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2,581,271

PHOTOELECTRIC DEVICE FOR INDICATING THE DIMINUTION OF LIGHT

Filed Sept. 9, 1947

Fig. 1.

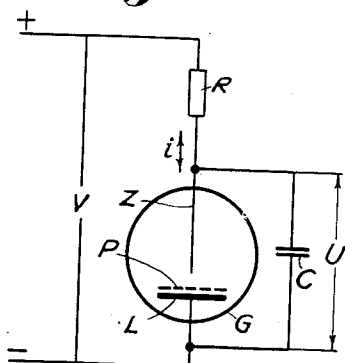


Fig. 2.

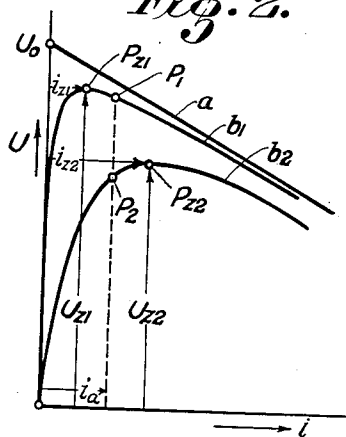


Fig. 3.

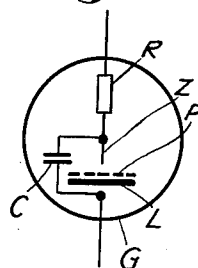


Fig. 4.

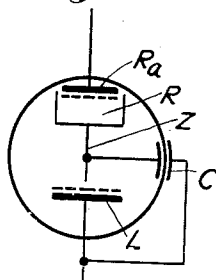


Fig. 5.

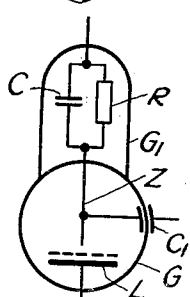


Fig. 6.

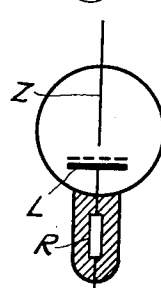


Fig. 7.

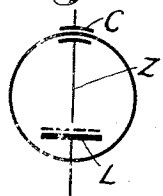


Fig. 8.

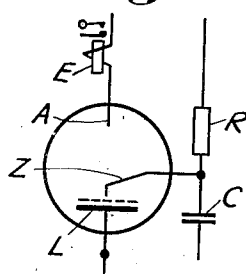


Fig. 9.

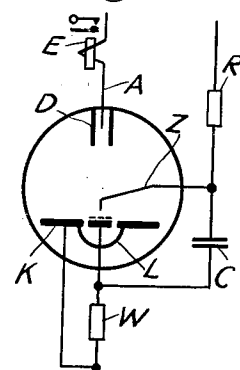


Fig. 10.

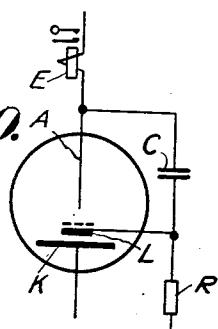
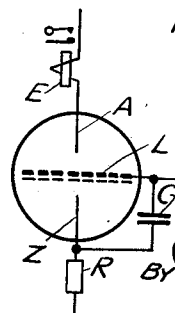


Fig. 11.



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PHOTOELECTRIC DEVICE FOR INDICATING
THE DIMINUTION OF LIGHT

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Section 1, Public Law 690, August 8, 1946
Patent expires January 18, 1966

14 Claims. (Cl. 250—211)

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The present invention relates to a device indi-
cating modifications in light for operating light
relays or other electrical release apparatus.

The device utilizes a gas discharge relay with
at least three electrodes, at least one of which
is light-sensitive. This device is operated by suit-
able auxiliary devices which produce an arc be-
tween the light-sensitive electrode and another
electrode, said arc being influenced by changes
in light. Thus in the case of the present inven-
tion a physical process is used which occurs at
the transition from a non-spontaneous to a spon-
taneous discharge.

