Jan. 20, 1925. 1,523,776

A. W. HULL

ELECTRIC DISCHARGE DEVICE

Filed Jan. 29, 1920 2 Sheets-Sheet 1

Fig. 1.

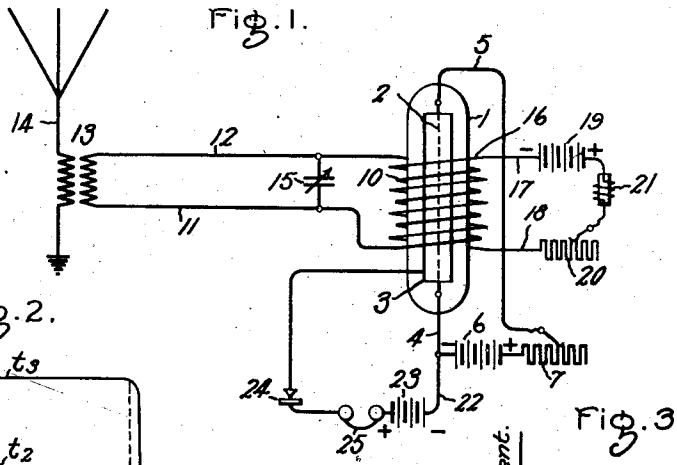


Fig. 2.

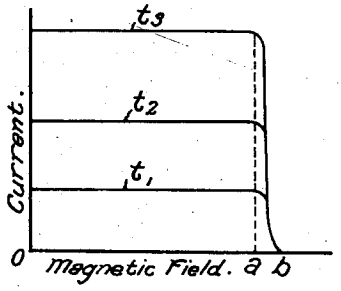


Fig. 1A



Fig. 1B.

Fig. 3.

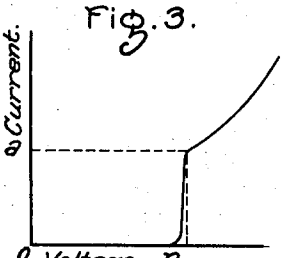


Fig. 5.

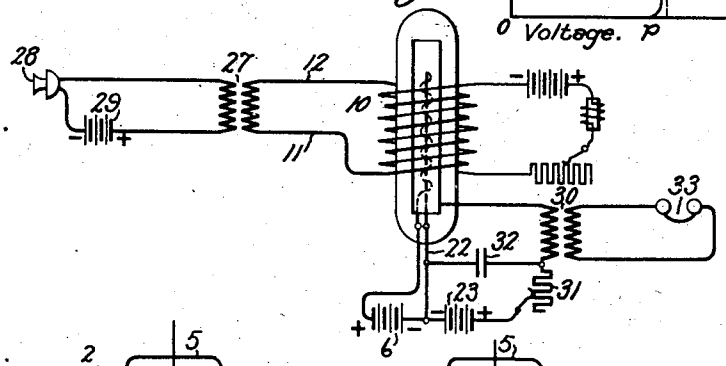
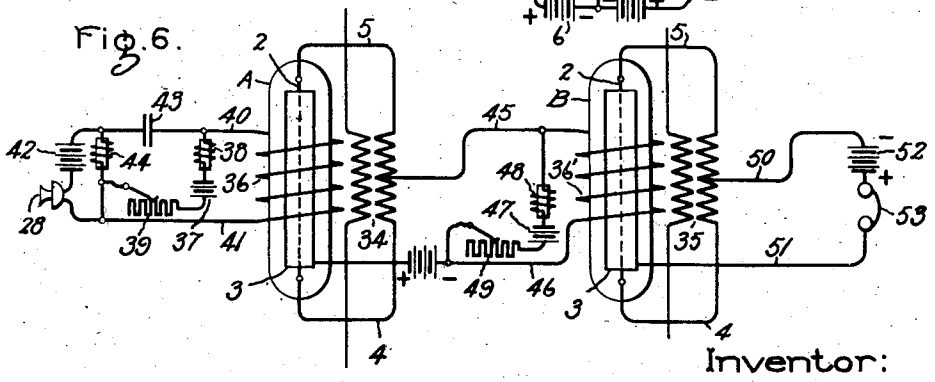


Fig. 6.



Inventor:
Albert W. Hull,
by Albert G. Davis
His Attorney.

