Dec. 5, 1939. F. M. PENNING 2,182,736

RECTIFYING DEVICE

Filed May 4, 1937 2 Sheets-Sheet 1

Fig. 1

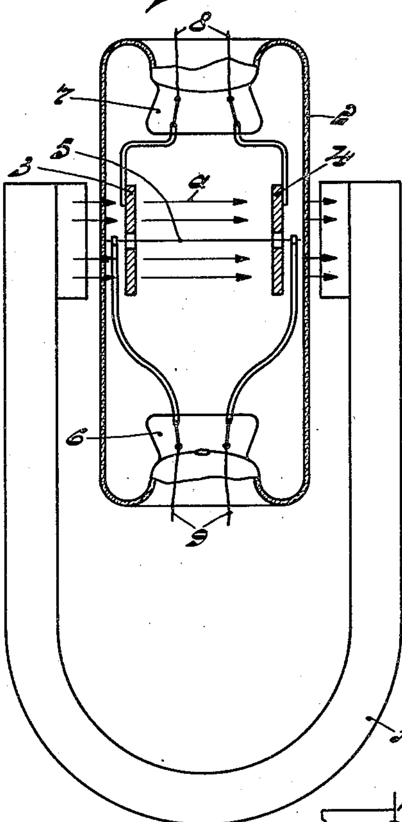
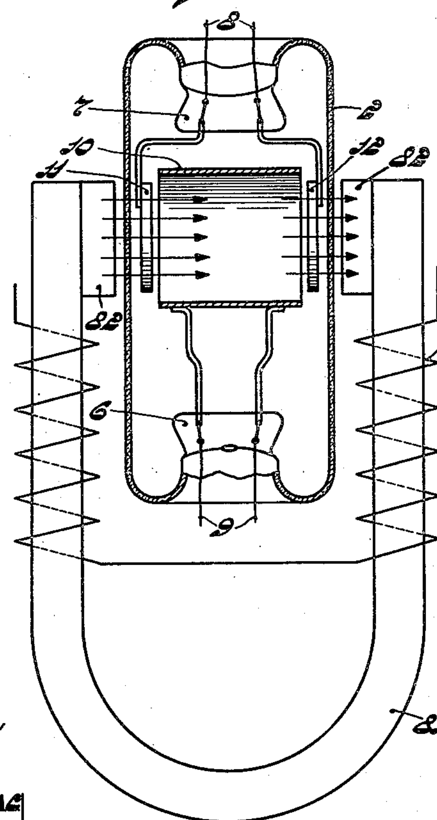


Fig. 2



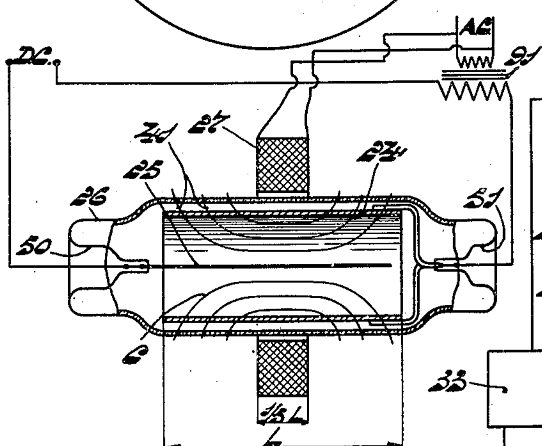
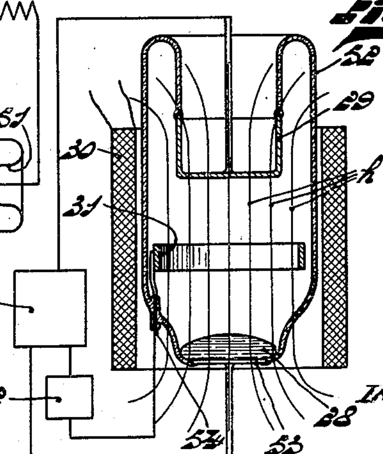