In order to make this operation easier to com-
prehend, it is first necessary briefly to elucidate
the physical processes of discharge by reference
to Figs. 1 and 2. In these and subsequent figures
corresponding parts are designated as far as
possible with the same letters. It is assumed that
in a sealed vessel G filled with a gas at low pres-
sure there are two electrodes Z and L, one of
which, L, is provided with a photo-sensitive coat-
ing P. Here, as in the subsequent text, light is
to be understood as meaning not only visible but
also infra-red or ultra-violet light. With appro-
priate special arrangement gas filling such dis-
charge gaps show in the dark a falling voltage
characteristic from the point of ignition onwards.
In Fig. 2 curve *a* represents such a characteristic.
The current *i* is the abscissa and the electrode
voltage *U* is the ordinate. The discharge voltage
U₀ of the spontaneous discharge is called the ig-
nition voltage. According to the choice of the
discharge parameters (type of gas, gas pressure,
form of and interval between the electrodes) and
of the external circuit elements, (resistance,
capacity, inductivity, etc.) the discharge burns at
low currents, i. e. within the range of the so-called
Townsend discharge, either stably or unstably.
If, for example, the discharge gap Z—L in Fig. 1
is connected via a high-ohmic resistor R to a
source of current V and a small capacitor C is
connected in parallel to the discharge gap, no
current flows when the electrodes are not exposed
so long as the voltage V is lower than the ignition
voltage *U₀*. If, on the other hand, the voltage
V exceeds the ignition voltage *U₀*, a gas discharge
ignites in the tube, and a spontaneous gas dis-
charge current *i* flows which in the case of sta-
bility assumes a certain value determined by volt-
age and resistance, but which in the case of insta-
bility rapidly reaches higher values, the voltage
U at the same time breaking down at the elec-
trodes.

During this discharge process the current *i* is
in the main supplied through the capacitor C.

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The voltage collapse of the capacitor C may reach
as low a value as that of the burning voltage of
the glow discharge or even lower. As a rule the
discharge then breaks off, the electrodes re-
charge to ignition voltage, whereupon the process
is repeated. This "tipping" or relaxation process
is designated below as surge discharge. These
surge discharges can also occur when no special
capacitor is connected in parallel, in that only
the self-capacitance of the electrodes and the
capacitance of the supply conduits operate as
discharge capacitor. The surge discharges are, of
course, then correspondingly weaker.

According to the invention an arrangement is
used for the device described below in which the
Townsend discharge is unstable in the falling sec-
tion of the current-voltage characteristic in the
sense of the above description. Many gas dis-
charge gaps display a similar behaviour, it is true,
but very special conditions have to be complied
with for this "tipping" or relaxation process to
take place even with minimum currents (less than
10⁻¹⁰ A.) and minimum capacitances (a few pf.).
Unless special precautions are taken, gas dis-
charge gaps show with very low currents, as a
rule, either small predischarges without an actual
surge discharge with considerable voltage collapse
occurring, or the Townsend discharge burns stably
(with either a rising or a falling characteristic)
so that here again no surge discharges take place.

If the cathode of a discharge gap as described
above is irradiated with light, electrons are re-
leased from the cathode which produce a primary
photo-current *i₀*. As the voltage *U* increases an
increase in the strength of this photo-current *i₀*
by gas ionisation takes place, an effect which is
utilized in the ordinary gas-filled photo-electric
cells. If the voltage *U* is stepped up still further,
the current increases until a certain point P_z is
reached from which onwards increasing current
corresponds to decreasing voltage. The value of
the current *i* and the voltage *U* corresponding to
the point P_z will hereinafter be designated as "ig-
nition current" *i_z* or with irradiation "ignition
voltage" *U_z*. In Fig. 2 the curve *b₁* represents
the course of the current-voltage characteristic
for a relatively low intensity of irradiation B₁.
Theoretical experimental investigations have re-
vealed that, with an increasing intensity of ir-
radiation, the ignition current *i_z* increases and
the ignition voltage *U_z* decreases. In Fig. 2 the
curve *b₂* accordingly represents the course of the
characteristic for a higher intensity of irradia-
tion B₂. It is again of decisive importance for
the process according to the invention that the
discharge is unstable on the falling portion of

3 the characteristic "with irradiation," that is to say after the ignition point P_z has been passed a surge discharge occurs.

