ends of the 50 device symmetrical. The inlead 4 is connected to one terminal of a suitable source of alternating current through the ballast resistance 9, while the inlead 5' is connected to the same terminal through said resistance 9 and the high resistance 55 10'. The lead 4' is connected to the opposite terminal of said source, to which the inlead 5 is also connected through the high resistance 10. This device, due to its symmetry, is thus adapted for full wave operation on alternating current. 60 The electrodes 2 and 2' are, of course, preferably coated in the same manner as has been described in connection with Fig. 1, and a similar gaseous atmosphere is sealed within the envelope 1.

The device shown in Fig. 3 is quite similar to 65 that shown in Fig. 1, the main difference being that an anode 3' of a sintered mixture of tungsten and barium oxide or the like, such as disclosed by Pirani et al. in their copending application, Ser. #377,044, filed July 9, 1929, is used in this 70 modification. The perforated cap 8' is also made slightly larger to accommodate the ballast resistance 9, which in this case is connected between the inlead 6 and said cap 8'. This location of the ballast resistance is desirable in some cases, 75 since it permits the heat therefrom to be more

easily dissipated, and is thus more applicable to lamps of high wattage.

In the structure illustrated in Figs. 4-6 the tubular vitreous envelope 20 has at one end thereof 5 of an anode 21, which may be graphite, iron, or other suitable material, supported by an inlead 22. At the other end of said envelope there is a cathode 23 of nickel or the like. About said cathode and in electrical connection therewith 10 are the cylindrical heat shields 24 and 25, which are also conveniently made of nickel. The outer heat shield 25 preferably extends to some distance beyond the end of the cathode 23. Said cathode is divided into a plurality of compartments by the 15 vanes 26, said vanes cooperating to form a central tube which closely fits the heater 27. Said heater is designed for operation on 110 volts, hence the heating coil thereof (not shown) is completely embedded in a suitable refractory insulating material, such as alundum, in order to 20 prevent the formation of an arc between different portions thereof. One terminal of said heating coil is connected to the inlead 28, while the other terminal thereof is connected to the heat shield 25, the latter terminal thus being 25 maintained at the potential of the cathode 23. Said inlead 28 is protected from gaseous conduction thereto by means of a nickel sleeve 29 which closely fits over both the end of the heater 27 and the end of the tubular vitreous sleeve 30 which forms part of the inlead seal. The inner 35 surface of the cathode 23 and the exposed surfaces of the vanes 26 are preferably coated with an alkaline or alkaline earth metal or compound thereof, in order to reduce the work function of these surfaces. For instance, I prefer to use a mixture of barium and strontium oxides, these 40 oxides being reduced from the carbonates in situ by the use of heat in a well known manner. In some cases I also coat that portion of the inner surfaces of the heat shields 24 and 25 which 45 extends beyond the cathode 23 with a material, such as powdered aluminum, which is known to resist activation by particles sputtered from the active cathode surface, in order to permanently confine the discharge to the desired surfaces within the cathode 22. The heat shield 25, which is in electrical connection with the cathode 23, is connected to the inlead 31, by which it is 50 in part supported. A third inlead 32 extends into said envelope 20 and terminates in a ring 33 which is concentric with the heat shield 25 and which lies in a plane close to the end thereof. Said ring serves as an auxiliary anode, and hence 55 is preferably made of nickel, iron, tungsten or other suitable material. In order to confine the effective surfaces of said auxiliary anode to the ring portion of said inlead 32 a vitreous sleeve 34 is preferably placed about the portion of said inlead 32 which extends alongside of the heat 60 shield 25. When operated from a direct current source the positive terminal of said source is connected through a ballast resistance 35 of the order of 10-100 ohms to the inlead 22. Said positive terminal is likewise connected directly 65 to the inlead 28, and through said resistance 35 and a high resistance 36, of the order of 1000 ohms, to the inlead 32. The negative terminal of said source is then connected directly to the inlead 31. When desired, it is obvious that a 70 screw base may be provided, as shown in Fig. 1 or 3. The envelope 20 is filled with any desired gas, together with a small percentage of another gas whose ionizing potential is lower than the metastable potential of the main gas. For 75

example, when a red light source is desired I use neon containing about 2% of argon at a pressure of 1-3 m. m. of mercury.

