May 30, 1939. G. K. TEAL 2,160,798

ELECTRON DISCHARGE APPARATUS

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FIG. 1

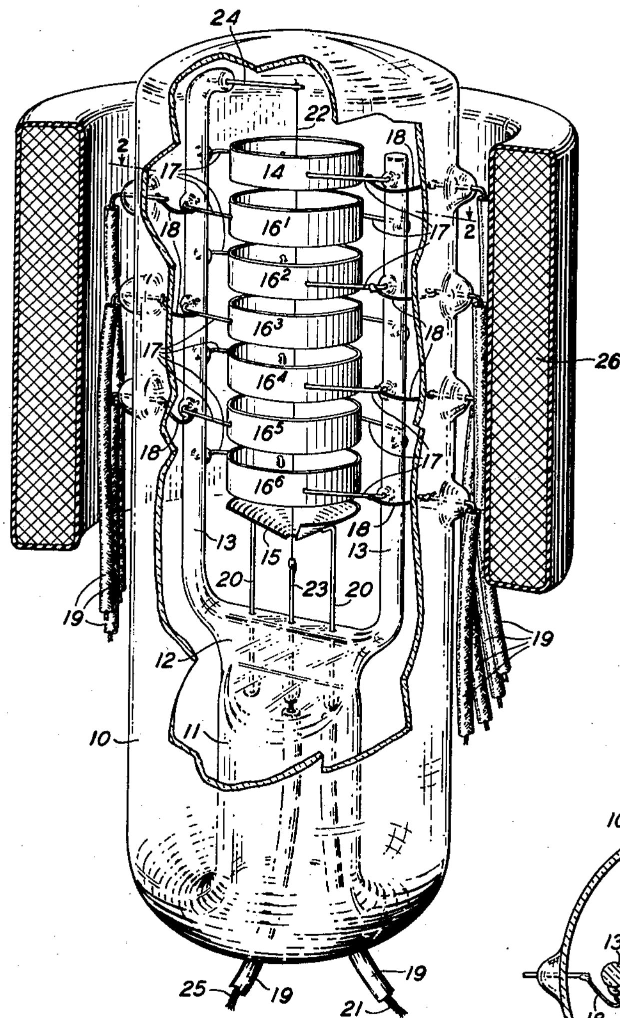
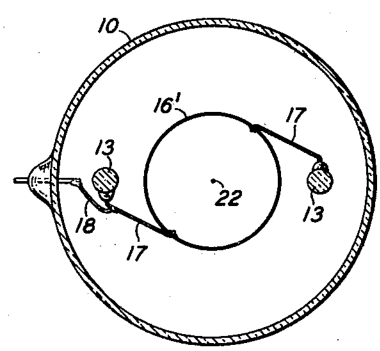