The process used in the device according to the invention consists (cf. Fig. 2) in that at a definite intensity of irradiation B_2 a definite preliminary current i_a is caused to pass across the discharge gap which is lower than the ignition current i_{z2} , i. e. the working point P_2 appertaining to i_a lies on the rising and therefore stable branch of the characteristic. If the irradiation is reduced the characteristic is displaced in such a way that a lower ignition current corresponds to the point of ignition. With adequate dimming of the light, for example to the value B_1 (characteristic b_1), the preliminary current i_a exceeds the ignition current i_{z2} ; the theoretical working point P_1 lies on the falling branch of the characteristic b_1 and a surge discharge occurs. This surge discharge recurs at periodic intervals, the intervals being determined by the charging current and the discharge capacity. As soon as irradiation again attains the original value of B_2 , the surge discharges cease.

Theoretical and experimental investigations have revealed that with level, parallel electrodes within the range of weak irradiations the ignition current i_z is proportional to the root of the current i_0 photo-electrically released at the cathode, i. e. the ratio is

$$i_z = K \cdot \sqrt{i_0}$$

(K =proportionality constant). It is evident from this that the ratio of ignition current i_z to primary photo-current i_0 assumes the value

$$\frac{K}{\sqrt{i_0}}$$

i. e.

$$\frac{i_z}{i_0} = \frac{K}{\sqrt{i_0}}$$

therefore, the lower the primary current is, the greater this ratio becomes. As, with appropriate designing of the discharge gap, K assumes values of the magnitude of 1-100, this means that with low intensities of irradiation enormous increases in the photo-current are possible up to the point of transition to spontaneous discharge. This ratio may easily amount to one million and over. Provided the total quantities of light remains constant the ratio becomes greater as a rule, if large-surfaced electrodes and small gaps are used and the light is distributed over a large area.

In the above description a Townsend characteristic falling linearly from the point of ignition onwards was pre-supposed. The effect is in no way restricted to this case, however, but it is sufficient if the characteristic is in any way falling; it is in certain cases even admissible for the characteristic to rise first and only to fall from a certain point. On the other hand, it is essential in every case that the ignition current should increase with increasing irradiation and that after the point of ignition has been passed a surge discharge should occur.

The use of gas-filled photo-electric cells and arrangements in which glow gaps are controlled by light is known.

Such ordinary gas-filled photo-electric cells are connected by means of a high resistance or other current-limiting device to a voltage which is higher than the ignition voltage. Then a

suitable selection of elements will produce so-called tipping oscillations, the frequency of which is determined by illumination and which may be used for the further operation of auxiliary devices. Since the currents are small, a separate amplifier is usually necessary.

The difference between the present invention and devices in which the principle of ignition voltage decrease by irradiation is applied is that, according to the invention, no tipping frequency is produced or influenced, but only the fact is made use of that with increasing irradiation the tipping is prevented and with sufficient diminution of the strength of illumination a current discharge is made possible. An important feature of the invention is that the light-sensitive discharge gap is used as an ignition gap of a multiple-electrode gas discharge relay, as will be described in detail hereinafter.