Jan. 20, 1925. 1,523,776

A. W. HULL

ELECTRIC DISCHARGE DEVICE

Filed Jan. 29, 1920 2 Sheets-Sheet 2

Fig. 7.

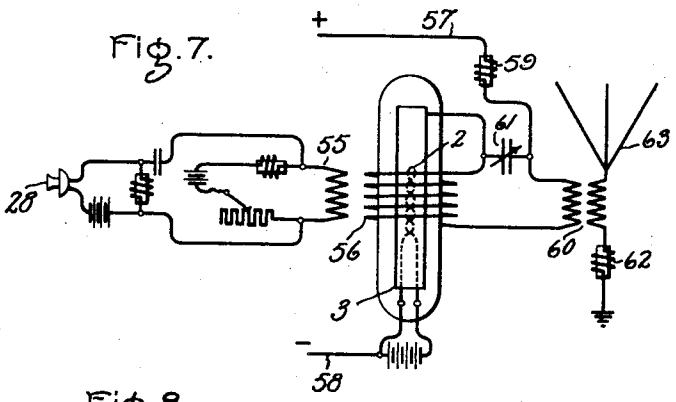


Fig. 8.

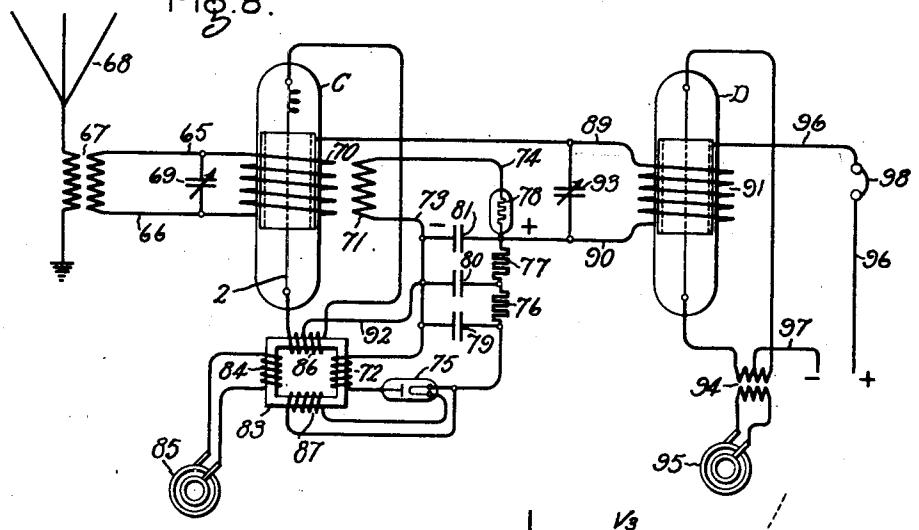
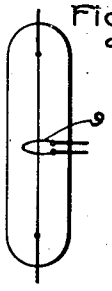


Fig. 9.



Fig. 10.



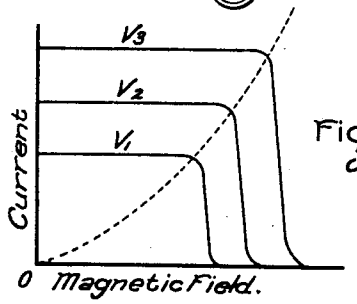


Fig. 4.

Inventor:
Albert W. Hull,
by Albert G. Davis
His Attorney.

Patented Jan. 20, 1925. 1,523,776

UNITED STATES PATENT OFFICE.

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

ELECTRIC DISCHARGE DEVICE.

Application filed January 29, 1920. Serial No. 354,914.

To all whom it may concern:

Be it known that I, ALBERT W. HULL, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electric Discharge Devices, of which the following is a specification.

The present invention relates to an electric discharge device and the controlling and amplifying of electrical currents by means of vacuum tubes.

It has been proposed heretofore to control an electric discharge in a partially evacuated tube by means of a magnetic field. In this case the current depended upon gas ionization and the effect of an increasing magnetic field was to increase the current.

I have discovered that in a properly constructed and sufficiently evacuated device a properly applied magnetic field may be made to reduce the current carrying capacity of the space, and that by a suitable arrangement the current may be reduced from a large value to substantially zero by a slight increase of magnetic field.

My invention comprises a novel device consisting of an evacuated envelope containing an electron-emitting cathode and an anode, provided with means for generating a magnetic field for controlling the current between cathode and anode, and also a method of controlling an electron current by a magnetic field.

