July 16, 1929. A. W. HULL 1,721,395

ELECTRON DISCHARGE APPARATUS

Filed May 24, 1921 3 Sheets-Sheet 1

Fig. 1.

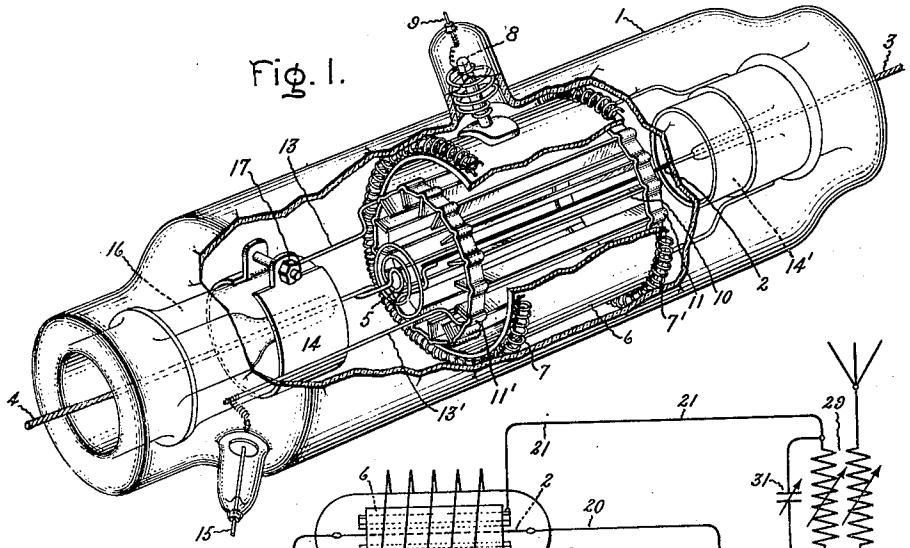


Fig. 2.

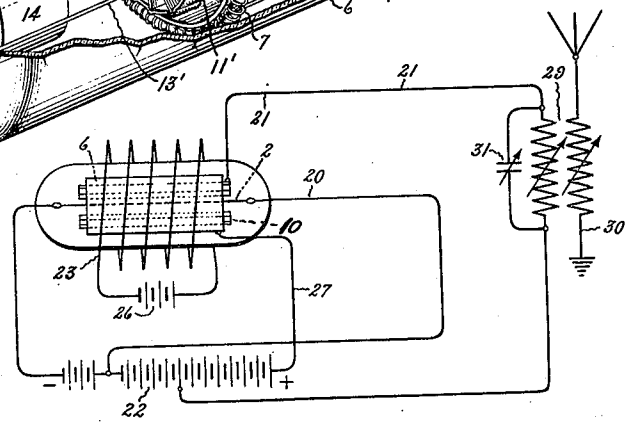


Fig. 3.

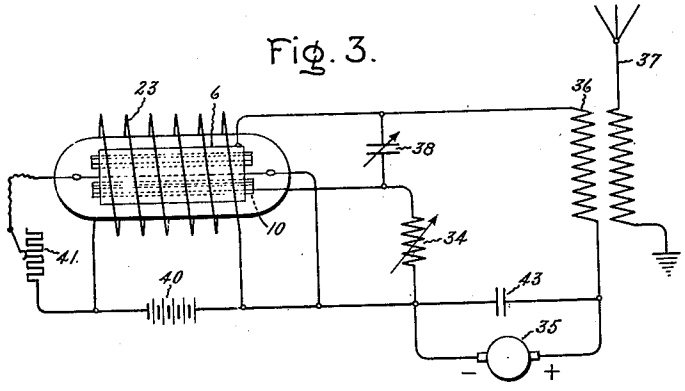
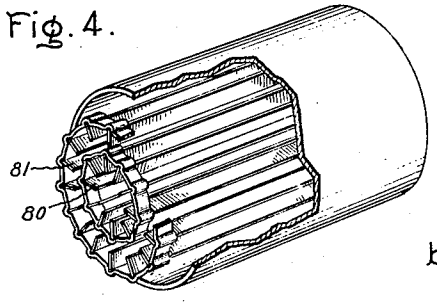


Fig. 4.



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Fig. 5.