Instructions are given below for the practical application of the process:

The photo-sensitive coating or layer may be applied either direct to the vessel wall or it may be used to coat a special electrode. For certain uses it may be expedient if the photo-sensitive layer is transparent so that exposure can be effected from behind. The photo-sensitive coating may, in principle, take the form of any coating such as is used for photo-electric cells, especially coatings of alkali and alkaline earth metals or combinations of these. For special requirements highly sensitive so-called "synthetic coatings" or so-called "alloy cathodes" are best used. As according to the invention an enormous amplification of the primary photo current can be achieved, it is frequently not necessary at all to have a highly sensitive coating. In many cases more importance will be attached to other properties, such as great temporal constancy, insensitiveness of the layer to the gas discharge and temperature resistance. These conditions are, as a rule, much easier to achieve with simple coating such as potassium or barium coatings.

The ignition-electrode must be so arranged in relation to the photo-electrode that even with the weakest currents (10^{-10} A.) and minimum capacitance (a few pf.) a discharge, unstable in the falling section of the characteristic, occurs, which should be as powerful as possible. This behaviour is favoured by a great difference between ignition voltage and burning voltage and by a small cross-sectioned area of discharge. These conditions may for example be complied with by giving the anode small dimensions in relation to the cathode and keeping the intervening distance small. (Ignition of a tip or of a thin wire against a surface.) The "tipping" or relaxation process may furthermore be promoted by the provision of insulating or conductive parts between the ignition electrode and the photo cathode, through the presence or field influence of which the ignition process is influenced.

Insofar as the ignition electrode is near the photo-electrode, it is only necessary to expose that part of the photo-cathode lying directly opposite the ignition electrode. In such a case it is expedient to concentrate the incident rays on this spot through a condenser lens or a concave mirror. In this way a high degree of light intensity is achieved even with relatively weak irradiation and in addition to this a marked degree of directional sensitivity of the arrangement is achieved.

The filling gas is of importance for the proper

operation of the tube. Hydrogen has proved very suitable, but as a rule rare gases are preferred as these generally produce lower ignition voltages and act less on the electrodes by chemical reaction, adsorption and diffusion. The filling gas may consist of one single gas or of mixtures of at least two rare gases, possibly with the addition of common gases. It has proved to be of advantage to select a relatively high gas pressure, namely, according to the type of gas, up to and even over 100 tor. It is possible by suitable mixtures and pressures to render the ratio

$$\frac{i_s}{i_0}$$

particularly high.

As already mentioned, it is necessary to induce a certain preliminary current through the gap. This current, which is very low according to circumstances and may be of less than 10^{-10} A., may be produced in different ways.

An expedient arrangement consists in connecting a suitable reactance to a driving voltage which is considerably greater than the ignition voltage of the gap, e. g. by the pre-insertion of resistor, an ionisation chamber with radio-active radiation, a glow tube, a pre-exposed photo-electric cell, a suitable gas discharge path (possibly with a photo-sensitive cathode). The ionisation chamber, glow tube and photo-electric cell present the advantage that within certain voltage ranges the current is practically independent of the voltage, thus providing very constant conditions. Glowing cathode and photo-electric cells also have the additional advantage, that, operated with alternating current, they rectify the current. If the cell is operated with alternating current or temporally inconstant direct current, a capacitor may also be pre-inserted. In order to adapt the preliminary current to the intensity of exposure, it is in many cases indicated to provide a variable or exchangeable current-determining element.

As, in accordance with the above remarks, the preliminary currents may, according to circumstances, be very weak, this means that one of the feeders to the tube must be very well insulated. As highly-insulated places usually lose their highly insulating properties in time if exposed to the air, it is expedient to design the tube so that the insulated place does not come into contact with the outer air. This is achieved by building the current-determining element into or onto the tube. If a special surge capacitor is provided, it is advisable to arrange this in such a manner that its highly-insulated conduits do not come into contact with the outer air, for example, by placing the condenser within the tube, or placing it upon the glass walls in the form of conducting layers. It is moreover not necessary for this capacitor to be inserted directly between the electrodes; it may lie between one of the electrodes and any desired point which has a certain potential in relation to the counterelectrode. The discharge container may be connected with a second vacuum-tight container which contains the reactance and/or the condenser, or the terminals with the reactance may be embedded in wax or the like.