Fig. 5

Fig. 6



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RECTIFYING DEVICE

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2 Sheets-Sheet 2

Fig. 7

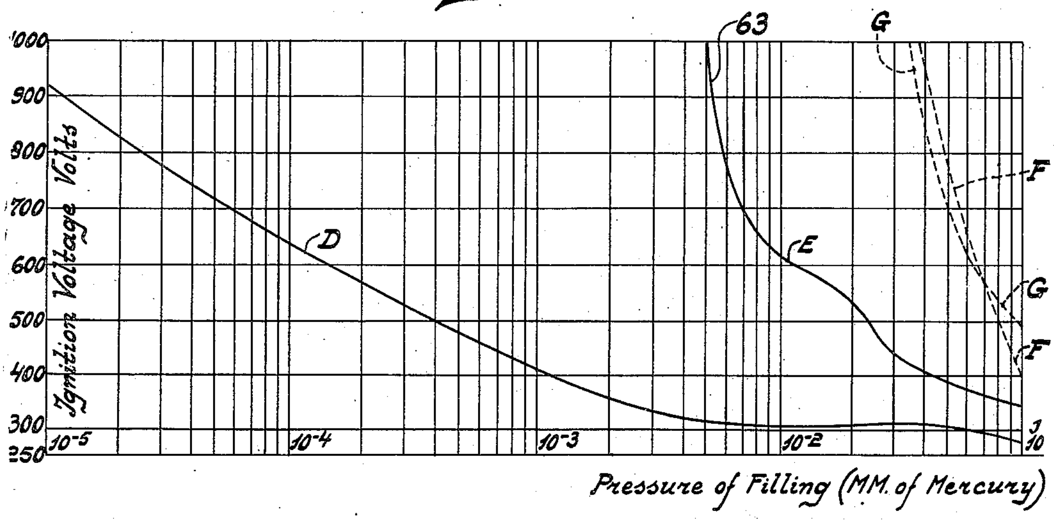


Fig. 3

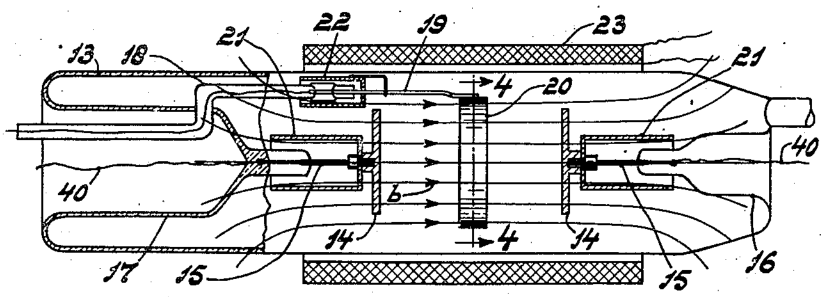
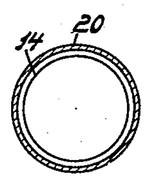


Fig. 4



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Patented Dec. 5, 1939 **2,182,736**

UNITED STATES PATENT OFFICE

2,182,736

RECTIFYING DEVICE

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Application May 4, 1937, Serial No. 140,772
In Germany May 7, 1936

10 Claims. (Cl. 250—27.5)

My invention relates to A. C. rectifying devices, and more particularly to devices comprising at least one cold-cathode ionic discharge tube having a low-pressure gaseous filling.

The term "cold-cathode" as used herein is to be understood to mean a cathode which is not heated to facilitate the disengagement of electrons, whereas the term "gaseous filling" is to be understood to mean a filling consisting of one or more gases or vapors, or mixtures thereof.

Considerable difficulties arise in operating present-day cold-cathode rectifier tubes at high alternating anode voltages, for instance 220 volts and more, and with a gaseous filling having a pressure of 1 mm. of mercury or more, due to the excessive flow of discharge current in the blocking or reverse direction, which current frequently attains a sufficient value to cause back-discharges. Furthermore, as the voltage drop of such tubes is always a comparatively large part of the voltage to be rectified, their efficiency is unsatisfactory. In addition, there is usually only a slight difference between the ignition voltage in the rectifying direction and the ignition voltage in the reverse direction. It has been impossible to entirely overcome these difficulties by reducing the pressure of the gaseous filling, becausing this greatly increased the voltage drop of the tube as well as the ignition voltage in the conductive direction, i. e. the direction in which the rectified current is allowed to pass.

The object of my invention is to overcome the above difficulties by reducing the high ignition voltage in the conductive direction, which is associated with the low pressures, without at the same time unduly decreasing the high ignition voltage in the non-conductive or reverse direction.