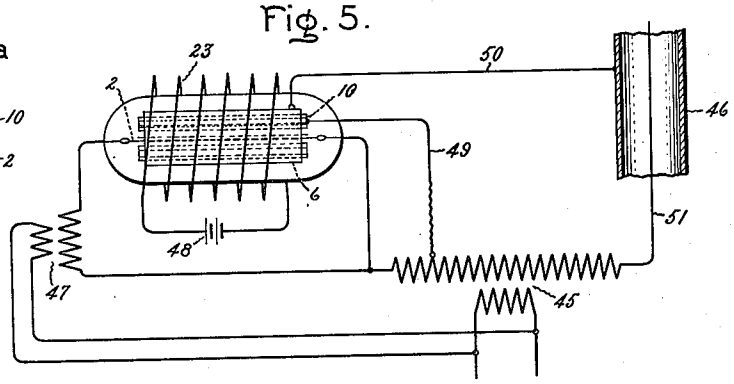


Fig. 5a

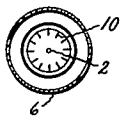


Fig. 6.

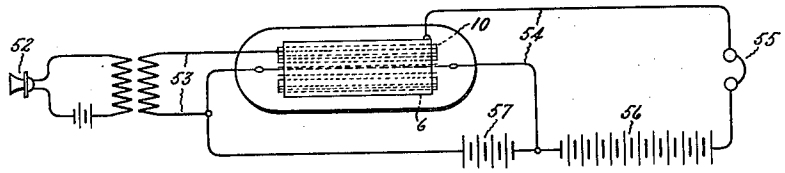


Fig. 7.

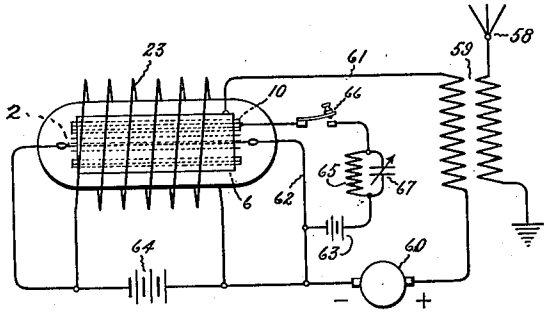


Fig. 8.

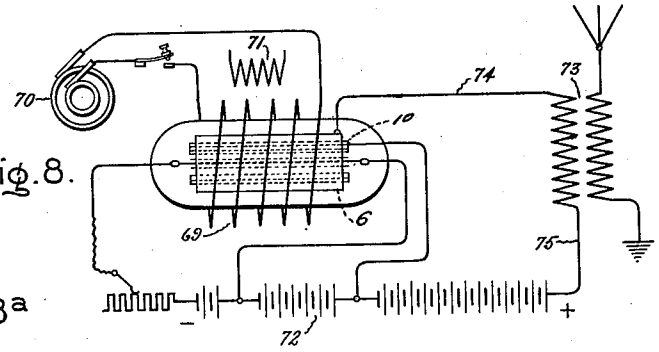
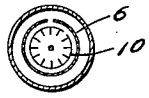


Fig. 8a



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ELECTRON DISCHARGE APPARATUS

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Fig. 9.

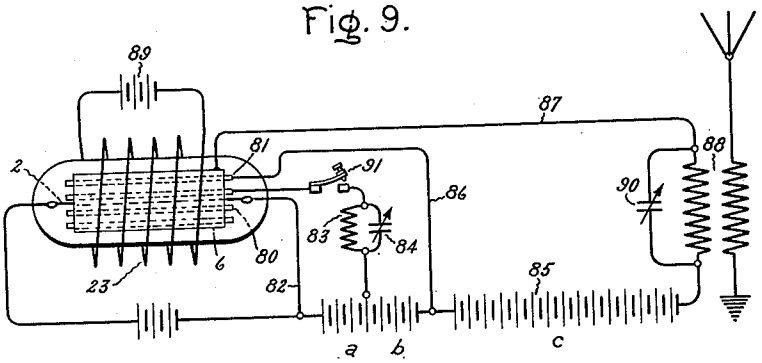


Fig. 10.