In Figs. 3-7 various embodiments are shown which serve to explain the principle mentioned. In Fig. 3 both the reactance R and a possible parallel capacitor C are housed inside the discharge vessel G. In Fig. 4 this reactance consists of an ionisation chamber R provided with a radio-active preparation R_a, the ionisation

chamber not being sealed, it being therefore in communication with the gas of the discharge gap. In this example the parallel capacitance C is provided by conductive linings on both sides of the insulating vessel wall. In Fig. 5 the current-determining element R is housed in a gas-tight vessel G₁, which is directly built on to discharge vessel G, so that the outer air has no access to the ignition electrode Z. The surge capacitor C is also housed in this vessel and bridges the reactor R. A variant of this arrangement is exemplified in Fig. 6 and consists in that the reactor R e. g. a resistor, is entirely embedded in an insulating material which at the same time encloses the feeder to the cell so that it does not come into contact with the outer air.

Since with the arrangements described the surge discharge takes place entirely within, it is, if no special measures are taken only possible by optical means to observe the "tipping" or relaxation process. In order to be able to observe this process by electrical means a capacitor can be provided, without leading the highly insulated electrode conductively to the outside, one electrode of which capacitor is located outside the vessel so that the surge discharge can be observed or used to control a further contrivance outside the cell. In Fig. 5 this is intimated by the capacitor C₁ via which, for example, an electrometer or an amplifier can be controlled.

In the embodiment hitherto mentioned it was usually pre-supposed that the photo-electrode was connected to the negative pole and the counter-electrode to the positive pole of the source of current. It will, however, be desirable in many cases to be able to operate the device with alternating current. It has already been mentioned that as current-determining element a reactor having a rectifying action may be used. In this case operation with alternating current is easily possible; it is true that a discharge of the capacitor occurs through the photo-electric current during the period of blocking. The time constant of the device determined by charging current and capacitance must therefore be such that when the light is dimmed ignition can nevertheless take place. If no rectification takes place in the reactor R, it must be taken into account that in one half-wave the photo-electrode is positive and the counter-electrode negative. Either the tube can be designed in such a way and the driving voltage be selected so low that in this phase no ignition takes place, or the tube and voltage may be such that in the blocked phase ignition occurs without there being any surge discharge. Both electrodes may also be made photo-sensitive so that in both half-periods surge discharges occur or do not occur according to the intensity of irradiation. Finally it is also permissible for surge voltages always to occur in the one half-period (photo-electrode positive), whilst in the other half-period the surge discharges are controlled by light. In all the cases mentioned the time constant must be so low that ignition can take place.

Since with technical alternating current this generally requires relatively heavy preliminary currents, exposure must be correspondingly intensive. It may therefore be of advantage if a slower alternating current is selected as operating frequency. For certain requirements it may also be desirable to operate the device with some temporally variable direct or alternating current for instance with pulsating direct current or with a "tipping" or relaxation oscillation cur-

rent. Since operations with a temporally inconstant voltage favours the occurrence of surge discharges, it is thus also possible to produce surge discharges with such tubes which when operated with direct current do not readily produce surge discharges. A particularly simple embodiment for operation with temporally variable voltage is exemplified in Fig. 7, the condition of not leading the electrode to the outside being at the same time realized in the simplest manner. As a reactor for producing the preliminary current a capacitor C is used in the form of conductive linings on both sides of the insulating vessel-wall. With an increase in the voltage V the voltage at Z increases, so that upon exposure a preliminary current flows which provokes a certain degree of discharge of the capacitor and prevents ignition. With a decrease in irradiation conditions of ignition can, on the other hand, be fulfilled.