According to the invention, I so arrange a magnetic field with respect to the electrodes of a cold-cathode discharge tube that magnetic lines of force traverse one portion of the cathode upon entering the discharge path between the anode and the cathode, and traverse another portion of the cathode upon emerging therefrom, and that only a small part of these lines, i. e. less than 10% thereof, traverses the anode.

I have found that with such an arrangement the above difficulties are overcome, whereas at the same time by using the magnetic field the current rectifying capacity of the device is materially increased. This may be explained by the fact that, in the devices according to the invention, the electrons remaining in the discharge path are compelled by the magnetic field to move either along, or in helical orbits around, the magnetic lines of force. During this movement, the electrons approach one cathode portion traversed by the magnetic lines of force, are repelled by its negative electrostatic field, and move back and approach the other cathode portion traversed by the lines of force, whereupon this cycle is repeated so that the electrons are attracted by the electrostatic field of the anode only after having repeatedly moved to and fro. This extension in the path of the electrons greatly increases the possibility of their colliding with neutral gas molecules or gas atoms, so that, with the same number of molecules or atoms, there is an increased ionization effect and consequently a greater current transmitting capacity of the tube with the same voltage, or with the same current there is a smaller voltage drop in the rectifying direction.

To insure that only a small part of the magnetic lines of force twice traversing the cathode will traverse the anode, that part of the anode surface which is opposite the active part of the cathode surface and extends parallel thereto should be materially smaller than the active part of the cathode area. By "active part of the cathode surface" is meant the part of the cathode area which is twice traversed by the magnetic lines of force and which limits the electron orbits extending along these lines.

The above-described effect takes place to a much greater degree when the electrons, without the magnetic field, are not very likely to collide, for instance when the spacing of the electrodes is of the order of magnitude of the free path of the electrons in the tube. For this reason, I prefer to so select the pressure of the gaseous filling that the free path of the electrons is greater than about one-tenth the length of the discharge path between the points at which the magnetic lines of force traverse the cathode. Thus, in suitable tube constructions, gaseous pressures, for instance of the order of 10^{-4} to 10^{-2} mm. of mercury, can be used without unduly increasing the ignition voltage and the voltage loss in the rectifying direction.

To insure that only a small number of the magnetic lines of force will cut the anode surface the active anode area is preferably so arranged that it extends substantially in the direction of the lines of force within the discharge space.

In one embodiment of my invention, the cathode is formed of two parallel plates and the anode is in the form of an elongated member extending perpendicularly between these plates, whereas in another embodiment the anode is shaped as a hollow cylinder, and two cathode plates are arranged at each end of the cylinder and normally to the axis thereof, whereby the discharge path is substantially enclosed by the electrodes. In these embodiments I use a magnetic field which is substantially homogeneous within the discharge space of the tube and has lines of force traversing the cathode plates and extending substantially parallel to the axis of the anode.

To permit the use of a single cathode body, such as a cylinder, I use in some embodiments of my invention a magnetic field which is non-homogeneous in the discharge space, i. e. has lines of force which are curved in the discharge space, and so arrange the anode that practically none of the lines strikes same.

I am aware that it has been proposed to arrange a magnetic field in the discharge path of discharge tubes for various purposes, for instance, to cause the discharge to follow a definite path for controlling the intensity of the discharge current, or to use an alternating magnetic field for the purpose of making the tube alternately pass discharge current or not. However, the object of my invention is to improve the rectification in cold-cathode ionic discharge tubes whereby they will have excellent blocking properties without materially increasing the ignition voltage in the "conductive direction".

Further features and advantages of my invention will appear as the specification progresses.

In order that my invention may be clearly understood and readily carried into effect, I shall describe same more fully with reference to the accompanying drawings, in which:

Figures 1 to 3 inclusive are partly-sectionized schematic views of rectifying devices according to the invention;

Fig. 4 is a view along line 4 of Fig. 3;

Fig. 5 is a partly-sectionized side view of a rectifying device according to another embodiment of the invention;

Fig. 6 is a partly-sectionized schematic view of a rectifying device according to the invention, provided with an ignition electrode; and

Fig. 7 is a graph illustrating the advantages of the present invention.