In a more specific aspect my device contains a cathode adapted to emit electrons independently of gas ionization and an anode contained in an evacuated envelope, and an electrical winding for producing and controlling a magnetic field whereby the electron current from the cathode to the anode may be varied or reduced to substantially zero. These and other aspects of my invention will be pointed out with more particularity in the appended claims. For a more detailed description of my invention, reference may be had to the following description taken in connection with the accompanying drawings.

In the drawings, Fig. 1 illustrates diagrammatically one embodiment of my invention used as an amplifier of radio signals; Figs. 1^A and 1^B are detail cross-sectional views of the anode structures; Figs. 2, 3 and 4 are diagrams showing electrical characteristics of my device; Fig. 5 illustrates diagrammatically an embodiment of my invention in a telephone repeater; Fig. 6 illustrates diagrammatically a series connection of amplifiers utilizing alternating current for heating the cathode; Fig. 7 illustrates a radio-telephone transmitting system for producing modulated high frequency oscillations; Fig. 8 is a radio-receiving system in which the new device is used as an amplifier and as a detector, and which illustrates other features of my invention; and Figs. 9 and 10 are diagrammatic views of modifications of tubes embodying my invention.

Fig. 1 illustrates one form of device embodying my invention comprising an elongated glass tube 1, containing a filamentary cathode 2 adapted to be heated to incandescence, and a surrounding concentric slotted cylinder 3 constituting the anode. The cathode is substantially equidistant from the anode at all points along its length and in general this structure is preferred in devices embodying my invention. The cathode 2 is adapted to emit electrons independently of the passage of the space current through the device. It consists of a suitable refractory material, preferably tungsten, and is connected by the conductors 4, 5, to a suitable source of electric current, such, for example, as a battery 6. A regulable series resistance 7 may be provided to control the heating current and thereby the temperature and electron emission of the cathode. The space within the envelope is evacuated and the parts within the envelope are deprived of gas to such extent that an electron discharge can occur therein substantially independent of gas ionization. A slight amount of gas ionization will do no harm and may improve the operation of the device by reducing space charge. If the gas pressure is too high, for example, so high as to enable a discharge to occur by ionization with a cold cathode, then the mean free paths of the electrons become so short that they are not controllable by a magnetic field in the manner described.

The anode conveniently may also consist of tungsten, but various other materials, for example molybdenum, copper or nickel, may also be used. The cylindrical anode is

slotted, as shown in Figs. 1^A and 1^B, to prevent the anode from screening the space between anode and cathode from the variable field produced by coil 10. A metallic deposit on the glass wall of the envelope may be used as anode instead of a metallic cylinder.

The electrodes in the device shown in Fig. 1 are arranged in circular or rotational symmetry with respect to each other. Such an arrangement is a desirable although not a necessary attribute of a device embodying my invention. By circular or rotational symmetry I mean an arrangement such that the surfaces of the cathode and the anode are substantially surfaces of revolution about a common axis which is preferably the major axis of the container. For example, a cathode construction whereby substantially circular symmetry is obtained is shown in Figs. 5 and 7.

In the construction shown in Fig. 5 the cathode has the form of a helix, and in Fig. 7 it has the form of a double helix. When the anode is relatively large the cathode may have a shape widely departing from a surface of revolution without losing the attribute of circular symmetry. For example, as shown in Fig. 9, the cathode may consist of two wires 8 in the form of a V without losing the attribute of circular symmetry providing the wires are close enough together so that the electric field between the cathode and the anode is essentially radial. The anode likewise may assume various forms without losing the attribute of circular symmetry. For example, the anode may consist, as shown in Fig. 10, of a substantially circular loop of wire 9 surrounding the cathode.

Surrounding the envelope 1 is some suitable means for generating a variable magnetic field. In the embodiment of my invention shown in Fig. 1, the tube is surrounded by a solenoid 10. This solenoid is connected to the conductors 11, 12, which receive current from the secondary winding of a transformer 13. The primary winding of the transformer 13 is connected in series with a grounded aerial 14. Connected across the conductors 11, 12, is a variable condenser 15 whereby the resonance of the input circuit 11, 12 may be varied as desired.