It is known in the art to ignite a gap the voltage of which is smaller than the ignition voltage, but greater than the operating voltage, by utilizing a comparatively weak discharge of a separate electrode. In accordance with the present invention this discharge is introduced into the described tipping discharge of the light-sensitive apparatus.

Fig. 8 shows an example of how this can be achieved. In addition to the ignition electrode Z and the photo-electrode L a further electrode A is provided which will here be called the intercepting electrode. The contrivance functions in such a way that the surge discharge occurring between Z and L leads to ignition between A and L also, i. e. the surge discharge is to a certain extent intercepted by the electrode A and maintained in the form of a secondary glow discharge between A and L. In the outer circuit a powerful current determined by voltage and resistance can therefore flow, which current operates the relay E. Since this discharge flows between the intercepting electrodes and the photo-electrode, destruction of the photo-sensitive coating may occur through bombardment by ions, especially if it is a synthetic coating. In order to reduce this effect, the cathode may, for example, be designed in such a way that the secondary glow discharge impinges chiefly on parts of the cathode which do not need to be photo-sensitive, which can, for example, be achieved by suitable spacing. Another solution is exemplified in Fig. 9. The cathode is subdivided in such a way that the part L which must be photo-sensitive is electrically separated from, and connected via a high-ohmic resistor W to, the other part K, so that the glow current can attain no considerable proportions on the part L of the cathode thanks to the said high-ohmic resistor.

Fig. 10 shows how this separation can be achieved with only three electrodes. The reactor R is inserted in the feed line to the photo-sensitive electrode L and the surge discharge, which ignites between this electrode and the electrode A, is intercepted between the electrodes A and K.

Fig. 11 shows an arrangement similar to that in Fig. 8 except that the ignition electrode and the intercepting electrode are arranged on different sides of the photo-electrode. The photo-electrode must in this case be perforated in the form of a sieve or mesh so that the surge discharge can extend also to the side of the intercepting electrode.

The current load capacity of the electrodes is subject to certain limits; in order nevertheless

to have sufficient control energy available in the secondary circuit it is of advantage to use an operating voltage which is considerably higher than the burning voltage. For this the ignition voltage between the intercepting electrodes must be sufficiently large. An increase in the ignition voltage may be achieved in the known manner by the following measures:

- (1) By increasing the distance between the electrodes;
- (2) By increasing the gas pressure choosing a suitable gas;
- (3) By the introduction of a further electrode which brings about at least a partial electrical screening of the principal electrodes, this electrode either being connected to an auxiliary potential or being insulatedly mounted;
- (4) By insulating bodies which influence the field configuration or prevent the formation of a discharge. An arrangement of this kind is suggested in Fig. 9, where the intercepting electrode A is concentrically surrounded by a small glass tube D;
- (5) By suitable design of the electrodes e. g. large-surfaced cathode, small-surfaced anode (tip).

There is the possibility of operating not only the surge discharge gap but also the control organ with alternating current or otherwise a temporally variable current. Apart from saving the rectifier this may present the advantage that a glow discharge, once ignited, extinguishes again without any special switching measures as soon as the ray of light is released once more. In operation with direct current this is not immediately possible; although it can also be achieved by the use of "tipping" switching devices which bring about the interruption of the glow discharge, for example, by the insertion of a relatively large capacity and a suitably large load resistance in the main circuit.

The number of switching or circuit elements required with alternating current is particularly small if rectifying action is present in the main glow discharge. It is then merely necessary to insert a direct current relay in the outer circuit, possibly with a capacitor connected in parallel. Apart from the known rectifying effect due to greatly differing surface areas of the anode and cathode, or to different ignition voltages on the changing of poles (glow rectifier), the primary surge discharge may also effect rectification either by the surge discharge only occurring in the one phase or by the spatial arrangement being such that a surge discharge in the other phase causes no ignition between the intercepting electrodes. This occurs, for example, with an arrangement wherein the receiving electrode and the ignition electrode are located on opposite sides of a mesh-like photo-cathode.