The rectifying device illustrated in Fig. 1 comprises an ionic rectifying tube having a substantially cylindrical envelope 2 forming two presses 6 and 7. Supported from press 7 is a cold cathode structure in the form of two parallel apertured plates 3 and 4, for instance of nickel or molybdenum, each provided with an external lead 8. Arranged perpendicularly to plates 3 and 4 and passing through the apertures therein with a clearance, is an elongated anode 5, of the same material, supported at its ends from press 6 by suitable conductive supports provided with external leads 9. The tube contains a gaseous filling of low pressure, for instance argon at about 0.02 mm. of mercury.

Disposed outside envelope 2 is a horseshoe permanent magnet 1, which produces within the discharge space of the tube a homogeneous and constant magnetic field having lines of force *a*, which traverse plate 3, then pass substantially parallel to anode 5, and finally traverse plate 4. It will be noted that substantially none of the lines of force strikes anode 5.

In this case the electrons move in the direction of the magnetic lines of force *a* and reach anode 5 arranged in the axis of the field, only after having oscillated between plates 3 and 4, in the manner described above. It should be noted that this effect can not be obtained by reversing the polarity of the electrodes, because in such a case the electrons would be immediately attracted by the cathode plates 3 and 4, which now have a positive charge, and they would be incapable of producing sufficient ionization by impact in greatly enlarged orbits.

Instead of the permanent magnet 1, an electromagnet can be used; however a permanent magnet, of course, gives a simpler construction and does not require energizing current. Furthermore, the polarity of the field is of no importance in obtaining the above results, and thus it is frequently convenient and possible to use an alternating magnetic field whose exciting current can be obtained in a very simple manner, for instance from an A. C. network which also supplies the anode voltage, so that the excitation of the magnet and the anode voltage will be in synchronism. In this case the circuit must be so arranged that the electromagnet is sufficiently excited during the phase in which the anode allows passage of current, and that the magnetic field disappears only at those moments at which it is not needed. Thus, the difficulties in producing D. C. excitation are avoided in a simple manner.

The rectifying device shown in Fig. 2 is somewhat similar to that of Fig. 1 and has similar parts indicated by the same reference numerals. However, in Fig. 2 the cathode is formed of two solid parallel plates 11 and 12, for instance of nickel or molybdenum, whereas the anode is in the form of a cylinder 10 of the same material, and surrounds the magnetic field produced by an electromagnet having a coil 80, a soft iron core 81, and pole pieces 82. Coil 80 can be energized in the manner described in connection with Fig. 1. In this figure, as in Fig. 1, the lines of force first traverse one of the cathode plates, then pass substantially parallel to the active surface of the anode, and finally traverse the second cathode plate. The magnetic field in this case can also be produced by a permanent magnet, as described in Fig. 1. It will be noted that in Fig. 2 the discharge path is shielded in an advantageous manner by the electrodes, and that the magnetic lines of force extending between plates 11 and 12 do not strike the anode cylinder 10, which surrounds these lines instead of being surrounded thereby as in Fig. 1.

The rectifying device of Figs. 3 and 4 comprises a rectifying tube having a hermetically-sealed vitreous envelope 13 forming two re-entrant portions each supporting, by means of conductive supports 15 provided with external leads 40, a cold-cathode in the form of a disc 14, for instance of nickel or nickel or molybdenum. Secured to envelope 13 is a glass rod 18 supporting a conductive rod 19 carrying an anode 20 in the form of a metal ring, for instance of nickel or molybdenum, (see Fig. 4). To prevent disintegrated electrode material from depositing on the inner surface of the envelope in the vicinity of the anode 20 and cathode 14 and forming a conductive layer thereon, I provide cup-shaped metal screens 21 suitably supported from the electrode supports. It will be noted that in Fig. 3 the disposition and type of the electrodes is somewhat similar to that of Fig. 2 except that anode cylinder 20 is substantially shorter than anode 10 of Fig. 2.

Coaxially surrounding the tube is a magnetic coil 23, which produces between anodes 14 a substantially homogeneous magnetic field, as indicated by the lines *b*. The coil 23 may be energized in the manner set forth in connection with Fig. 1 or a permanent magnet of proper shape may be used.