Surrounding the envelope 1 is a second magnetic coil 16 which is supplied with direct current through the conductors 17, 18, by a battery 19. Desired adjustments of energizing current are made by an adjustable resistance 20. It is the function of the coil 16 to generate a polarizing field of desired value upon which is superimposed the fluctuating or variable magnetic field generated by the coil 10, thereby varying the electron current, as hereinafter explained. A choke coil 21 prevents the circulation of high frequency current induced in the coil 16. The output circuit 22 contains a source of direct current represented by a battery 23, a suitable detector as represented by a crystal 24, and a receiving instrument, as, for example, the telephone receiver 25.

When the cathode 2 is maintained at suitable incandescence by the heating current and a suitable voltage is impressed upon the electrodes, a current flows in the output circuit 22. With no modifying magnetic field, the value of this current is determined by various factors, among which are the impressed voltage, the cathode temperature, the size and geometrical relations of the electrodes, and the resistance of the output circuit. The electrons which carry or constitute this current travel outwardly in straight radial paths from the cathode to the surrounding anode. When a magnetic field is generated substantially parallel to the cathode and hence substantially at right angles to the electric field between the electrodes, then the electrons are deflected and caused to travel in a spiral path about the cathode on their way to the anode. As the field strength is increased the spiral path of the electrons becomes longer until finally at a critical magnetic field strength characteristic of any particular device, some of the electrons fail to reach the anode by reason of this deflection, thereby resulting in a decrease of current. When the field strength is still further increased, above this critical value, the electron current rapidly falls and is finally reduced substantially to zero. In order to express the fact that the electrons are prevented from flowing through the space, as distinguished from deflection, to another electrode, I may say that the effective electron emission or generation is reduced or entirely suppressed.

This relation between magnetic field and current transmitted by the device is indicated for different cathode temperatures by the diagram constituting Fig. 2, the values of the magnetic field being plotted as abscissæ and the corresponding current values as ordinates, the impressed voltage being constant. It will be observed that with any given filament temperature as the strength of the magnetic field is increased from zero, the current remains substantially constant until the magnetic field has reached a value represented as *oa*. A further increase of field strength produces a rapid reduction of current until by a relatively small increase of field strength *ob* the current is reduced substantially to zero. The branches of the curves designated as t_1, t_2 and t_3 refer to different temperatures of the cathode. The maximum value of the current may be limited either by the electron emissivity of the cathode or by space charge

without departing from the characteristic shown in Fig. 2. For example, the curves t_1 and t_2 may be assumed to refer to temperatures such that the maximum current is limited by the electron emissivity and the curve t_3 may be assumed to refer to a temperature so high that the maximum electron current is limited by space charge.

If the polarizing field generated by the coil 16 is fixed at some value between *oa* and *ob*, then even a small change of field strength caused by a variation of field generated by the coil 10 will cause a relatively great variation in the current transmitted by the device.

The volt-ampere characteristic of the device with a constant magnetic field is shown in Fig. 3. It will be observed that no current passes until the voltage has risen to a critical value, *op*, depending on the value of the applied magnetic field. An increase of voltage above *op* causes a very rapid increase in current up to a critical current value *oa*, characteristic of the device. A further increase of voltage causes the current to rise as a 3/2 power function of the voltage up to a saturation current not indicated in the figure.

Fig. 4 represents by three curves the relation between current and magnetic field at different constant electrode voltages designated by V_1, V_2 and V_3, the cathode temperature being assumed to be sufficiently high so that the current is limited by space charge. The dotted line drawn from zero through the knees of the curves V_1, V_2 and V_3 has substantially the form of a parabola. For the sake of convenience, I will refer to the device above described by the name of "magnetron" by which it has become known to engineers.

In the radio receiving system shown in Fig. 1, signals received by the aerial 14 produce a variation of the current in the plate circuit 22 in amplified measure providing the polarizing field has been properly adjusted. A suitable rectifying detector 24, shown symbolically as a crystal, renders the signals audible by a telephone receiver 25. As will hereinafter be described in connection with Fig. 8, the magnetron may itself be used as a detector of radio signals.

In Fig. 5 is illustrated a system for amplifying current of audio frequency in a wired telephone system. The terminal conductors 11, 12 of the coil 10 are connected to the secondary of a transformer 27, the primary of which is connected to a transmitter 28 in circuit with a battery 29. The output circuit 22 of the tube is connected to the primary of a transformer 30, and contains a battery 23 and an adjustable resistance 31. A condenser 32 is connected across the series combination of the battery and the resistance 31 to offer a low resistance path for the audio frequency current. The secondary of the transformer 30 is connected to a telephone receiver 33.