FIG. 2



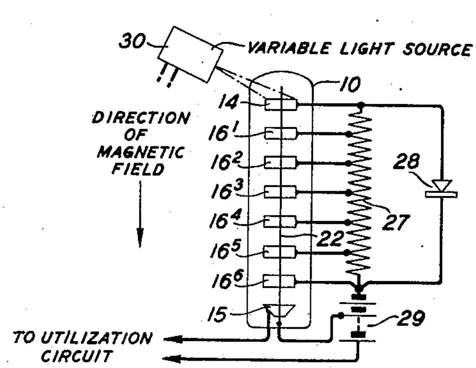


FIG. 5

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FIG. 3

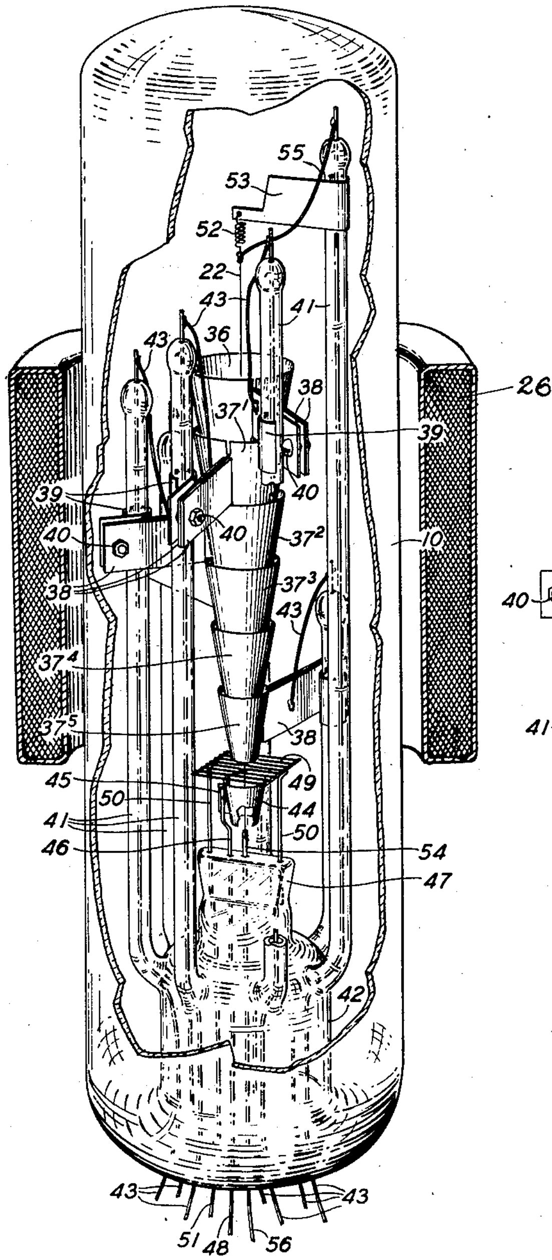

FIG. 4

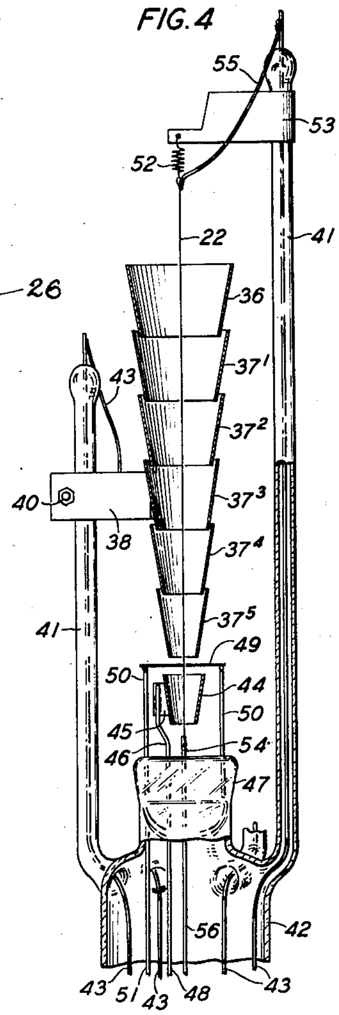

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FIG. 6

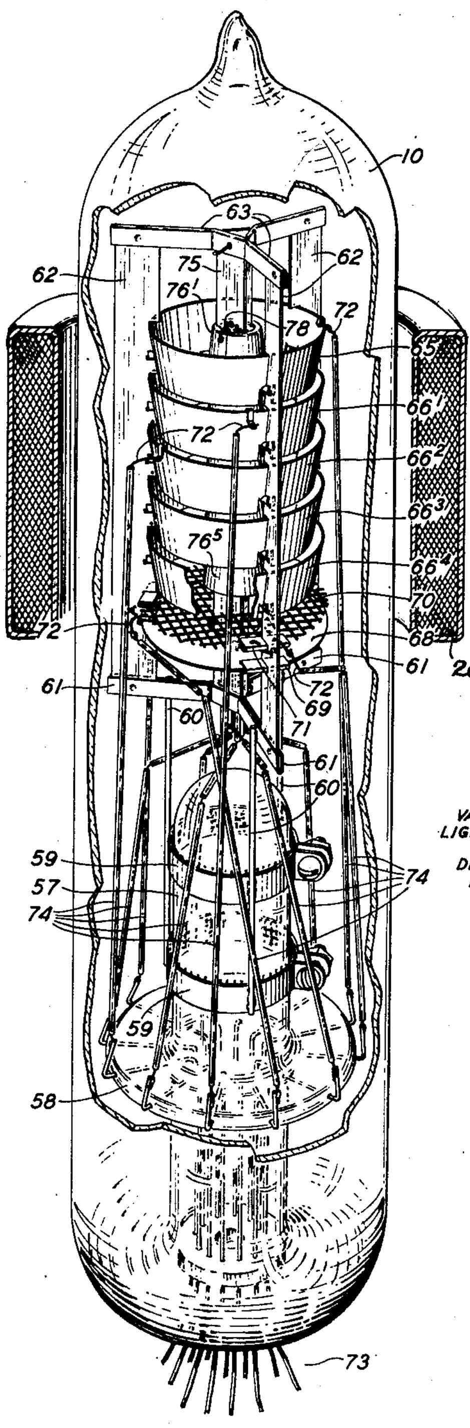


FIG. 7

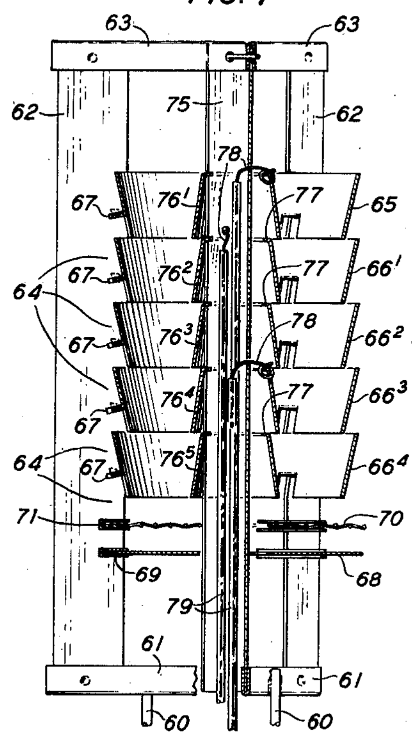
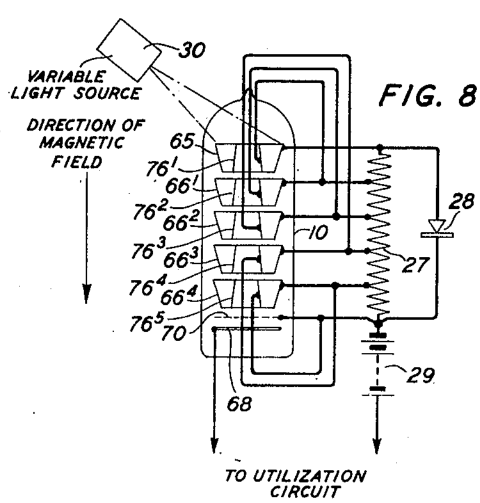


FIG. 8



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UNITED STATES PATENT OFFICE

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ELECTRON DISCHARGE APPARATUS

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Application November 20, 1936, Serial No. 111,810

15 Claims. (Cl. 250—166)

This invention relates to electron discharge apparatus and more particularly to such apparatus adapted to amplify high frequency impulses and including electron discharge devices having secondary electron emitting electrodes.

One object of this invention is to facilitate the attainment of faithful translation of high frequency signals.

Another object of this invention is to simplify electron discharge amplifying apparatus whereby the number of component elements necessary to produce a high degree of amplification is reduced.

Another object of this invention is to obtain a high signal to noise ratio in electronic amplifiers.

Still another object of this invention is to increase the efficiency of electron discharge devices including secondary electron emitting electrodes.

A further object of this invention is to expedite the construction of electron discharge devices having secondary electron emitting electrodes and to facilitate the sensitization of such electrodes therein.

In one illustrative embodiment of this invention, electron discharge apparatus comprises a primary cathode, a collector electrode or anode spaced from the primary cathode, and a plurality of auxiliary electrodes or secondary cathodes disposed in superposed relation between the primary cathode and the collector electrode