

July 28, 1931.

I. LANGMUIR
ELECTRON DISCHARGE DEVICE

1,816,682

Filed March 10, 1926

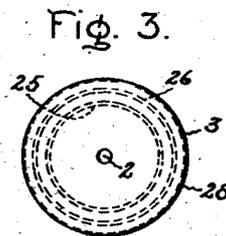
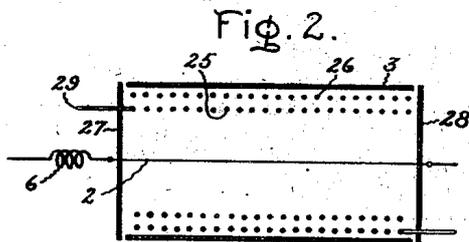
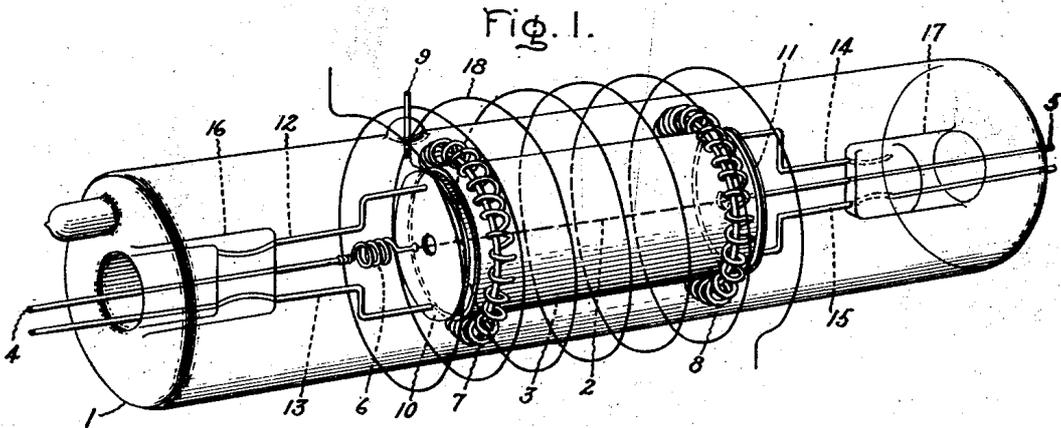


Fig. 6.

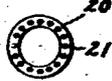


Fig. 4.

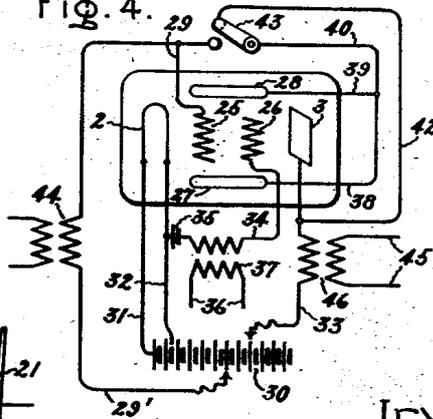
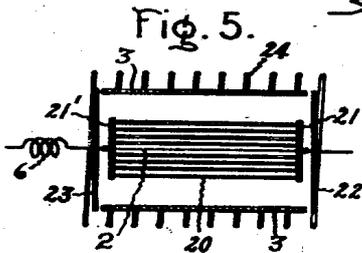
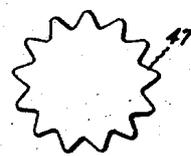


Fig. 7.



Inventor:
Irving Langmuir,
by *Alexander S. Lewis*
His Attorney.

UNITED STATES PATENT OFFICE

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK

ELECTRON DISCHARGE DEVICE

Application filed March 10, 1926. Serial No. 93,727.

The present invention relates to the class of electrical discharge devices which are so constructed that positive ions formed in the space between the electrodes are trapped in a space surrounding the cathode and by their presence reduce space charge.

Kenneth Kingdon in the Physical Review, Vol. 21, page 408 (1923) and in his Patent 1,579,117, issued March 30, 1926, has described devices whereby the effect of gas ionization in modifying space charge may be enhanced by preventing the discharge of positive ions. For example, by the means described, space charge neutralization by positive ions may be obtained in electronic devices in which the gas pressure is so low that the gas would otherwise have no appreciable effect on the electrical characteristics of the device. Devices of this type will be referred to hereinafter as "trapped ion" devices.

The present invention comprises improvements whereby the efficiency of trapped ion devices may be increased and whereby such devices are rendered more suitable for control purposes.

Included in my invention is a new form of electric discharge device and a method of operation whereby in part of the space traversed by electrons, ions are trapped with a consequent neutralization of space charge, the remainder of the discharge space being traversed by a substantially pure electron discharge. In this latter part of the discharge space, the motion of the electrons can be controlled either by a magnetic field or by an electric field.

Other novel features of my invention are the following:

An apparatus and a method whereby the trapped ion effect is increased or modified by subjecting the current carriers therein to a magnetic field.