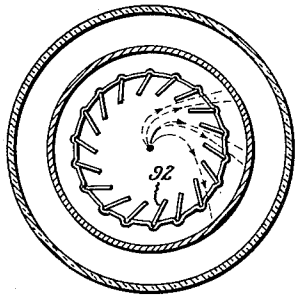


Fig. 12.

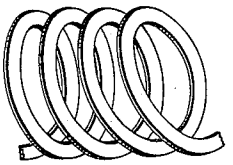


Fig. 11.

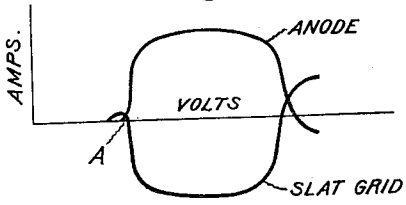


Fig. 14.

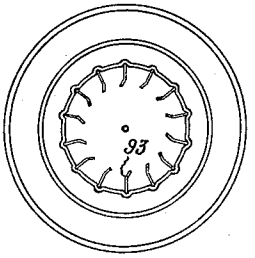
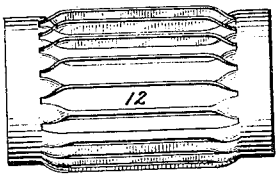


Fig. 13.



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Patented July 16, 1929. 1,721,395

UNITED STATES PATENT OFFICE.

ALBERT W. HULL, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

ELECTRON-DISCHARGE APPARATUS.

Application filed May 24, 1921. Serial No. 472,139.

The present invention comprises an improvement in the construction of electron discharge apparatus which is applicable to a wide range of uses.

In various forms of electron discharge devices, a supplementary electrode, frequently known as a grid, is provided in addition to the cathode and the anode, the usual function of this electrode being the control of the electron current although it may have other uses. The grid electrode has usually been constituted by a wire coiled into various shapes although perforated cylinders and similar structures have also been employed. In all of these prior constructions the surface obstructing the passage of the electrons has been a relatively large part of the total surface of the intermediate electrode, resulting in lowered efficiency.

In accordance with my invention, I have provided an electrode structure adapted to interpose a relatively small part of its total surface to the normal path of electrons emitted by the cathode. My new structure constitutes an improved grid, but it has other important uses, for example, it may function as an emitter of secondary electrons, as described hereinafter.

My improved electrode structure, in an embodiment hereinafter more fully described has its main extension in the direction of the normal path of the electrons. For example, in the case of a concentric cathode and anode, a grid embodying my invention may consist of a plurality of conducting slats which are respectively arranged in the direction of the shortest paths between the cathode and the anode.

In the accompanying drawings, Fig. 1 is a perspective view of a device embodying my invention, the envelope being in part broken away; Figs. 2, 3, 5, 6, 7, 8 and 9 illustrate different uses of a device embodying my invention; Figs. 5ª and 8ª are sectional views of the device shown in Figs. 5 and 8; Figs. 4, 10, 12, 13 and 14 illustrate modifications of my improved device, and Fig. 11 is a curve of electrical characteristics of one embodiment of my invention.

The device shown in Fig. 1 comprises an envelope 1 containing a centrally located filamentary cathode 2, consisting of a refractory material, as, for example, tungsten, which is connected to the sealed-in conductors 3, 4, and being held taut by a spring 5. The anode 6 consists of a cylinder of conductive material, conveniently molybdenum, held in position by the coiled wires 7, 7′, which are sprung between the anode 6 and the glass envelope 1. A stem 8 which is cushioned by a spring anchors the anode as indicated, current connections being made by a conductor 9. Intermediate the cathode 2 and the anode 6 is a supplementary electrode 10 consisting of a plurality of flat strips, or slats, spaced in radial planes about the cathode. In the construction shown, the slats are mounted upon two conductive bands 11, 11′ by welding, or otherwise. They may be stamped, as shown in Fig. 13, from sheet material and bent into desired shape, the strips 12 being bent at an angle, in this case radially, to the periphery of the cylindrical surface of the electrode. The cage-shaped electrode 10 constituted by the slats is carried by the wires or rods 13, 13′ which are welded or otherwise connected to collars 14, 14′ external electrical connection being made by a conductor 15. The collars 14, 14′ are mounted upon the reentrant tubes 16 of the envelope by any convenient means such as small bolts 17, shown only at one end of the tube. It is not essential that an electrode embodying my invention shall consist of longitudinal elements, as shown in Figs. 1 and 13. Other forms having a major surface extension in the direction of the electron flow may be used in some cases. For example, when this electrode functions as an electrostatic control grid, as in the system shown in Fig. 6, a flat spiral electrode illustrated in Fig. 12 may be substituted for the electrode 10. This form of electrode also may be used as an anode in a dynatron. The latter is described in Proceedings of Institute of Radio Engineers, vol. 6, p. 5, 1918.