The tube shown in Fig. 3 is drawn to scale, and in a suitable construction in which envelope 13 is about 280 mm. long and about 70 mm. in diameter (the other dimensions being in the proportion shown), the following results were obtained. With an argon filling at a pressure of about 10^{-3} mm. of mercury, the ignition voltage in the conductive direction was of the order of 400 volts, and a single-phase rectified current of the order of 10 milliamperes was obtained.

Although excellent results are obtained when using a rare gas filling in the tubes according to the invention, I prefer to use a mercury-vapor filling as this allows the pressure of the filling to be maintained at the same value during the entire life of the tube. This can be obtained in the well-known manner by providing a reservoir of liquid mercury within the tube, which is maintained at the proper temperature as regards the admissible values of vapor pressures. For example, in Fig. 3 one of the cathodes 14 may be replaced by a pool of mercury as shown in Fig. 6. Furthermore, in such cases the cathode may be of a metal having a low melting point, preferably less than 30° C., for instance caesium or mercury, as in this case the disintegrating material again collects at the cathode. In this manner, and by providing mercury to secure a mercury filling, a considerably higher current value is obtained, for instance 1 amp. and more. This is due chiefly to the fact that the mercury cathode advantageously permits the obtainance of an arc-like discharge.

In Figures 1 to 3 inclusive the cathode is formed of two parts; however a single cathode body can be used by using a magnetic field which is non-homogeneous within the discharge space, and whose lines of force are curved so as to traverse part of the cathode body both upon entering and leaving the discharge path between anode and cathode. Also in this case it is possible to cause the electrons to move along the curved magnetic lines of force between the two parts of the cathode body without striking the anode to an appreciable degree.

Such a construction is illustrated in Fig. 5 in which the discharge tube comprises an envelope 26 forming two presses 50 and 51. Supported from press 50 and extending coaxially with the envelope is an anode in the form of an elongated metal member 25, for instance of molybdenum or tungsten. Supported from press 51 and arranged substantially coaxially with anode 25 is a cold cathode 24 in the form of a metal cylinder, for instance of nickel. Surrounding the tube substantially coaxial with anode 25 and cathode 24 is an electric coil 27, which produces a magnetic field whose lines of force are indicated by lines *c*. The field so produced is a rotational-symmetrical non-homogeneous field. In this case the coil 27 should have a length less than half the length of the cathode cylinder 24, and should be arranged about the middle portion of the cylinder 24, whereas cylinder 24 should be of such a size as to surround a greater portion of the lines of force. As shown, coil 27 has a length equal to ⅓ L, L being the length of cylinder 24. In such an arrangement the number of lines of force twice traversing the cathode cylinder 24 is large due to the greater length of this cylinder and to the comparatively small radial distance between the cylinder and coil 27.

Fig. 5 also shows the connections for single-phase half-wave rectification, in which the A. C. current to be rectified is supplied from a transformer 91, whereas the coil 27 is energized from the primary winding thereof.

With regard to the electrode arrangements shown in the drawings, it should be noted that even with certain deviations from the required conditions of symmetry, satisfactory operation of the tube is obtained.

The invenion is particularly advantageous for initiating the discharge in a mercury-cathode discharge tube, In this case a comparatively high voltage, sufficient for initiating a discharge between cold electrodes, can be set up between the anode and the cathode parts, and two cathode parts can be used as a fixed and liquid electrode for a separate discharge of high current intensity and lower voltage; the discharge issuing from the anode initiating the discharge of lower voltage. One form of construction of such a device is illustrated in Fig. 6.

The device illustrated in Fig. 6 comprises a discharge tube having an hermetically-sealed envelope formed of a vitreous portion 52, a cap-shaped portion 29, for instance of chrome iron, and serving as an anode, and a disc 53, for instance of chrome iron. Within the envelope is a mercury cathode 28, and an annular electrode 31, for instance of molybdenum, suitably supported from the envelope by a conductive support 54.

Surrounding the tube is a cylindrical magnet coil 30, which produces a rotational-symmetrical magnetic field whose lines of force, as indicated by *h*, traverse cathode 28 and anode 29 and pass through the annular electrode 31 without striking the same to any appreciable degree.