An arrangement in a trapped ion device of one or more grids, whereby the current may be modified or controlled without interfering with the accumulation of positive ions.

An arrangement for securing a joint effect of grids and magnetic field for modifying or controlling the current.

The utilization of the guard members

whereby the escape of positive ions is prevented for the control or modification of the current.

The above and other features of my invention will be pointed out with greater particularity in the appended claims and described in detail in the following specification taken in connection with the accompanying drawings.

In the drawings Figs. 1 and 5 illustrate trapped ion devices provided with means for enhancing gas ionization by a magnetic field; Figs. 2 and 3 illustrate a trapped ion device provided with grid or control electrodes; Fig. 4 is a diagram of electrical connections suitable for use with the apparatus shown in Figs. 2 and 3; Figs. 5 and 6 illustrate diagrammatically a device in which the combined effect of a grid and a magnetic winding is obtained; and Fig 7. is a cross section of a modified form of anode.

The device shown in Fig. 1 comprises an evacuated envelope 1 containing a filamentary cathode 2, and a cylindrical anode 3 which preferably is arranged symmetrically about the cathode. The cathode may consist of tungsten, tantalum, or other material which, when heated, will effectively emit electrons. It is supported by the sealed-in conductors 4, 5; a spring 6 preferably being inserted to maintain the cathode taut. The anode 3 may consist of nickel, molybdenum or the like and may be held frictionally in a desired position by coiled springs 7, 8. A sealed-in anode conductor 9 is provided as usual. The end plates or guards 10, 11 are supported by the wires 12, 13 and 14, 15 respectively, the wires 13 and 15 being conducted through the stems 16, 17 to suitable external contact devices (not shown). They may be positively charged as by being connected to the anode or to the external source of positive potential to prevent the escape of positive ions.

The residual gas pressure within the container 1 should be so low that in the absence of trapped ions, a substantially pure electron discharge can take place between the electrodes, that is, a discharge in which the effect of positive ions is negligibly low.

This much of the device of Fig. 1 does not differ essentially from the trapped ion device described in the above Kingdon patent. I have discovered, however, that contrary to what might be expected by reason of the enormously greater effect of a magnetic field upon the motion of electrons as compared with the effect of a magnetic field upon positive ions, the trapping of ions may be enhanced by a magnetic field which is insufficient to cut off the electron current by the method described by A. W. Hull in United States Patent 1,523,776 and in the Journal of the American Institute of Electrical Engineers for September, 1921, page 715.

An external magnetizing winding 18 is provided about the trapped ion device for generating a magnetic field, a component of which is parallel to the cathode and which imparts to both the electrons and the ions motion in a tangential direction, that is, gives them an angular velocity about the cathode. As a consequence the orbits of both the electrons and the ions are curved. The amount of curvature of the orbits depends on various factors, such as the mass of the electrons or ions, the propelling voltage and the magnetic field strength. The deflecting force in the case of an ion moving from a point near the anode 3 to the filamentary cathode 2 need only be small to cause an ion to miss the filamentary cathode and to execute orbits to and fro about it for an appreciable interval.

The angular momentum of an ion is equal to the product of the mass, the tangential velocity and the radius. It remains constant (assuming a symmetrical device) even though the ion moves toward the cathode. Hence as the radius decreases, the mass being constant, the tangential velocity increases. In the case of the electrons moving from the cathode to the anode the tangential velocity decreases. A magnetic field less than the cut off value, that is, a field giving the electrons a radius of curvature which is greater than half the radius of curvature of the anode (approximately) permits the electrons to reach the anode even though their path is curved by the magnetic field. In other words, in the case of the positive ions, with a chosen gas and a proper correlation of conditions, in particular the voltages on the tube, and the ratios of cathode and anode diameters, this magnification of the tangential velocity permits an applied magnetic field, which is below the value at which the flow of electrons from cathode to anode becomes reduced or prevented by the action of the magnetic field, to enhance the trapping of the positive ions.

By an increase of magnetic field within a working range the accumulation of positive ions increases with a given gas pressure and conversely with a decrease of magnetic field the positive ion accumulation decreases. As the current carrying capacity of a trapped

ion device varies with the number of ions trapped, the electron current between the electrodes 2, 3 may be varied by varying the magnetic field within working limits.

In the absence of a magnetic field the ratio of anode diameter to cathode diameter preferably should be about 200 to 1 or greater. When using a magnetic field an effective trapping of ions may be obtained with smaller ratios and hence heavier or larger diameter cathode conductors can be utilized without the sacrifice of efficiency. The effect of a magnetic field is most marked in the case of light gases, such as hydrogen or helium. The gas pressure ordinarily should be less than about a micron of mercury pressure but will vary with the kind of gas used.