The envelope and electrodes are freed from gas in the usual way. Although my invention is ordinarily applied to devices in which the residual gaseous pressure has been reduced sufficiently to enable a substantially pure electron discharge to be obtained, it is not limited in its usefulness to this particular class of devices.

The advantages of my improved electrode will appear from a consideration of its function in the apparatus illustrated in the drawings.

Fig. 2 illustrates a dynatron oscillator. The cathode 2 and the slat electrode 10 are connected by conductors 20, 21 to a source of

direct current, such, for example, as a part of a battery 22, the filamentary cathode being heated by a section of the battery, as indicated. Surrounding the device is a magnetic winding 23 connected to a battery 26. The outer cylindrical electrode 6 is connected by a conductor 27 to a point of higher potential on the battery 22. In the absence of a magnetic field tending to deflect the electrons, the electrode 6 will receive substantially all of the electrons as it is of higher potential with respect to the cathode 2 than the electrode 10, and the electrode 10 interposes but little surface to the passage of the electrons. When the electrons are deflected from the normal radial direction by the magnetic field, they will strike the slat electrode 10 and liberate secondary electrons which will be attracted to the more positive electrode 6.

The radial extension of the slats of the electrode 10 is a structure favorable to the reception of the electrons by the slats when their path becomes curved by the action of the magnetic field and a relatively small increase in magnetic field will cause all of the electrons to strike the slat electrode 10. With a proper choice of potential upon the electrode 10, the emission of secondary electrons exceeds the reception of the primary electrons. The device, therefore, acts as a most efficient oscillator, the alternating current being utilized, in the system illustrated, for radio purposes. The primary winding of the transformer 29 is included in the circuit 21, the secondary winding being in the grounded antenna circuit 30. The primary winding of the transformer 29 is shunted by a condenser 31. By properly adjusting the inductance and capacity in the circuit 21, high frequency oscillations may be produced. If desired, the condenser 31 may be omitted and the primary and secondary of the transformer 29 may be closely coupled.

My improved grid device may be used to advantage in an oscillator system in which it acts as a discharge-controlling electrode, while at the same time acting as a secondary cathode, as shown, for example, in Fig. 3. In this system, the slat electrode 10 is connected in series with an adjustable inductance 34 to the negative terminal of a source of direct current 35. The anode 6 is connected to the positive terminal of the generator 35 through a load 36, which in this case is represented by the primary of a transformer having a secondary winding connected to a grounded antenna 37. An adjustable condenser 38 is connected between the electrodes 6 and 10. The cathode 2 is heated by a battery 40, which is connected in series with a regulable resistance 41. The magnetic winding 23 is excited by a substantially constant current from a suitable source such as the battery 40. A condenser 43 preferably is connected in shunt to the generator 35.

When the electrode 10 is negative, or is insufficiently positive, no current can pass to the electrode 6, but when the electrode 10 has a positive potential above a value determined by the magnetic field generated by the winding 23, it receives the primary electrons and emits secondary electrons to the electrode 6, as will be later described in connection with Fig. 11. The magnetic field generated by the winding 23 continuously deflects the electrons so that substantially all strike the slat members when the electrode 10 is sufficiently positive while at the same time the exposed surface of these slats opposes little obstacle to the passage of the secondary electrons to the electrode 6. The number of secondary electrons greatly exceeds the number of primary electrons striking the slats. As a result my improved device has a greater efficiency and the filament a longer life than similar tubes with grid constructions heretofore used. In this system the new grid construction gives good grid control and a high efficiency without the use of a negative bias potential for the grid.