or anode. These auxiliary electrodes or secondary cathodes may be, for example, annular members of cylindrical or frusto-conical form, arranged coaxially with one another and with the primary cathode and the collector electrode or anode. Portions of the secondary cathodes, for example, the inner surfaces thereof, may be coated or treated to assure copious emission of secondary electrons therefrom.

During operation of the device, a strong magnetic field is produced, as by a coil encompassing the electron discharge device, axially of the electrodes of the device and adjacent the coated or treated portions of the secondary cathodes, and the secondary cathodes are maintained at successively increasing positive potentials with respect to the primary cathode. The primary cathode may be energized in any suitable manner to cause emission therefrom, and the electrons thus emitted, under the influence of the potentials and the magnetic field extant in the device, are directed to and impinge upon the secondary cathode nearest the primary cathode. As a result, secondary electrons are released from this cathode, and these electrons are directed to and impinge upon the next adjacent secondary cathode. This phenomenon is repeated at each of the secondary cathodes down to the one furthest removed from the primary cathode. The secondary electrons emanating from this last secondary cathode are drawn to the collector electrode or anode and constitute the output current of the device.

Inasmuch as portions of the secondary cathodes are treated or coated, each primary or secondary electron impinging thereon will cause the release of a plurality of secondary electrons so that in effect an electron multiplication, and hence an amplification, occurs at each of the secondary cathodes. The magnitude of the secondary electron streams may be varied by varying the emission from the primary cathode or by modulating the primary electron stream flowing from the primary cathode to the secondary cathode thereadjacent.