As shown in Fig. 5, a magnetic field may be used to advantage in combination with a grid in a trapped ion device. In the device here illustrated a grid 20 is interposed between the cathode 2 and the anode 3. As shown in Figs. 5 and 6 the grid 20, consisting of longitudinal wires, is supported between the rings 21, 21'. When the grid 20 and the guard plates 22, 23 are positively charged to a sufficiently high potential, materially above the ionizing potential of the gas in the tube, say to fifty volts or higher, the positive ions are trapped within the space enclosed by the grid and guard plates and neutralize electron space charge.

Most of the electrons pass through the spaces between the members of the grid 20 and flow to the positively charged anode 3. The grid 20 may be said to act as a "virtual cathode" because it is the effective source of the electrons which are controlled by the magnetic field generated by the winding 24. Between the grid 20 and the anode 3, the conditions of a substantially pure electron discharge exist, and the electrons are controlled by the magnetic field, as in the magnetron, which is described in United States patent to A. W. Hull, No. 1,523,776, of January 20, 1925.

In the device shown in Fig. 2, two grids 25, 26, have been provided for current control purposes. The inner grid 25 and the guard plates 27, 28 trap ions and act as a virtual source in the same manner as the grid 20, Fig. 5. As shown diagrammatically in Fig. 4, the grid 25 may be positively charged through the conductors 29, 29' by the battery 30. As indicated this battery also furnishes, through the conductors 31, 32, a heating current for the cathode 2 and a space current through the device by being connected to the anode 3 by a conductor 33. The outer grid 26 is connected to a circuit 34, the opposite terminal of which is connected to the cathode circuit 32, preferably in series, with a polarizing battery 35. An input circuit 36 is connected to the primary of a transformer 37, the secondary of which is intercalated in the

circuit 34 to impress suitable potential variations on the grid 26. The conductors 38, 39, leading to guard plates 27, 28 may be connected by the conductor 40 either to an intermediate positive terminal of the battery 30 through the conductor 29' or may be connected directly to the anode 3 by a conductor 42. A switch 43 is provided whereby either connection may be made or the end plates may be disconnected from either circuit.

In the space between the grid 25 and the anode 3 the conditions of pure electron conduction are present. The electron current may be controlled in the usual manner by the grid 26 which may receive from the input circuit 34 potential variations of audio or radio frequency.

Included in the inner grid circuit 29, 29' is the secondary of a transformer 44 (preferably an audio frequency transformer) whereby the positive potential on the grid 25 and the guards 27, 28 may be varied thereby controlling the amount of positive ionization in the device. In other words, by means of an input device which is symbolically represented by the transformer 44 the current carrying capacity of the device may be varied.

When the grid 25 is charged to a sufficiently high positive potential in excess of the ionizing potential of the residual gas, it is effective in cooperating with the end plates to trap the ions in the space enclosed by the grid 25 but when its potential becomes less positive or becomes negative, then the grid 25 becomes ineffective. This may occur at audio frequency in a radio sending apparatus and may be used to vary the loudness of the signals being transmitted by the output circuit 45 which is coupled to the plate circuit 33 by a high frequency transformer 46.

In some cases, one of the grids, for example, the grid 26, may be omitted and the current may be controlled or modified entirely by the positive grid 25. Such an arrangement is most effective when the potential of the grid 25 swings between a positive value approximating the potential of the anode and a lower or a negative value, as in an oscillator.

Fig. 7 is an end view of a corrugated anode 47, that is, an anode having longitudinally extending convolutions whereby the deflection of the ions from a direct path to the cathode is enhanced.

In the case of Figs. 2, 3, 5, 6 and 7 the outer envelope of the device has been omitted in the drawings but its presence in the physical devices is assumed.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The combination of means for generating an electron discharge accompanied by an amount of positive ionization which is insufficient to materially neutralize space

charge, means for trapping positive ions in the discharge space and magnetic means for varying the effectiveness of said trapping means.

2. The combination of a linear thermionic cathode, an anode surrounding the same, an evacuated enclosure for said electrodes, means for trapping positive ions in a space surrounding said cathode and magnetic means for imparting to ions in said space an angular momentum about said cathode whereby the effectiveness of the trapping means is increased.

3. The combination of a linear thermionic cathode, a cylindrical anode symmetrically spaced about said cathode, an evacuated enclosure, means located at the ends of said anode for trapping ions in the discharge space therein, a grid surrounding said cathode and spaced away from said anode, a grid adapted to be charged sufficiently positive to enhance the effect of said ion trapping means, and means for generating a magnetic field in said device having a component at right angles to the orbits of electrons passing from cathode to anode still further to enhance the ion trapping function.

4. The method of operating an electron discharge in an attenuated gas which consists in impressing upon said discharge a magnetic field having a component at right angles to said discharge and having a strength insufficient to suppress said discharge but being capable of materially increasing the production of positive ions by said discharge and trapping positive ions in the discharge space.

5. The method of operating an electron discharge in an attenuated gas which consists in trapping positive ions adjacent the cathode, subjecting said discharge to a magnetic field applied at right angles thereto, and varying said discharge external to the trapped ion space.

In witness whereof, I have hereto set my hand this 9th day of March, 1926.

IRVING LANGMUIR.