The device shown in Fig. 7 differs from the device shown in Fig. 4 mainly in that a duplicate cathode assembly is substituted for the anode 21. This tube, being symmetrical, is especially adapted for use on alternating current. One terminal of an alternating current source is connected to the inlead 31 through the ballast resistance 35, to the inlead 32' through the high resistance 36', and directly to the inlead 28', while the other terminal of said source is connected directly to the inleads 31' and 28, and through the high resistance 36 to the inlead 32.

In the modification of Fig. 4 which is shown in Fig. 8 the anode 21 is replaced by an electrode assembly which is substantially identical with that at the other end of the tube, save that there is no auxiliary anode, and that the heating coil of the heater 27' is designed to carry the main discharge current. A conventional screw base 40 is cemented to the cathode end of the envelope 20, the inlead 31 being connected directly to the tip thereof. The inlead 28 is connected directly to the sleeve of said base, while the inlead 32 is also connected thereto through the high resistance 36, which is conveniently disposed in a well known manner within said base 40. A conducting cap 41 is cemented to the opposite end of said envelope 20, the inlead 28' being connected thereto. Said cap 41 is in turn connected with the sleeve of the base 40 through the conductor 42, which is conveniently formed of aluminum foil cemented to the envelope 20, and so disposed as to afford a minimum of interference with the light emission from said envelope 20.

Fig. 9 shows a further modification of the structure of Fig. 4 in which an anode 43 of the type described in connection with Fig. 3, and consisting, for example, of a sintered mixture of tungsten and barium oxide, is used in place of the anode 21. The connections of the various inleads are the same as in Fig. 4, except that the inlead 32 is connected through the high resistance 36 to a point of suitable potential on the potentiometer 44, said potentiometer being connected across the line.

Fig. 10 is similar to Fig. 9, save that in this case the inlead 32 is connected to the anode through a gaseous discharge device 45 of the cathode glow type and a ballast resistance 36' which has somewhat less resistance than the corresponding resistance in the other circuits illustrated. Said discharge device has a breakdown potential considerably below the available line potential and also has a current capacity equal to that desired in the auxiliary discharge.

In the use and operation of the electric discharge device shown in Fig. 1, upon the application thereto of a potential of the order of 100-110 volts D. C. a discharge of the order of 5-30 milliamperes immediately takes place between the cathode 2 and the auxiliary anode 5, this current being limited by the resistance 10. Where a neon-argon mixture is present, as described, this discharge will emit the characteristic radiations of neon, including the resonance lines thereof. While the core of these resonance lines is absorbed within a very short distance, it has been found that the fringe thereof penetrates the gas for a considerable distance. The neon atoms which absorb these resonance radiations are put into an excited state thereby. The life of this excited state is extremely short, but during the

duration thereof a large number of these excited atoms gain or lose enough energy to put them in a metastable condition, these metastable atoms having a relatively long life, as is well known. Upon collision of these metastable neon atoms with argon atoms a transfer of energy is frequently effected, with a resulting ionization of the argon atoms. The ionization of the argon atoms is also presumably possible when any of the excited neon atoms collide therewith, since these excited atoms also have the requisite energy. This ionization extends throughout the length of the tube, due to the penetration of the resonance radiations, and permits a small current to flow between the cathode 2 and the anode 3. This current, of course, causes a change in the distribution of the electric field resulting from the potential applied between the cathode 2 and the anode 3, causing a general speeding up of the ions and electrons with a resulting increase in ionization by collision. This increase in ions continues until the concentration of ions is so great that the discharge between the cathode 3 and the anode 2 changes into an arc having a typical negative volt-ampere characteristic, the current then being limited by the resistance 9. When this condition is reached the continuance of the discharge no longer depends upon the continuance of the auxiliary discharge. Upon initiation of the arc the energy consumption in the auxiliary discharge is automatically decreased due to the increased voltage drop in the resistance 9, with a resulting increase in the efficiency of the device. While these phenomena have been described as occurring sequentially it is to be understood that the starting of the positive column is virtually instantaneous, no delay period being observable. As a result of this novel utilization of the resonance radiations to promote ionization throughout the discharge path I have found it possible to start and operate a tube such as shown in Fig. 1 having a positive column approximately 13 inches long and 1 inch in diameter on potentials as low as 100 volts D. C. Hence such a lamp will operate satisfactorily on commercial circuits having a nominal potential of 110 volts D. C. despite severe voltage fluctuations therein. Where desired the device of Fig. 1 may also be operated on alternating current circuits, it being evident, however, that the positive column will only be formed on alternate half cycles, due to the high work function of the anode 3. It is, of course, obvious that with other gases the maximum possible length of the positive column will vary, being somewhat less, for example, with helium, and greater with argon or mercury.