I claim:

1. An electric device for indicating changes in intensity of irradiation, comprising a gas-filled tube comprising an airtight casing, a first photo-sensitive electrode and at least a second and a third electrode, said electrodes being located in said casing, the photosensitive and said second electrode forming a control gap and said third electrode and the photosensitive electrode forming a main gap, means connected with said photosensitive electrode and said second electrode and including a reactance for passing a weak electrical preliminary current through said control gap, the magnitude of said preliminary current

being determined by said reactance as being at least periodically smaller than the ignition current of the control gap at a certain predetermined irradiation of the photosensitive electrode, but at least periodically greater than the ignition current of the control gap at a certain lower intensity of said irradiation, conditions of the discharge in the control gap being such that the discharge current becomes unstable and a surge discharge occurs, the current intensity of which at least periodically exceeds that of the preliminary current, when the ignition current is smaller than the preliminary current owing to a decrease in irradiation, said surge discharge causing the ignition of the mentioned main gap.

2. A device in accordance with claim 1, characterized in that for increasing the ignition voltage of the main discharge gap insulating parts are disposed in the discharge vessel.

3. A device in accordance with claim 1, characterized in that an ionisation chamber determining the preliminary current and constituting the reactor is provided.

4. A device in accordance with claim 1, characterized in that a pre-exposed photo-electric cell determining the preliminary current and constituting the reactor is provided.

5. A device in accordance with claim 1, characterized in that the reactor determining the preliminary current is located at least partly inside the discharge vessel.

6. A device in accordance with claim 1, characterized in that at least one electrode is of perforated or sievelike design.

7. An electric gas discharge tube for indicating a charge of light, said tube comprising a casing, two electrodes located within said casing and forming a discharge gap, one of said electrodes being photo-sensitive and being irradiated, a third electrode located within said casing and forming another discharge gap with said photo-sensitive electrode, and means connected with said photo-sensitive electrode and said third electrode and including a reactance for passing a weak electrical preliminary current through the first-mentioned discharge gap, the magnitude of said preliminary current being determined by said reactance as being such that it is at least periodically smaller than the ignition current at a certain predetermined intensity of said irradiation but at least periodically greater than the ignition current at a certain predetermined lower intensity of said irradiation, conditions of the gas discharge being such that the discharge current becomes unstable and a surge discharge, the current intensity of which at least periodically exceeds that of the preliminary current, occurs when the ignition current is smaller than the preliminary current owing to a decrease in irradiation, said surge discharge causing the ignition of the second-mentioned discharge gap.

8. A device in accordance with claim 7, characterized in that a surge capacitor is connected in parallel to the two electrodes of the ignition gap.

9. A device in accordance with claim 7, characterized in that at least one electrode of the surge capacitor is so disposed as to exclude the outer air.

10. A device in accordance with claim 7, characterized in that the two electrodes of the gap have surfaces of differing area.

11. A device in accordance with claim 7, characterized in that a glow tube determining the preliminary current and constituting the reactor is provided.

12. A device in accordance with claim 7, characterized in that the reactor takes the form of a capacitor.

13. A device in accordance with claim 7, characterized in that the electrodes between which the secondary discharge takes place have surfaces of differing area.

14. A device in accordance with claim 7, characterized in that at least one fourth electrode is provided and in that the main current of the secondary discharge flows through two electrodes different from the two electrodes of the ignition gap.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,800,337	Campbell	Apr. 14, 1931
1,840,055	Rentschler	Jan. 5, 1932
1,973,286	Knowles	Sept. 11, 1934
1,980,198	Gray	Nov. 13, 1934
1,996,556	Sinden	Apr. 2, 1935
2,098,217	Aubert et al.	Nov. 9, 1937

FOREIGN PATENTS

Number	Country	Date
337,477	Great Britain	Nov. 6, 1930