In order to increase the electron flow between the various electrodes, an auxiliary or accelerating electrode may be provided. This electrode may be, for example, a linear wire disposed in the axis of alignment of the secondary cathodes. It may be maintained at a positive potential somewhat higher than that of the first secondary cathode so that it assures a velocity component of the electrons away from the coated or treated portions of the secondary cathodes.

In another embodiment, a plurality of coaxial auxiliary or accelerating electrodes may be employed, one for each of the secondary cathodes and laterally aligned therewith. Each of these accelerating electrodes may be maintained at a positive potential somewhat higher than that upon the corresponding secondary cathode.

The invention and the various features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings in which:

Fig. 1 is an elevational view of electron discharge apparatus illustrative of one embodiment of this invention, a portion of the external coil and of the enclosing vessel and a portion of the anode of the electron discharge device being broken away to show the electrodes more clearly;

Fig. 2 is a view in cross-section of the electron discharge device illustrated in Fig. 1, showing the configuration of the primary and secondary cathodes and the mounting thereof;

Fig. 3 is an elevational view in perspective of another illustrative electron discharge device constructed in accordance with this invention, a portion of the external coil, of the enclosing vessel and of one of the electrode supports being broken away to show the electrode structure more clearly;

Fig. 4 is an elevational view partly in cross-section of the electrode structure of the device shown in Fig. 3;

Fig. 5 is a circuit diagram of an amplifier constructed in accordance with this invention and including an electron discharge device of the design shown in Fig. 1 or in Fig. 3;

Fig. 6 is an elevational view in perspective of an electron discharge device illustrative of another embodiment of this invention, a portion of the external coil and portions of the enclosing vessel being broken away to show the internal structure more clearly;

Fig. 7 is a view in elevation and partly in cross-section of the electrode assembly embodied in the discharge device shown in Fig. 6; and

Fig. 8 is a circuit diagram of an amplifier including an electron discharge device of the construction illustrated in Fig. 6.

Referring now to the drawings, the electron discharge device shown in Figs. 1 and 2 comprises an elongated cylindrical enclosing vessel 10 having a stem 11 at one end, the stem being provided with a press 12 and a pair of parallel insulating arms or uprights 13. Disposed between the uprights 13 is a primary cathode 14, a collector electrode or anode 15 and a plurality of auxiliary or secondary cathodes 16^1 to 16^6 inclusive, the several electrodes being coaxially arranged and equally spaced and preferably being of the same diameter. The primary cathode 14 and the secondary cathodes 16 may be bands of metal having portions, preferably the inner surfaces thereof, coated or treated to assure copious electron emission therefrom. For example, the several cathodes may be of silver having their inner surfaces oxidized and treated with caesium to form a layer or coating of silver, caesium oxide and some free caesium.

The primary and secondary cathodes are supported by metallic rods or wires 17 embedded at one end in the insulating uprights 13 and suitably affixed at the other to the metallic bands. Suitable potentials may be impressed upon the cathodes 14 and 16 through leading-in conductors 18 which are connected to the rods or wires 17 and are sealed in and extend through the cylindrical wall of the enclosing vessel 10. The external portions of the conductors 18 preferably are encased in insulating material such as rubber sleeves 19.

The anode or collector electrode 15, which may be substantially conical in form and apertured at its apex, is supported by a pair of metallic rods or wires 20 embedded in the press 12, one of the rods or wires 20 having a leading-in conductor 21 connected thereto.

Disposed within the cathodes and the anode or collector electrode, and preferably in the axis thereof, is an auxiliary or accelerating electrode which may be a linear rod or wire 22, supported at one end by a rigid stub or wire 23 and at the other end by a resilient wire 24 embedded in one of the arms or uprights 13. A suitable potential may be applied to the accelerating electrode 22 through a leading-in conductor 25.

The enclosing vessel 10 may be encompassed by a coil 26 or a cylindrical magnet adapted to produce an intense concentrated magnetic field of constant strength parallel to the longitudinal axis of the vessel 10, toward the collector electrode, and adjacent the inner surfaces of the cathodes 14 and 16.

Preferably the coil or magnet is so constructed that the magnetic field is of greatest intensity in the vicinity of the primary cathode and decreases uniformly toward the collector electrode in order to compensate for the non-uniformity of the electrostatic field between the cathodes and the auxiliary or accelerating electrode, said electrostatic field being strongest in the vicinity of the primary cathode and decreasing substantially uniformly to adjacent the secondary cathode nearest the collector electrode.