The device of Fig. 2 starts on any given half cycle in the same manner as has been described in connection with the structure of Fig. 1, it being evident that the discharge is restarted in the same manner at the beginning of each half cycle from alternate ends of the device. The maximum length of the positive column which can be readily started on 110 volts with this structure is about 50% greater than is attainable with the structure shown in Fig. 1, say 18 inches when 1 inch tubing is employed. In some cases it is possible to omit the auxiliary anode 5', together with the associated lead and resistance 10', it having been found that the ionization persists long enough to carry over from one half cycle to the next. This is especially true where the positive column is somewhat shorter than the maximum possible with the symmetrical structure illustrated.

The device of Fig. 3 starts in a manner identical with that described in connection with the structure of Fig. 1, a half wave discharge occurring when the device is operated on alternating current. As the discharge heats up the anode 3', however, said anode begins to emit electrons, with the result that it then functions as a cathode on the reverse half cycle. As a result full wave operation, similar to that obtained with the device shown in Fig. 2, but with the auxiliary anode 5' omitted, as described above, is attained with this structure.

The device illustrated in Figs. 4-6 functions in essentially the same manner as the device shown in Fig. 1. Upon application of 110 volts D. C. to this device, which may have a positive column of the order of 18 inches long and an inch in diameter when neon is employed as the main gas, current flows through the heater 27, causing the cathode 23 to be heated. When said cathode begins to emit electrons under the influence of this heating a discharge takes place from the auxiliary anode 33 thereto. This discharge, which is limited by the resistance 36 to a current of the order of 100 milliamperes, provides the resonance radiations which are essential to my new method of starting these devices, as described hereinbefore. Since these radiations can pass through the opening in the ring anode 33 they irradiate the entire gas space between the cathode 23 and the anode 21, so that initiation of the main discharge therebetween promptly ensues. This device may likewise be operated on alternating current, if so desired, a discharge then occurring on alternate half cycles.

The device shown in Fig. 7 operates in the same manner as that of Figs. 4-6, except that the discharge is reinitiated on each half cycle from alternate ends of the device. Positive columns as long as 30 inches and one inch in diameter may be satisfactorily started, where neon is used as the principal gas, on voltages as low as 110 volts A. C. in a device constructed in this manner. The heat shields 24, 24', 25 and 25' are effective as anodes on the reverse half cycles, adding to the electrode area, and thus decreasing the anode heating. It will also be noted that once the discharge is initiated the energy input to the heaters 27 and 27' is automatically decreased, due to the increased voltage drop in the resistance 35. While I have illustrated the heaters 27 and 27' as being connected in parallel it is obvious that they can be connected in series when desired.

The device shown in Fig. 8 is especially designed for operation on alternating current. Upon application of a suitable potential, such as 110 volts, thereto a half-wave positive column discharge is initiated therein in the manner described in connection with the device of Fig. 4. This discharge current flows through the series connected heater 27', heating the associated electrode, which at starting serves only as an anode, said heater 27' thus serving both as a heater and as a ballast for the discharge. The temperature of this electrode thereupon rises, due both to the heat received from the heater 27' and to the heat generated by the anodic bombardment thereof. As soon as said electrode reaches an electron emitting temperature it begins to serve as a cathode on the reverse half cycle, this current increasing as the thermal emission increases until a temperature equilibrium is attained, at which time a balanced, full-wave discharge current passes through the device. As a result of the

dual use of the ballast this device is obviously somewhat more efficient than the full wave device of Fig. 7. In addition, but one connection is needed to the anode end of the tube, making this device better adapted for operation in a conventional screw socket.