In Figs. 5 and 5ª, I have shown an electron discharge device provided with an electrode 10 having a radial extension which acts only to increase the current by the emission of secondary electrons. Between the cathode 2 and the electrode 6 is connected a suitable source of current, for example, the secondary of a high potential transformer 45. The load 46 in this figure has been represented diagrammatically as a smoke precipitation device. The filamentary cathode 2 is heated by a transformer 47. A battery 48 supplies the magnetic winding 23. The electrode 10 is connected to an intermediate point of potential on the transformer secondary by a conductor 49. A given electron current from the cathode 2 to the electrode 10 causes a much larger current of secondary electrons to flow from the electrode 10 to the anode 6 passing over the conductors 50, 51 through the load device 46.

In Fig. 6, I have shown a telephone amplifier system provided with a grid 10 embodying my invention. A telephone transmitter 52 controls the grid circuit 53. The plate circuit 54 is connected to a telephone receiver 55 in series with a battery 56. A battery 57 serves to heat the cathode: For the purpose here shown the slat grid is advantageous as obstruction of the electron flow by the grid is materially less when the grid members extend mainly in radial planes about the cathode than when the grid consists of wires or sections of a cylindrical surface.

In Fig. 7, I have illustrated another type of oscillator, differing from the oscillator shown in Fig. 2, by having the load, as represented by an antenna 58, coupled by a transformer 59 to the anode 6 instead of to the oscillating circuit in series with the electrode 10. As shown

in this figure, a suitable source of energy, as represented by a direct current generator 60 is connected in circuit with the primary winding of the radio transformer 59 to the cathode 2 and the third electrode 6 by conductor 61, 62. A battery 63 is inserted between the cathode 2 and the slat electrode 10 to give the slat electrode a negative resistance characteristic. The magnetic winding 23 is constantly energized by a battery 64. Oscillations are set up in the tuned circuit containing an inductance 65 and a condenser 67 by reason of the negative resistance characteristic of the circuit the electrode 10 giving up secondary electrons when bombarded by primary electrons. Signals may be sent by use of any suitable means such as a telegraph key 66. When the potential in the electrode 10 oscillates a variable secondary electron current is received by the outer electrode 6.

In the system shown in Fig. 8 a somewhat different utilization of my improved device is illustrated. The slat electrode 10 and the anode 6 in this apparatus are slotted longitudinally, as shown in Fig. 8ª, so that current cannot be induced therein by the variable magnetic field produced by a winding 69 connected to an alternating current generator 70. A polarizing winding 71 steadily energized also is provided which deflects the electrons to cause them to bombard the slat electrode, when a suitable source of energy 72 is provided. The passage of secondary electrons from the electrode 10 to the electrode 6 is controlled by the variable magnetic field which may be adjusted to cut off the secondary electron current when the magnetic field is at a maximum, the field strength required depending on the voltage of the source 72. Any suitable load as represented by the radio transformer 73 may be supplied. If the constantly excited field 71 is omitted, the frequency of the current in the load circuit 74, 75 is twice as great as the frequency of the alternator 70.

In some cases my invention may be embodied in a device with two slat electrodes 80, 81, as illustrated in Fig. 4, the outer envelope being shown in part broken away. In Fig. 9 I have shown a radio system utilizing such a device. Between the cathode 2 and the slat electrode 80 an oscillating circuit 82 is connected containing an inductance coil 83 and a condenser 84 connected in parallel as in Fig. 7, energy being supplied by section *a* of a battery 85. Section *b* supplies current to the outer grid 81 and section *c* is connected by conductors 86, 87 between the electrode 81 and the outer cylindrical electrode 6 in series with a load represented by the radio transformer 88. The magnetic winding 23 is constantly excited by a battery 89. An adjustable condenser 90 may be connected across the primary of the radio transformer 88 to adjust the natural frequency of the circuit 87.