During operation of the device, the secondary cathodes 16 are operated at successively and uniformly increasing positive potentials with respect to the primary cathode 14. That is to say, during operation the secondary cathode 16^1 may have a positive potential of the order of 250 volts with respect to the primary cathode 14 applied thereto and each of the secondary cathodes 16^2 to 16^6 may have a positive potential of the order of 250 volts higher than that upon the next preceding cathode applied thereto. The anode or collector electrode 15 may be at a potential of the order of 500 volts positive with respect to the last of the secondary cathodes 16^6 and the auxiliary or accelerating electrode 22 may be at a potential of the order of 1750 volts positive with respect to the primary cathode 14.

The potentials for the electrodes may be obtained conveniently as shown in Fig. 5.

The cathodes 14 and 16 are connected to equally spaced taps on a potentiometer 27 which is energized from a suitable source such as a rectifier 28. Because of the large current drain, a separate source, such as a battery 29 is provided for supplying a suitable positive potential to the anode or collector electrode 15. An output or utilization circuit may be connected to the anode or collector electrode and the source 29. A suitable source 30 of variable light is provided for energizing the primary cathode 14. The auxiliary electrode 22 may be connected to a tap on the battery 29.

When the primary cathode 14 is energized, electrons are emitted therefrom and these electrons under the influence of the magnetic field produced by the coil 26 and of the potentials upon the first secondary cathode 16^1 and upon the auxiliary electrode 22 are directed toward and impinge upon the inner surface of the secondary cathode 16^1 and cause the emanation of secondary electrons therefrom. Inasmuch as the inner surface of this secondary cathode is coated or treated as described heretofore, the secondary electron current therefrom will be materially greater, for example 8 times the primary electron current thereto. Consequently, in effect, an electron multiplication and an amplification of the signal corresponding to the primary current from the cathode 14 results. The secondary electrons emanating from the cathode 16^1 are influenced by the magnetic field of the coil 26 and the potentials upon the cathode 16^2 and the auxiliary electrode 22 and impinge upon the secondary cathode 16^2 to cause the emanation of other secondary electrons therefrom. The phenomenon is repeated at each of the secondary cathodes down to the last one 16^6 so that six electrone multiplications and amplifications result. The secondary electrons from the secondary cathode 16^5 flow to the collector electrode or anode 15 and constitute the output current of the device.

As the energization of the primary cathode 14 is varied in accordance with a signal, the output current to the anode or collector electrode

15 will be varied accordingly although the amplification at each secondary cathode, and hence the overall amplification, will remain substantially constant.

In the embodiment of this invention illustrated in Figs. 3 and 4, the primary cathode 36 and the secondary cathodes 37^1 to 37^5 inclusive are funnel-shaped or frusto-conical and coaxially arranged. Preferably these cathodes taper at the same rate and are partially nested as shown clearly in Fig. 4. Each of the cathodes 36 and 37 is provided with integral parallel flanges 38 to which a clip 39 is secured, as by a bolt 40. Each of the clips 39 is bent around and securely grasps one of a plurality of tubular arms or uprights 41 extending from the stem 42 and thereby supports the cathode with which it is associated. Leading-in conductors 43 extend through the tubular uprights 41 and are affixed, as by welding, to the flanges 38.

The cathodes 36 and 37 may have portions, preferably the inner surfaces thereof, coated or treated, as described heretofore in connection with the description of the apparatus shown in Fig. 1, to provide copious electron emission.

The anode or collector electrode 44 also may be funnel-shaped or frusto-conical and is provided with an integral flange 45 affixed to a rigid support wire 46 embedded in the press 47 on the stem 42 and having a leading-in conductor 48 connected thereto. The anode or collector electrode 44 preferably is coaxial with the primary and secondary cathodes and tapers at the same rate as the cathodes.

Disposed between the lowermost secondary cathode 57^5 and the collector electrode 44 is a shield or screen electrode 49 comprising a plurality of parallel wires supported from the press 47 by a pair of rigid uprights 50, one of which has a leading-in conductor 51 connected thereto. This electrode serves to prevent reaction upon the cathode 37^5 of potential variations upon the anode or collector electrode. It may be operated at a potential of 135 volts positive above the cathode 37^5.