The device illustrated in Fig. 9 is also designed for full-wave operation on alternating current. This device, however, starts with a half-wave discharge, changing over to full-wave as the anode 43 reaches an electron emitting condition as a result of the anodic heating thereof, in a manner similar to that described in connection with the structure of Fig. 3. Where thermionic cathodes are employed the auxiliary discharge sometimes starts, this in turn starting the main discharge, before the cathode emission is sufficient to support the normal positive column discharge current. In this case the cathode may be destroyed, or its efficiency seriously impaired, or undesired gaseous impurities may be liberated, due to the concentration of the discharge at a "hot spot" on the cathode. One way of eliminating this difficulty is shown in this figure. By means of the potentiometer 44 the voltage between the auxiliary anode 33 and the cathode 23 is limited to say 30-40 volts so that the auxiliary discharge cannot start until there is practically normal operating emission from said cathode. As a result initiation of the positive column discharge is positively delayed until the cathode gives the necessary electron emission.

Another way of solving this difficulty is shown in Fig. 10. In this structure the discharge device 45 which is in series with the auxiliary anode 33 requires a potential of say 60-70 volts (where the device is to be operated on a 110 volt circuit) to produce a discharge therein. Hence until the electron emission from the cathode 23 is sufficient to very appreciably reduce the voltage drop between the cathode 23 and said auxiliary anode 33 no current can flow through said device 45, and there can be no auxiliary discharge. Once the emission attains a desired value, however, the potential distribution is so changed that breakdown occurs in the device 45, with the attendant initiation of the auxiliary discharge. The positive column discharge is thereupon initiated. But as soon as the main discharge current flows through the ballast 35 the voltage across the device 45 is reduced below the voltage necessary to maintain a discharge there-through with the result that the auxiliary discharge is discontinued. It is obvious, of course, that if the discharge fails to restart on any successive cycle, due to the initial half-wave operation, the auxiliary discharge will again momentarily take place, but as soon as full-wave operation is attained there will be no further need for this. This discontinuance of the auxiliary discharge is obviously effective to increase the efficiency of the device, due to the elimination of the wattage consumed by this discharge. But an even greater increase in efficiency results therefrom due to changes which occur in the positive column when the auxiliary discharge is discontinued, it having been found that there is a very appreciable increase in light emission without a corresponding increase in current. In addition to this very appreciable increase in efficiency this device also has an extremely long useful life, since the initial delay in the initiation of the auxiliary discharge prevents cathode disintegration, while the discontinuance of the auxiliary discharge during operation removes a pos-

sible source of sputtering. It is, of course, obvious that this circuit is not limited to the specific type of device shown, nor to alternating current operation. It is furthermore to be understood that other means of discontinuing the auxiliary discharge may be used where desired.

In some cases, particularly where a condensable vapor is used as the principal component of the gaseous atmosphere, the roles of the two components of the atmosphere may be reversed at starting. For instance, in a mercury vapor lamp, argon may be introduced at a low pressure. At starting only a trace of the mercury vapor will be present due to the low vapor pressure thereof. Hence the auxiliary discharge will emit the resonance lines of the argon, exciting argon atoms throughout the discharge space, and resulting in a copious formation of metastable argon atoms. Since the potential of these metastable atoms is greater than the ionizing potential of mercury, it is obvious that collisions of these metastable argon atoms with mercury atoms results in the ionization of the latter. As the device heats up the proportion of mercury vapor increases, so that at all times the energy is transferred chiefly by the mercury ions. Unfortunately such a device cannot be restarted while it is hot, however, due to the fact that the principal gas is then mercury. This difficulty may be overcome by the addition of a little cesium. When the lamp is cold this cesium is of little effect, due to its extremely low vapor pressure. The arc is, however, easily started when the lamp is cold due to the presence of the argon. As the lamp heats up the cesium vaporizes in sufficient quantity to serve as the auxiliary gas by means of which the lamp can be restarted while hot. In this case the auxiliary discharge emits mercury resonance radiations, which excite mercury atoms throughout the discharge space, resulting in the formation of metastable mercury atoms. These metastable mercury atoms ionize the cesium atoms upon collision therewith, and the arc is started as a result of this ionization, whereupon the mercury vapor is ionized and serves to transfer practically all of the energy.

Where a mercury-cesium combination is employed alone it is obvious that some means must be provided to warm the cesium and mercury sufficiently to get the vapor required. Similar heating means is also required when zinc, cadmium, any of the alkali metals or the like are employed, according to the general rule laid down hereinbefore, as either the principal or auxiliary vapor.