Oscillations are set up between the cathode 2 and the inner slat electrode 80 by reason of the negative resistance characteristic of the device. The secondary electrons emitted by the electrode 80 travel radially outwardly when unaffected by such forces as a magnetic field. By the magnetic effect of the field generated by the coil 23 these secondary electrons are deflected and strike the sides of the radial vanes of the electrode 81. Here they generate a greater number of secondary electrons which finally go to the outer electrode 6, this being at a higher positive potential than the electrode 81. By a suitably tuned capacity 84 and an inductance 83 in the circuit 86, oscillations of desired frequency can be produced and controlled by a key 91. The three inner elements, that is, the cathode 2 and the electrodes 80, 81, operating as a dynatron, or negative resistance oscillator, feed current to the electrode 6 during a short part of each cycle. The inductance in the circuit 87 automatically adjusts the phase, so that the plate voltage is low when the current passes. Two magnifications of the electron current generated by the cathode occur by secondary emission successively from the grids 80, 81 so that the cathode may be run at a correspondingly lower temperature with an accompanying longer life. The magnetic winding 23 is not essential to the device but when such a winding is used whereby the electrons are deflected and a greater number caused to strike the vanes of the electrodes 80, 81, a corresponding increase is secured of the current by secondary emission. When the apparatus shown in Fig. 9 is operated either with or without a magnetic field, the frequency of the oscillations is determined entirely by the inductance 83 and the capacity 84 and is independent of the constants of the load circuit 87 or of the antenna.

My invention is not limited to the specific form of electrode shown in Figs. 1 and 4 with radial vanes or slats. In some cases the vanes may extend at an angle to the radii, as shown in Fig. 10. In this case the major extension of the vanes 92 is parallel to the path of the electrons when the electrons are deflected as indicated.

In some cases the slats may be bent to advantage, as shown at 93 in Fig. 14. Such a construction produces a maximum electrostatic shielding of the filament without interfering with production and escape of secondary electrons. In each of these modifications the vanes extend at an angle to a surface of revolution about the axial cathode.

The electrical characteristics of my new device with a constant magnetic field are illustrated by Fig. 11 in which the ordinates indicate currents and the abscissæ voltages between the cathode, and the cooperating electrodes in a device of the type shown in Fig. 1. The curve above the horizontal axis

indicates the current-voltage relation between the cathode and outer electrode 6. The curve below this axis indicates the current-voltage relation between the cathode and the slat electrode 10, in a system such as shown in Fig. 5.

When the potential of the slats is less than a given voltage which depends on the value of the magnetic field, the electrons are deflected back to the cathode by the magnetic field and hence neither the anode nor the slat electrode receive current. As the voltage exceeds the value A the slats lose electrons by secondary emission so that the current between the cathode and the slats is negative, that is, in opposite direction to the voltage, the value of the current being equal to the excess of the secondary electrons over the primary electrons. The secondary electrons leaving the grid go to the anode, as represented by the positive curve. The value of this current is larger than that emitted by the cathode in the ratio of the secondary to the primary emission.

The described embodiments of my invention illustrate some of its main advantages: (1) It offers a maximum electrostatic shielding while interposing a minimum of material obstruction to the passage of electrons; (2) in other embodiments my new electrode generates a maximum number of secondary electrons; (3) in other cases, as in a dynatron, it will collect more efficiently secondary electrons from a surrounding anode without interfering with the passage of primary electrons. My new construction has the advantage of greater mechanical strength and rigidity over prior constructions.

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

1. An electron discharge device having an electron-emitting cathode, an anode and an electrode comprising one or more ribbon-shaped conducting members which are so arranged, between said cathode and anode, that the surface of said members which obstructs electron flow between said cathode and said anode constitutes a minor part of the total surface and means for generating a magnetic field substantially parallel to said cathode.

2. An electron discharge device having an electron-emitting cathode, a surrounding anode, and conducting members arranged between said cathode and anode, said members being respectively oriented to present a major surface extension in the general direction of the shortest paths between said cathode and said anode and means for generating a magnetic field substantially parallel to said cathode.

3. An electron discharge device having a cathode and an electrode, cooperating with said cathode, arranged to have a main extension in the direction of the normal path of electrons emitted by said cathode and means for magnetically deflecting the electrons emitted by the cathode out of substantially radial paths.

4. An electron discharge device comprising a cylindrical electrode, an axially located filament within said electrode adapted to operate at incandescence, an intermediate electrode comprising one or more flat members having a main extension in a substantially radial direction about said filament and means for magnetically deflecting the electrons emitted by said filament out of substantially radial paths.