The auxiliary or accelerating electrode 22 may be a linear metallic rod or wire disposed in the axis of the cathodes and anode, and is supported at one end by a helical spring 52 carried by a band 53 clamped about one of the arms or uprights 41, and at the other end by a rigid wire 54 embedded in the press 47. Suitable electrical connection to the electrode 22 may be made through leading-in conductors 55 and 56 connected to opposite ends thereof. If desired, a current may be passed through the conductor 22 to produce a magnetic field.

In order to produce a reatively intense magnetic field the conductor 22 may be of large diameter and hence of high current carrying capacity, or alternatively, a plurality of parallel conductors may be employed.

The enclosing vessel may be encompassed by a field coil, such as the coil 26, and the device may be connected in circuit as shown in Fig. 5. The operation of the device is the same as set forth fully heretofore in connection with the description of the apparatus shown in Fig. 1. It may be noted that the electrode construction in the device shown in Figs. 3 and 4 provides a greater concentration of electrons within the various cathodes and assures flow of substantially all the electrons emanating from each of the cathodes toward the next adjacent electrode whereby a high operating efficiency is obtained.

In the embodiment of the invention illustrated in Figs. 6, 7 and 8, the electron discharge device comprises an enclosing vessel 10 having a stem 57 provided intermediate its ends with an integral annular flange 58 and having clamped thereabout metallic bands or colars 59 from which a unitary electrode assembly is supported. The bands or collars 59 have affixed thereto a plurality, for example three, of rigid metallic supports 60 which are securely fastened to the arms 61 of a tri-armed supporting spider. The arms 61 are channel-shaped and tightly fitted therein and held thereby are insulating uprights 62, for example strips of mica or the like. The insulating uprights 62 are maintained in spaced relation at the end thereof remote from the stem 57 by a spider 63 having channel-shaped arms, each parallel to one of the arms 61, securely grasping the uprights 62. Each of the uprights 62 is provided with a plurality of fingers 64 for supporting a primary cathode 65 and a plurality of secondary or auxiliary cathodes 66^1 to 66^4 inclusive. As shown clearly in Fig. 7, the cathodes 65 and 66 are frusto-conical and coaxial and have their adjacent bases coplanar. Preferably the several cathodes are of the same dimensions and have their inner surfaces coated or treated to assure copious emission of electrons therefrom. Each cathode bears against the sloping edge of one of the fingers 64 on the uprights 62 and has one of its bases abutting the lateral edge of another of the fingers 64. The cathodes may be locked to the fingers 64 by integral flanges or projections 67 clamped thereagainst.

Disposed adjacent the lowermost secondary cathode 66^4 is a collector electrode or anode 68 which may be a metallic annulus having spaced clips 69 thereon frictionally fitted in slots in the uprights 62. Preferably the collector electrode or anode 68 is mounted coaxially with the cathodes 65 and 66 and at right angles to the axis of alignment of the electrodes.

A screen or shield electrode 70 is disposed between the secondary cathode 66^4 and the anode or collector electrode 68 and comprises an annular mesh disc parallel to the collector electrode and having affixed thereto spaced clips 71 which are securely fitted in slots in the insulating uprights 62.

Electrical connection to the various electrodes may be established through wires 72 each connected to one of the electrodes and to one of a plurality of leading-in conductors 73 sealed in the annular flange 58 and projecting therefrom. The wires 72 may be encased in insulating material such as glass sleeves 74.

Extending between the spiders 61 and 63 is a triangular hollow insulating pillar or support 75 which may be composed, for example, of strips of mica or the like fitted at their ends in channels in the spiders. The pillar or support 75 carries a plurality of frusto-conical electrodes 76^1 to 76^5 inclusive, one for each of the cathodes 65 and 66, which are coaxial with one another and with the cathodes 65 and 66 and each of which is of the same length as the cathodes. The electrodes 76 encircle the support 75 and are provided with flanges 77 frictionally fitted in slots in the strips of which the support is composed. Preferably the electrodes 76 are of the same dimensions. Electrical connection to the electrodes 76 may be established through conductors 78 disposed within the pillar or support 75 and each connected to one of these electrodes and to one of the leading-in conductors 73. The portions of the conductors 78 within the support 75 may be insulated from one another by encasing insulated members such as glass sleeves 79.

The enclosing vessel 10 of the device shown in Figs. 6 and 7 may be encircled by a field coil such as the coil 26.