The type of thermionic cathode illustrated in Figs. 5 and 6 has been found to be particularly effective, possibly due to the fact that the gas is hotter within the cavity than in the remainder of the device. It is believed that this tends to shift the relative amount of energy available in the core and in the fringes of the resonance lines, making these lines more effective at a distance. Moreover, it is well known that electrons emitted from within a hollow metallic chamber have a relatively low random velocity, or temperature. These low temperature electrons do not produce as strong a charge on the walls of the arc tube as would higher temperature electrons, so that the sheath thickness is minimized, permitting a larger area through which ions may flow free from interference by this sheath. It is to be understood, however, that while I prefer to use this type of thermionic cathode, I am not limited

thereto, but that good results may be obtained with any of the usual thermionic cathodes.

The intensity of the resonance radiations with which the gas in the arc path is irradiated is dependent upon several factors. One of these factors is, of course, the current flowing in the auxiliary discharge. This current, which is usually of the order of a few milliamperes, as has been indicated hereinbefore, is limited chiefly by economic factors, it being undesirable to put very much energy into this discharge due to the low efficiency of utilization therein. In some cases, however, as where extremely long positive columns are desired, this current may be considerably increased with a resulting increase in the length of the positive column which may be started at a given voltage. Or in lieu thereof, an additional discharge may be provided at another point in the discharge column to overcome the attenuation of the resonance radiations due to absorption. Or the resonance lines may be broadened, as by the Doppler effect, so that more of the radiation will penetrate to an appreciable distance into the gas.

While I have described the use of a resistance to ballast the discharge it is to be understood that where alternating current is employed an inductance can be substituted therefor at will. In some cases this is desirable, since the overall efficiency of the device will be increased, with some sacrifice in the power factor, however, the inductance moreover serves to maintain the discharge through a longer portion of each half cycle.

Various other additions, substitutions or changes, within the scope of the appended claims, may of course be made either in the devices, or in the method, without departing from the spirit of my invention.

I claim as my invention:

1. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere within said envelope, said atmosphere comprising a major component and a minor component, the metastable potential of the major component being greater than the ionizing potential of the minor component, two electrodes sealed into said envelope, and means to simultaneously irradiate the gaseous atmosphere throughout the entire space between said electrodes with the resonance radiations of said major component.

2. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere within said envelope, said atmosphere comprising a major component and a minor component, the metastable potential of the major component being in excess of the ionizing potential of the minor component by less than about 5 volts, two electrodes sealed into said envelope, and means to simultaneously irradiate the gaseous atmosphere throughout the entire space between said electrodes with the resonance radiations of said major component.

3. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere within said envelope, said atmosphere comprising a major component and a minor component, the metastable potential of the major component being greater than the ionizing potential of the minor component, two main electrodes and at least one auxiliary electrode sealed into said envelope, said auxiliary electrode being so positioned with respect to another electrode that the normal applied potential will initiate an auxiliary discharge therebetween, the gas column throughout the en-

tire space between said main electrodes being simultaneously exposed to radiations from said discharge, the minor component of said gaseous atmosphere being insufficient in amount to appreciably affect the radiations from said auxiliary discharge.

4. An electric gaseous discharge device comprising a sealed envelope, neon containing from .01% to 1% of argon in said envelope at a pressure of less than 10 m. m. of mercury, two main electrodes sealed into said envelope, and an auxiliary electrode sealed into said envelope and so positioned with respect to one of said main electrodes that the normal applied potential will initiate a discharge therebetween, the entire gas column between said main electrodes being exposed to radiations from said discharge, whereby said gas column is ionized throughout its length.

5. An electric gaseous discharge device comprising a sealed envelope, neon containing 0.2% of argon in said envelope at a pressure of between 1 and 6 m. m. of mercury, a cathode of low work function sealed into said envelope, another electrode at an appreciable distance therefrom, and an auxiliary anode so disposed with respect to said cathode that the normal applied potential will initiate a discharge therebetween, the entire gas column between said cathode and the second mentioned electrode being exposed to radiations from said discharge.

6. An electric gaseous discharge device comprising a sealed envelope, neon containing 0.2% of argon in said envelope at a pressure of 3-6 m. m. of mercury, a cathode sealed into said envelope, said cathode having a surface of caesium intermixed with caesium oxide, and an auxiliary anode so disposed with respect to said cathode that the normal applied potential will initiate a discharge therebetween, the entire gas column between said cathode and the second mentioned electrode being exposed to radiations from said discharge.

7. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere within said envelope, said atmosphere comprising a major component and a minor component, the metastable potential of the major component being greater than the ionizing potential of the minor component, a thermionic cathode, an auxiliary anode so disposed with respect to said cathode that the normal applied potential will initiate a discharge therebetween, another electrode at an appreciable distance from said cathode, the entire gas column between said electrode and said cathode being exposed to radiations from said discharge.

8. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere within said envelope, said atmosphere comprising a major component and a minor component, the metastable potential of the major component being greater than the ionizing potential of the minor component, two thermionic cathodes within said envelope, an auxiliary electrode associated with each cathode and so disposed with respect thereto that the normal applied potential will initiate a discharge therebetween, the entire gas column between said cathodes being exposed to the radiations from the discharges between each cathode and its associated auxiliary electrode.

9. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere within said envelope, said atmosphere comprising a major component and a minor component, the metastable potential of the major component being greater than the ionizing potential

of the minor component, two thermionic cathodes within said envelope, one of said cathodes having a heater in series therewith, an auxiliary electrode associated with the other of said cathodes, and so disposed with respect thereto that the normal applied potential will initiate a discharge therebetween, the entire gas column between said cathodes being exposed to radiations from said discharge.

10. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere in said envelope, said atmosphere comprising a major component and a minor component, the metastable potential of the major component being greater than the ionizing potential of the minor component, two main electrodes and at least one auxiliary electrode sealed into said envelope, said main electrodes having a surface of low work function, said auxiliary electrode being so positioned with respect to another electrode that the normal applied potential will initiate a discharge therebetween, the entire gas column between said main electrodes being exposed to radiations from said discharge.

11. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere in said envelope, said atmosphere comprising a major component and a minor component, the metastable potential of the major component being greater than the ionizing potential of the minor component, two main electrodes sealed into said envelope, one of said electrodes consisting of a sintered mixture of a metal and a substance of low work function, the other of said electrodes having a surface of low work function, and an auxiliary electrode sealed into said envelope and so disposed with respect to one of said main electrodes that the normal applied potential will initiate a discharge therebetween, the entire gas column between said main electrodes being exposed to radiations from said discharge.

12. An electric gaseous discharge device comprising a sealed envelope containing argon, mercury and caesium in said envelope, two main electrodes sealed into said envelope, and an auxiliary electrode sealed into said envelope and so disposed with respect to one of said main electrodes that the normal applied potential will initiate a discharge therebetween, the entire gas column between said main electrodes being exposed to radiations from said discharge.

13. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere within said envelope, a thermionic cathode and an anode therefor sealed into said envelope, an auxiliary anode adjacent to said thermionic cathode, and means to prevent initiation of a discharge to said auxiliary anode until the free electron emission from said cathode will support the normal discharge current to said first mentioned anode without formation of a hot spot thereon.

14. An electric gaseous discharge device comprising a sealed envelope, a gaseous atmosphere within said envelope, a thermionic cathode and an anode therefor sealed into said envelope, an auxiliary anode adjacent to said thermionic cathode, a separate gaseous discharge device in series with said auxiliary anode, and a ballast impedance in series with both said auxiliary anode and said first mentioned anode.

15. The method of initiating a discharge in an electric gaseous discharge device having a desired gaseous atmosphere containing a trace

of a gas having an ionizing potential which is lower than the metastable potential of said gaseous atmosphere which comprises irradiating the entire gas column between the electrodes of the device with the radiations of said gaseous atmosphere while normal potential is applied between said electrodes.

16. The method of starting and operating an electric gaseous discharge device having a desired gaseous atmosphere intermixed with a trace of another gas whose ionizing potential is lower than the metastable potential of said gaseous atmosphere which comprises creating a localized discharge in said device by applying the normal operating potential between a pair of adjacent electrodes in said device, utilizing radiations from said discharge to excite atoms of said gaseous

atmosphere to a metastable condition throughout the space between a pair of more widely separated electrodes, availing of the energy of said metastable atoms to ionize atoms of said trace of another gas, and applying the normal operating potential between the latter pair of electrodes to initiate the main discharge therebetween through said ionized gas.

17. The method of starting and operating an electric gaseous discharge device on alternating current which comprises initiating a half-wave discharge between an electrode of low work function and another electrode, and utilizing said discharge to heat the other electrode to an electron emitting temperature, whereby a full wave discharge is obtained.

TED E. FOULKE.