In the telephone amplifier system shown in Fig. 6 several additional features of my invention are embodied. In this system two magnetrons A and B are connected in series or cascade to amplify current undulations produced by the telephone transmitter 28. The cathode filaments of the magnetrons A and B are heated by alternating current supplied by transformers 34, 35, respectively, to the secondary windings of which the cathode conductors 4, 5 are directly connected.

In the magnetrons shown in this figure the functions of the polarizing and control field windings of devices A and B are combined in single windings 36 and 36′, respectively. The polarizing field of the tube A is produced by a battery 37, connected in series with a choke coil 38, and an adjustable resistance 39 across the conductors 40, 41. A transmitter 28 is connected in series with a battery 42 and a condeser 43 to the input circuit conductors 40, 41. Current of audio frequency will pass through the condenser 43 but is kept out of the polarizing circuit by the choke coil 38 while the polarizing unidirectional current is prevented from flowing in the transmitter circuit by a condenser 43. The direct current component of the transmitter current will flow in the circuit of the inductance coil 44.

The circuit 45, 46, joining the output circuit of the magnetron A to the input circuit of the magnetron B is connected to the middle point of the secondary winding of the transformer 34, so that the anode 3 will be at an average potential with respect to the cathode. The polarizing field of the amplifier B is produced by a battery 47 connected in series with a choke coil 48 and a resistance 49 across the conductors 45, 46. The output circuit 50, 51, connected between the anode of the magnetron B and the middle point of the secondary of the transformer 35 contains a battery 52 and a telephone receiver 53.

In Fig. 7, I have shown my new device in connection with a radio-telephone system. The magnetron is used in this system to generate high frequency oscillations modulated by an audio frequency current.

The magnetron shown in Fig. 7 is provided with two magnetic windings 55 and 56. The winding 55 for convenience is shown on the drawing apart from the tube but it is to be understood that the field of this winding is interlinked in any desired way with the field of the winding 56 as shown for example in Fig. 1. The winding 55 combines the functions of a polarizing winding and a control winding as already

described in connection with the windings 36 and 36′ of Fig. 6. As the connections of the telephone transmitter 28 to the winding 55 is identical with the corresponding connection of Fig. 6 no further explanation is necessary.

The winding 56 is connected in series with the electrodes 2, 3, to a source of direct current (not shown) by the conductors 57, 58. Included in the conductor 57 is a choke coil 59 and the primary winding of a transformer 60. An adjustable condenser 61 is connected in shunt to the coil 56 and the transformer primary. The secondary winding of the transformer is connected in series with a choke coil 62 in a grounded antenna 63. With proper tuning high frequency oscillations are produced by the action of the coil 56 on the electron current, these oscillations being modulated by the coil 55. If unmodulated oscillations are desired the coil 55 and its circuit members are omitted.

The radio receiving system of Fig. 8 employs two magnetically controlled tubes, a magnetron C being used as an amplifier and the magnetron D being used as a detector.

The input circuit 65, 66 of the tube C is connected to the secondary winding of a transformer 67, having its primary winding connected in series with a grounded antenna 68. An adjustable condenser 69 is connected in shunt to the control winding 70. The polarizing winding 71 is supplied with rectified current derived from the transformer winding 72 through the conductors 73, 74 containing a rectifier 75, two series connected resistances 76, 77 and a ballast resistance 78 which steadies the current. Connected across the circuit, as indicated, are condensers 79, 80, 81 which with the resistances 76, 77, 78 constitute a capacity-resistance filter to smooth out the undulating rectified current. The core 83 of the transformer has a primary winding 84 supplied with current by an alternating current generator 85. A secondary winding 86 supplies the cathode 2 of the tube C with heating current and a winding 87 supplies the cathode of the hot cathode rectifier 75 with heating current.

The output circuit 89, 90 is connected to the winding 91 of the tube D, the conductor 90 being carried to the middle point of the winding 86 by the conductor 92 in series with the condenser 81. Resonance is secured by an adjustable condenser 93. The cathode of the tube D is heated by alternating current from a transformer 94. The output circuit 96, 97 is connected in series with a suitable direct current source (not shown) to an indicator 98, such, for example, as a telephone receiver.