5. An electron discharge apparatus comprising a sealed evacuated envelope, an electron-emitting cathode therein, a second electrode at least in part surrounding said cathode, an intermediate electrode comprising a flat member arranged edgewise between said electrodes and means for generating a magnetic field substantially parallel to said cathode.

6. An electron discharge device comprising an evacuated envelope, a cathode therein having a linear extension, an anode surrounding the same, an intermediate electrode comprising flat conducting strips arranged radially about said cathode and means for magnetically deflecting the electrons emitted by said cathode out of substantially radial paths.

7. An electron discharge device comprising an evacuated envelope, a cathode therein having a linear extension, an anode surrounding the same, an intermediate electrode comprising flat conducting members located in substantially radial planes about said cathode and substantially parallel thereto and means for magnetically deflecting the electrons emitted by said cathode out of substantially radial paths.

8. An electron discharge device comprising an evacuated envelope, a refractory filamentary cathode therein having a linear extension, a surrounding anode, and an intermediate electrode comprising a plurality of flat strips arranged radially about said cathode and parallel thereto, conducting rings joining said strips at their respective ends, and means for magnetically deflecting electrons emitted by the cathode out of substantially radial paths thereby causing said electrons to strike said intermediate electrode.

9. An electron discharge device comprising a sealed envelope, an electron-emitting cathode therein and a plurality of electrodes spaced successively about said cathode, said electrodes comprising one or more flat members which are respectively constructed and arranged with respect to said cathode to present a main surface extension at an angle to a surface of revolution about said cathode and means for generating a magnetic field substantially parallel to said cathode.

10. An electron discharge apparatus comprising an electron-emitting cathode, an

anode, an intermediate electrode comprising one or more flat conducting members arranged edgewise between said electrodes, means for deflecting electrons emitted by said cathode to impinge upon said members, a source of current connected between said cathode and said intermediate electrode and a source of current of higher potential connected between said cathode and anode.

11. An electron discharge apparatus comprising an evacuated envelope, a cathode having a linear extension, an anode arranged symmetrically about said cathode, a source of electric energy connected between said electrodes, a plurality of electrodes located between said cathode and anode and having a surface extension mainly radial with respect to said cathode, connections between said electrodes, and points of intermediate potential on said energy source and means for generating a magnetic field substantially parallel to said cathode.

12. An electrical discharge apparatus comprising a cathode, an enclosing anode, an intermediate electrode comprising one or more ribbon-like members arranged edgewise between said electrodes, an enclosing envelope, means for deflecting electrons emitted by said cathode, and means for charging said intermediate electrode to a potential positive with respect to said cathode.

13. An electrical discharge apparatus comprising a linear cathode, a cylindrical enclosing anode, an intermediate electrode comprising a plurality of ribbon-shaped members arranged radially about said cathode, an enclosing sealed evacuated envelope, means for deflecting electrons out of a direct path between cathode and anode so as to impinge on said intermediate electrode, and means for charging said intermediate electrode to a positive potential with respect to said cathode.

14. An electrical discharge apparatus comprising an electron-emitting cathode, an anode, an intermediate electrode so arranged that the main extent of the surface thereof extends substantially parallel to the direct paths of electrons passing between said electrodes, means for deflecting said electrons so as to strike said intermediate electrode, a source of alternating current, connections between said source and said cathode and anode, and a connection between said intermediate electrode and a point of intermediate potential on said source.

15. An electrical discharge device comprising a sealed, evacuated envelope, a substantially linear cathode therein, a cylindrical anode, symmetrically arranged about said cathode, a third electrode located intermediate said cathode and anode, said electrode being constituted by sheet material, which is subdivided by a plurality of slits extending in the direction of the axis of said cathode and having the subdivisions thereof oriented to extend in the direction of the shortest paths between said cathode and said anode and separate conductors leading to said respective electrodes sealed into said envelope and means for magnetically deflecting the electrons emitted by said cathode out of substantially radial paths.

16. An electrical discharge device comprising an evacuated container, a substantially linear cathode mounted therein, and a cooperating electrode surrounding said cathode and comprising a plurality of members which have a main surface extension at an angle to a surface of revolution about the axis of said cathode and means for magnetically deflecting the electrons emitted by said cathode out of substantially radial paths.

In witness whereof, I have hereunto set my hand this 23rd day of May, 1921.

ALBERT W. HULL.