The electrodes 29, 28 and 31 are interconnected through circuit arrangements, schematically indicated by reference numerals 32 and 33, whereby circuit arrangement 33, electrodes 28 and 29, and the discharge path of the tube form an optional rectifying circuit having a materially lower voltage, and whereby electrodes 28 and 29, as regards the higher voltage of circuit 32, are both negative and receive substantially the same potential. Thus, the discharge incorporated in this circuit arrangement and passing between cathode 28 and anode 29 can be initiated at a cathode spot formed by means of electrode 31.

It will be noted that electrodes 28, 29, and 31 have substantially the arrangement of the electrodes in Fig. 3 except that one of the cathode plates 14 is replaced by the liquid cathode 28. It is also possible to produce in Fig. 6 a homogeneous magnetic field traversing cathode 28 and anode 29, in the same manner as the magnetic field of Fig. 2 traverses cathode plates 11 and 12; this being obtained by a permanent magnet such as shown in Fig. 1 or by an electromagnet as shown in Fig. 2.

The advantages obtained by the present invention will appear from the curves given in the graph of Fig. 7, in which the abscissae represent the pressure of the filling in millimeters of mercury, and the ordinates represent the ignition voltage in a tube constructed according to Figures 3 and 4. Dotted curves F and G represent the ignition curves in the conductive direction and in the non-conductive direction respectively, for a cold cathode discharge tube without the use of a magnetic field, whereas the solid curves D and E represent the ignition curves in the rectifying and blocking directions respectively, for a cold-cathode discharge tube for the same discharge tube, but with a magnetic field arranged according to the present invention and having a field strength of about 3000 oersted.

Inspection of Fig. 7 clearly reveals that without the magnetic field the ignition voltages, as indicated by curves F and G, closely approach each other and will obtain values of several thousand volts (at a point off the graph) even with a filling pressure of about 2.10^{-2}.

On the other hand, with the magnetic field and as indicated by curves D and E, the ignition voltages in both directions are considerably lower and also considerably different. Note that below a pressure of about 5.10^{-3} mm. of mercury the ignition voltage in the non-conductive direction (curve E) is extremely high, whereas the blocking voltage in the conductive direction (curve D) attains a value of 500 volts only at about 4.10^{-4} mm. of mercury, and an ignition voltage of 1000 volts is attained only at a pressure of less than 10^{-5} mm. of mercury.

Of course the data given in Fig. 7 are merely for the type of construction mentioned above and the results obtained will differ to some degree with the particular construction used. In some constructions the steep slope of the ignition voltage in the blocking direction and with the magnetic field (i. e. the portion indicated by reference numeral 63 in Fig. 7) may occur at pressures of the order of 10^{-2} mm. of mercury and more.

While I have described my invention in connection with specific examples and constructions, I do not wish to be limited thereto, but desire the appended claims to be construed as broadly as permissible in view of the prior art.

What I claim is:

1. An A. C. rectifying device comprising, an ionic discharge tube comprising an envelope, a cold cathode and an anode spaced apart to form a discharge space, and a low-pressure gaseous filling within said tube, and means to produce within said space a non-homogeneous magnetic field having lines of force entering and leaving the space through said cathode with most of said lines passing through the space without intersecting the anode.

2. An A. C. rectifying device comprising an ionic discharge tube comprising an envelope, a tubular-shaped cold-cathode, an elongated anode extending coaxially within said cathode and forming a discharge space therewith, a low-pressure gaseous filling within said envelope, and means to produce a non-homogeneous rotational-symmetrical magnetic field having an axis coinciding with the axes of said cathode and anode and lines of force intersecting said cathode near the ends thereof, most of said lines of force passing through the discharge space without intersecting the anode.

3. An A. C. rectifying device comprising an ionic discharge tube comprising an envelope, a tubular-shaped cold-cathode, an elongated anode extending coaxially within said cathode and forming a discharge space therewith, a low-pressure gaseous filling within said envelope, and means including an electric coil surrounding said tube and having a length less than half the length of said cathode to produce a non-homogeneous rotational-symmetrical magnetic field having an axis coinciding with the axes of said cathode and anode and lines of force intersecting said cathode near the ends thereof, said cathode surrounding a greater part of said field and most of said lines of force passing through the discharge space without intersecting the anode.