The ampere turns of the winding 91 upon the magnetion D are so chosen that the magnetic field produced thereby is at the critical polarizing value described in connection with Fig. 1, at which an increase of field strength produces a decrease of current. Hence a signal received by the antenna and amplified by the tube C produces on increase of magnetic flux of the winding 91 and a decrease of current in the circuit 96, 97, which is audibly or otherwise indicated.

Devices embodying my invention are stable and reproducible, are operable over a wide range of impressed voltages and a small variation of magnetic field above the critical value produces a relatively large variation of space current in the device. These properties render the device particularly advantageous as an amplifier, and for other purposes. As distinguished from the three-electrode magnetically-controlled electron device of my prior Patent 1,387,985 issued August 16, 1921, my present device requires essentially but two main electrodes and the space between these electrodes is unobstructed. The variation and control of the current between the electrodes occurs solely by the action of the magnetic field as distinguished from the interception of electrons by an intermediate electrode.

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

1. A vacuum tube of the pure electron discharge type having a cathode adapted to emit electrons in combination with means for impressing upon the space surrounding said cathode a magnetic field in such direction that when said field has a sufficient magnitude a reduction in the value of the effective electron emission of said cathode will occur and means for varying said field.

2. An electron discharge apparatus comprising a vacuum tube of the thermionic type, cooperating electrodes therein including a cathode adapted to emit electrons independently of gas ionization, means for impressing a magnetic field upon an electron current in said tube, said means being so positioned with respect to said electrodes that a small increase of field strength above a critical value at a given operating voltage will cause the effective emission of said cathode to be reduced and means for varying said magnetic field within an operating range above said critical value.

3. An electric device comprising a cathode adapted to emit electrons independently of positive ionization, an anode, an enclosing sealed envelope, the space and parts within said envelope being freed from gas to such extent that transfer of energy between said electrodes occurs substantially independently of positive ionization, means for subjecting the space between said electrodes to a magnetic field of sufficient strength to pro-

duce a decrease of current flow between said electrodes at a given voltage and means for superimposing a variable field upon said field.

4. A discharge device comprising a plurality of electrodes, one of which is adapted to emit electrons independently of gas ionization, an enclosing sealed envelope, means for impressing a magnetic field upon the space between said electrodes, said field being spacially so related to said electrodes and said device being sufficiently evacuated so that an increase of the effective strength of said field above a critical value materially decreases the current carrying capacity of said device.

5. An electric device comprising an electron-emitting cathode, a cooperating electrode, an enclosing sealed envelope, said device being freed from gas to such extent that passage of current across the space between said electrodes take place substantially independent of gas ionization, electromagnetic control means for varying an electron current between said electrodes, the electrodes and magnetic means being spacially so related that an increase of magnetic field above a critical value produces a decrease of current.

6. An electric device comprising a cathode operable at incandescence, an anode arranged in unobstructed spacial relation to said cathode, an enclosing evacuated envelope, means for generating a magnetic field of predetermined value substantially parallel to said cathode, and of such strength that an increase of field strength produces a decrease of current at a given operating voltage, and means for varying said magnetic field.

7. An electric device comprising a cathode adapted to emit electrons independently of ionization effects, an anode located in unobstructed relation to said cathode, an enclosing evacuated envelope, means for generating a polarizing magnetic field for controlling the passage of electrons from said cathode to said anode, said electrodes being so positioned and the space within said envelope being sufficiently evacuated and the effective value of the magnetic field being so chosen with respect to a given electrode voltage that an increase of magnetic field above a critical value produces a decrease of current, and means for superimposing upon said field a variable magnetic field for varying the current transmitted by said device.

8. An electron discharge device comprising electrodes so positioned in rotational symmetry with respect to one another that the electron flow may assume straight unobstructed radial paths therebetween, magnetic means spacially so positioned with respect to said electrodes that a magnetic field may be generated thereby which will be substantially at right angles to an electron discharge occurring therebetween, and an envelope enclosing said electrodes, said envelope being evacuated to a residual gas pressure so low that the operation of said device will be substantially unaffected by ionization.