During operation of the device, the secondary cathodes 66, screen electrode 70, and anode or collector electrode 68 are maintained at successively increasing positive potentials with respect to the primary cathode 65. The auxiliary electrodes 76 also are operated at successively increasing positive potentials, each of these electrodes being at a positive potential somewhat above that upon the corresponding one of the cathodes 65 and 66. For example, the auxiliary electrode 76^1 may be at a potential of the order of 135 volts positive with respect to the primary cathode, and the electrode 76^2 may be at a positive potential of the order of 135 volts above that upon the electrode 76^1 and hence of the order of 135 volts positive with respect to first secondary cathode 66^1. The other auxiliary electrodes 76^3 to 76^5 may be at potentials equally more positive with respect to the secondary cathodes 66^2 to 66^4 respectively.

The operation of the device shown in Figs. 6 and 7 is substantially the same as that of the device shown in Fig. 1 and described in detail heretofore. The electrons emanating from each of the cathodes 65 and 66 come under the influence of at least three forces, namely, that of the magnetic field, of the potentials upon the cathodes and the collector electrode and of the potentials upon the auxiliary electrodes, the resultant of the forces being such that the electrons traverse spiral or arcuate orbits in passing from one of the cathodes toward the next adjacent electrode.

The various electrodes may be connected in circuit as shown in Fig. 8. The cathodes 65 and 66 and the screen electrode 70 may be connected to equally spaced taps on a potentiometer 27 supplied by a suitable source such as a rectifier 28. The anode or collector electrode 68 may have a suitable potential applied thereto from a separate source such as a battery 29. Each of the auxiliary electrodes 76^1 to 76^4 is connected, as shown, to the next succeeding secondary cathode and the auxiliary electrode 76^5 is connected to the screen electrode 70. The primary cathode 65 may be energized by a light beam emanating from a suitable light source 30.

In the amplifier circuit shown in Fig. 8, the electrodes 65 and 66 are operated as cathodes and the electrodes 76 serve primarily to provide a field substantially normal to the emitting surfaces of the cathodes 65 and 66. These electrodes may be operated also in the reverse relation; that is to say, the outer surfaces of the electrodes 76 may be coated or treated to allow copious electron emission therefrom and the electrodes 65 and 66 may be left uncoated. The electrodes 76 may then be operated as cathodes, the electrode 76^1 serving as the primary cathode and the electrodes 76^2 to 76^5 serving as secondary cathodes, and the electrodes 65 and 66 may be operated at positive potentials, each at a potential somewhat above that of the electrode 76 laterally opposite.

In another arrangement, both the electrodes 65 and 66 and the electrodes 76 may be operated as cathodes. That is, the electrodes 65 and 66 may have their inner surfaces treated or coated and the electrodes 76 may have their outer surfaces similarly coated or treated. The potentials upon the electrodes then may be so related that electrons emanating from the outer electrodes impinge upon the inner electrodes to cause the release of secondary electrons therefrom and vice versa. For example, the electrode 65 may be utilized as the primary cathode and the electrons emitted therefrom directed to and impinge upon the cathode 76^1 to cause the release of secondary electrons therefrom. These secondary electrons are directed to and impinge upon the electrode 66^1 to cause the release of other secondary electrons therefrom. This action is repeated along the electrode structure, an electron multiplication and hence amplification obtaining at each of the electrodes 66 and 76.

Although specific embodiments of this invention have been shown and described, it will be understood, of course, that they are merely illustrative of the invention and that various modifications may be made therein. For example, although devices having four and five secondary cathodes have been illustrated, a greater or lesser number may be utilized depending upon the degree of amplification desired. Also, although the primary cathodes have been disclosed as of the photoelectric type, other types such, for example, as thermionic, directly or indirectly heated may be used, and a separate control electrode or grid may be employed to vary the intensity of the electron stream from the primary cathode to the next adjacent secondary cathode. Moreover, the auxiliary electrode 22 may be of magnetic material and permanently magnetized to produce a field thereadjacent and directed toward the collector electrode. Furthermore, the primary cathodes may be coated or treated on their exterior surfaces instead of their interior surfaces and the anode or collector electrode suitably mounted in cooperative relation to the exterior surface of the secondary cathode nearest thereto. Other modifications may occur to those skilled in the art without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising an enclosing vessel, a stem having an annular flange intermediate the ends thereof, a plurality of leading-in conductors sealed in said flange, a supporting frame within said vessel, means mounting said frame on said stem, a primary cathode, a collector electrode and a plurality of secondary cathodes disposed in alignment and affixed to said frame, conductors connecting said electrodes to said leading-in conductors, and insulating means encasing said connecting conductors.