4. A device for rectifying high alternating voltages, comprising an ionic discharge tube having an envelope, a cold cathode and an anode within said envelope and spaced apart to form a discharge space, and an ionizable gaseous filling within said envelope and having a pressure between 10^{-4} and 10^{-2} mms. of Hg, and means to produce a magnetic field having lines of force traversing the space within the envelope with a major portion of said lines passing through the discharge space between the anode and cathode and entering and leaving said discharge space through portions of the active cathode surface adjacent the same, most of the lines of said major portion passing through the discharge space without intersecting the surface of the anode.

5. A device for rectifying high alternating voltages, comprising an ionic discharge tube having an envelope, a cold cathode having an active surface, an anode spaced from said cathode to form a discharge space and having an active surface opposing said active cathode surface and parallel thereto, and an ionizable gaseous filling within said envelope and having a pressure between 10^{-4} and 10^{-2} mms. of Hg, and means to produce a magnetic field having lines of force traversing the space within the envelope with a major portion of said lines passing through the discharge space between said active surfaces and entering and leaving said discharge space through portions of said active cathode surface, most of the lines of said major portion passing through the discharge space without intersecting the surface of the anode.

6. A device for rectifying high alternating voltages, comprising an ionic discharge tube having an envelope, a cold cathode structure comprising two cathode members spaced apart, an anode extending between said cathode members and forming a discharge space therewith, and an ionizable gaseous filling within said envelope and having a pressure between 10^{-4} and 10^{-2} mms. of Hg, and means to produce a magnetic field having lines of force traversing the space within the envelope with a major portion of said lines passing through the discharge space between the anode and members and entering said discharge space through the active surface of one of said members and leaving said space through the active surface of the second member, most of the lines of said major portion passing through the discharge space without intersecting the surface of the anode.

7. A device for rectifying high alternating voltages, comprising an ionic discharge tube having an envelope, a tubular anode, a cold cathode comprising two members each disposed at one end of said anode and extending substantially perpendicular to the axis thereof, said members and anode forming a discharge space, and an ionizable gaseous filling within said envelope and having a pressure between 10^{-4} and 10^{-2} mms. of Hg, and means to produce a magnetic field having lines of force traversing the space within the envelope with a major portion of said lines passing through the discharge space between the anode and members and entering said discharge space through the active surface of one of said members and leaving said space through the active surface of the second member, most of the lines of said major portion passing through the discharge space without intersecting the surface of the anode.

8. A device for rectifying high alternating

voltages, comprising an ionic discharge tube having an envelope, a cold-cathode structure comprising two substantially plate-shaped members spaced apart, an anode extending between said members and substantially perpendicular thereto, said anode and members forming a discharge space, and an ionizable gaseous filling within said envelope and having a pressure between 10^{-4} and 10^{-2} mms. of Hg, and means to produce a magnetic field having lines of force traversing the space within the envelope with a major portion of said lines passing through said discharge space and entering said space through the active surface of one of said members and leaving said space through the active surface of the second member, most of the lines of said major portion passing through the discharge space without intersecting the surface of the anode.

9. A device for rectifying high alternating voltages, comprising an ionic discharge tube having an envelope, a liquid mercury cathode, and an anode within said envelope and spaced from said cathode to form a discharge space, an ionizable gaseous filling within said envelope and having a pressure between 10^{-4} and 10^{-2} mms. of Hg, and a control electrode in said discharge space, and means to produce a magnetic field having lines of force traversing the space within the envelope with a major portion of said lines passing through the discharge space and entering and leaving said discharge space through portions of the active surfaces of said anode and cathode, most of the lines of said major portion passing through the discharge space without intersecting the surface of said control electrode, means to apply a voltage between said anode and cathode, and means to apply a higher voltage between said cathode and control electrodes.

10. A device for rectifying high alternating voltages, comprising an ionic discharge tube having an envelope, a cold cathode of a material having a melting point less than 30° C., and anode within said envelope and spaced from said cathode to form a discharge space, and an ionizable gaseous filling within said envelope and having a pressure between 10^{-2} and 10^{-4} mms. of Hg, and means to produce an alternating magnetic field having lines of force traversing the space within the envelope with a major portion of said lines passing through the discharge space between the anode and cathode and entering and leaving said discharge space through portions of the active cathode surface, most of the lines of said major portion passing through the discharge space without intersecting the surface of the anode.

FRANS MICHEL PENNING.