9. An electric discharge device comprising an electron emitting cathode, and an anode, said cathode being substantially equidistant from the anode at all points, an enclosing sealed envelope, means for generating an electromagnetic field normal to the path of electrons passing from said cathode to said anode, the degree of evacuation of the tube being such that an increase of the magnetic field will cause a decrease in space current, a load circuit connected to said electrodes, and an input circuit connected to vary said electromagnetic field.

10. In combination, an electron discharge apparatus adapted to operate substantially independently of gas ionization, the electrodes of which are constituted exclusively by a cathode adapted when heated to emit electrons and an anode surrounding said cathode and arranged in substantially circular symmetry with respect to said cathode, the space between said electrodes being unobstructed, means for producing a magnetic field in a direction parallel to the axis of symmetry of said electrodes, and a load circuit connected to said anode.

11. An electron discharge device having electrodes constituted solely by a cathode capable of emitting electrons independently of gas ionization, an anode normally receiving substantially the entire discharge from said cathode, means for generating a magnetic field at right angles to the path of the electron discharge between said cathode and anode, and means for varying said field between a value at which an electron discharge flows between said electrodes and a higher value at which the current is reduced substantially to zero.

12. In combination, an electron discharge device comprising an evacuated envelope, electrodes therein constituted exclusively by an electron emitting cathode and a cylindrical anode arranged in circular symmetry about said cathode leaving the intervening space unobstructed for the passage of electrons, a load circuit connected to said anode and means for producing a magnetic field in a direction parallel to the axis of symmetry of said electrodes for controlling the flow of electrons from said cathode to said anode, the relation of the parts of said device to the gas residue being such that the device is capable of operation substantially unaffected by gas ionization.

13. An electron discharge device comprising electrodes one of which is arranged in rotational symmetry with respect to the

other and normally carrying substantially all of the current during operation, the intervening space being unobstructed, an enclosing envelope which is evacuated sufficiently to permit a discharge to pass between said electrodes without substantial gas ionization, means for generating a magnetic field at substantially right angles to the general direction of flow of electrons between said electrodes and means for varying said field between a lower value at which the electron current is substantially unaffected and a higher value at which the electron current is reduced to substantially zero.

14. An electric discharge device comprising main current-carrying electrodes arranged in circular symmetry in unobstructed relation about a main axis, a container therefor evacuated sufficiently to prevent gas ionization discharges therein, means for producing an electromagnetic field normal to the discharge path between said electrodes whereby an increase of field strength from zero to a critical value produces no substantial change of electron current obtainable with a given voltage applied to said electrodes and at field values above said critical value produces a rapid decrease of electron current with a progressive increase of said field.

15. An amplifier comprising the combination of a discharge device comprising an electron-emitting cathode, an anode arranged in circular symmetry about said cathode and means for impressing a magnetic field upon the space between said electrodes, the degree of evacuation of said device being such that an increase of effective field strength above a critical value causes a decrease of current, means for varying the strength of said magnetic field within the range over which changes of effective field strength are accompanied by changes in current carrying capacity of said device, an input circuit connected to said magnetic means, an output circuit connected to said cathode and anode, a source of current in said output circuit and a translating device in said output circuit.

16. An electric discharge device having two electrodes only, one of which is a cathode adapted to emit electrons independently of gas ionization, the space between said electrodes being unobstructed, an enclosing evacuated envelope and means for generating a magnetic field normal to the discharge path between said electrodes.

17. An electric discharge device containing two electrodes only, one of which is a cathode adapted to emit electrons independently of positive ionization, the space between said electrodes being clear to permit unobstructed passage of electrons, an enclosing evacuated envelope, means for impressing a magnetic field upon the space between said electrodes, the magnitude of said field and the degree of evacuation of said device being such that an increase of effective strength of said field above a critical value produces a decrease of current, and means for varying the effective strength of said magnetic field.

18. An amplifier comprising the combination of a discharge device comprising an electron-emitting cathode, an anode, and means for impressing a magnetic field upon the space between said electrodes, the degree of evacuation of said device being such that an increase of effective field strength above a critical value causes a decrease of current, an input circuit connected to said magnetic means, an output circuit connected to the electrodes of said device, a source of current in said output circuit, and a translating device in said output circuit.

19. The method of operating an electron discharge apparatus comprising an electron-emitting cathode and an anode arranged in circular symmetry directly about said cathode which consists in setting up a magnetic field parallel to said cathode, and increasing the strength of said field beyond a critical value characteristic of the device whenever a reduction in current-carrying capacity of said apparatus is desired.