2. Electron discharge apparatus comprising a primary cathode, a collector electrode, and a plurality of superposed frusto-conical auxiliary electrodes between said cathode and said collector electrode and having portions thereof adapted to emit secondary electrons, said auxiliary electrodes being coaxial and partially nested.

3. Electron discharge apparatus comprising an enclosing vessel having a stem, a plurality of insulating uprights extending above said stem and longitudinally of said vessel, a primary cathode, a collector electrode, a plurality of coaxial annular secondary cathodes mounted between said uprights and disposed between said primary cathode and said collector electrode, a coating of electron emissive material on the inner surface of said secondary cathodes, and supporting members

projecting outwardly from said secondary cathodes and affixed to said uprights.

4. Electron discharge apparatus comprising a stem, a primary cathode, a collector electrode, a plurality of annular secondary cathodes between said primary cathode and said collector electrode, a plurality of insulating uprights extending from said stem, means supporting each of said secondary cathodes from a corresponding one of said uprights, and individual leading-in conductors for said secondary cathodes extending through said uprights.

5. Electron discharge apparatus comprising a primary cathode, a collector electrode, a plurality of separate annular secondary cathodes mounted in end to end relation between said primary cathode and said collector electrode, and electrode means within said secondary cathodes, said electrode means and said secondary cathodes having the opposed surfaces thereof at an oblique angle to one another whereby said means when energized produces an electrostatic field at an oblique angle to said secondary cathodes, adjacent ends of successive secondary cathodes being in immediate proximity.

6. Electron discharge apparatus comprising a primary cathode, a collector electrode, a plurality of superposed annular secondary cathodes between said primary cathode and said collector electrode, said secondary cathodes being coaxial with one another and in alignment with said primary cathode, individual leading-in conductors for said secondary cathodes, and a plurality of electrodes mounted in end to end relation within said secondary cathodes and coaxial therewith for causing electrons emanating from said cathodes to flow toward and impinge upon the next succeeding cathode toward said collector electrode, each secondary cathode extending at least to the boundary of the nearest end of the preceding cathode.

7. Electron discharge apparatus comprising a primary cathode, a collector electrode, a plurality of superposed annular secondary cathodes between said primary cathode and said collector electrode, and a plurality of superposed auxiliary electrodes laterally opposite said secondary cathodes.

8. Electron discharge apparatus comprising a primary cathode, a collector electrode, a plurality of superposed, coaxial annular secondary cathodes between said primary cathode and said collector electrode, and a plurality of superposed annular auxiliary electrodes coaxial with said secondary cathodes and laterally opposite said secondary cathodes.

9. Electron discharge apparatus comprising a primary cathode, a collector electrode, a plurality of superposed coaxial frusto-conical secondary cathodes between said primary cathode and said collector electrode, and a plurality of superposed coaxial annular auxiliary electrodes each laterally opposite one of said secondary cathodes.

10. Electron discharge apparatus comprising a primary cathode, a collector electrode, and a plurality of rows of auxiliary electrodes between said cathode and said collector electrode, one of said rows being disposed within another, and the auxiliary electrodes in one of said rows being adapted to emit secondary electrons.

11. Electron discharge apparatus comprising a primary cathode, a collector electrode, and a pair of coaxial rows of coaxial annular auxiliary electrodes between said cathode and said collector electrode, one of said rows being within the other, and the auxiliary electrodes in one of said rows having electron emitting surfaces directed toward the electrodes in the other of said rows.

12. Electron discharge apparatus comprising a primary cathode, a collector electrode, and a pair of coaxial rows of coaxial frusto-conical auxiliary electrodes between said cathode and said collector electrode, said rows of electrodes being disposed one within the other, and the electrodes in one said rows having electron emitting surfaces facing the electrodes in the other of said rows.

13. Electron discharge apparatus in accordance with the next preceding claim wherein the electrodes in said rows taper in opposite directions.

14. An electron multiplier comprising a primary cathode, a collector electrode, a plurality of secondary cathodes between said primary cathode and said collector electrode, a plurality of auxiliary electrodes for producing an electrostatic field adjacent said primary and secondary cathodes, and means for producing a magnetic field adjacent said primary and secondary cathodes and decreasing in intensity toward said collector electrode.

15. An electron multiplier comprising an annular primary cathode, a plurality of separate annular secondary cathodes in end-to-end relation, having adjacent ends thereof in immediate proximity, and mounted coaxial with one another and with said primary cathode, a collector electrode, and means including a metallic member within said secondary cathodes for producing a magnetic field thereadjacent.

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