20. The method of controlling the passage of current in a device having an evacuated receptacle containing an anode and a cathode capable of emitting electrons independently of an impressed voltage which consists in applying a voltage between cathode and anode, impressing a magnetic field substantially parallel to said cathode and producing variations in the strength of said field between a critical value at which an increase of field strength decreases the current and a saturation value of magnetic field strength at which substantially no electron current flows.

21. The method of controlling the passage of current in a device having an electron-emitting cathode and an anode which consists in impressing a voltage between said electrodes to produce current flow between the same, impressing substantially parallel to said cathode a varying magnetic field and maintaining the gaseous pressure about said electrodes so low that a variation of magnetic field produces a variation of current between said electrodes in an inverse sense.

22. The method of controlling current in a circuit which consists in causing the emission of electrons from a cathode in said circuit independently of gaseous ionization, producing a flow of electrons from said cathode to an anode in substantially straight radial paths in an evacuated space, and generating a magnetic field at right angles to the general course of said discharge, said

field value being made of sufficient magnitude to materially reduce the effective electron emission from said cathode when a reduction of current is desired.

23. An apparatus for modifying electric currents comprising the combination of a device having electrodes adapted to produce an electron discharge, means for magnetically controlling said discharge, an output circuit connected to said electrodes, a second device having electrodes adapted to produce an electron discharge, a second output circuit connected thereto, means for magnetically controlling said second discharge, connections between said first output circuit and the control means for said second discharge, and a translating device in said second output circuit.

24. An apparatus for modifying or controlling electric currents comprising the combination of a set of electrodes arranged in substantially circular symmetry with respect to each other, an enclosing evacuated container, magnetic control means, an input circuit connected to said control means, a second set of electrodes arranged in substantial circular symmetry, magnetic control means therefor, a circuit connecting said first set of electrodes with said second control means, a source of electric energy in said circuit, an output circuit connected to said second set of electrodes, and a source of energy in said output circuit.

25. An apparatus for amplifying variable electric currents comprising the combination of a set of electrodes arranged in substantial circular symmetry with respect to one another, the cathode being adapted to be independently heated to incandescence, an evacuated container therefor, means for generating a magnetic field substantially parallel to said cathode, an input circuit connected to said means, a second set of electrodes comprising an incandescible cathode, an evacuated container therefor, means for generating a magnetic field substantially parallel to said second cathode, a circuit connecting said first set of electrodes with said second magnetic means, a source of direct current in said connecting circuit, choke coils connected in shunt to said respective magnetic control means, a load circuit connected to said second set of electrodes, and a source of energy in said load circuit.

26. An apparatus for amplifying currents of audio frequency comprising the combination of a magnetron, a telephone transmitter connected to the input circuit of said magnetron, a source of direct current in said circuit, a condenser connected in series with said transmitter and source, a second source of energy connected to said input circuit in shunt to said transmitter current source and condenser, a choke coil connected in series with said second source, and a telephonic receiving apparatus connected to the output circuit of said magnetron.

27. A telephone amplifier comprising the combination of a magnetron, a source of current for generating a polarizing field connected to the magnetic control winding of said magnetron, a telephone transmitter also connected to said winding, a condenser connected between said telephone transmitter also connected to said winding, a condenser connected between said telephone transmitter and said source, a transformer connected to heat the cathode of said magnetron, a second magnetron, an electrical circuit connecting the magnetic winding of said second magnetron to the middle point of said transformer, and to the anode of the first magnetron, a source of current in said circuit, a polarizing source of current connected to the magnetic winding of said second magnetron, a choke coil connected in series with said polarizing source, and a telephone receiving circuit connected to the electrodes of said second amplifier.

28. An electric discharge device having two load-carrying electrodes only constituted by a substantially linear cathode and a cylindrical anode located symmetrically about said cathode, an evacuated container therefor, and means for producing a magnetic field substantially parallel to the axis of said anode.

29. An electric discharge device containing two electrodes exclusively, one of which is adapted to emit electrons independently of voltage applied thereto, said electrodes being constituted by a generally rectilinear electrode and a second electrode having the general shape of a surface of revolution about said rectilinear electrode, a container for said electrodes evacuated sufficiently to prevent substantial positive ionization, and means for producing a magnetic field at an angle to the discharge path between said electrodes.

30. An electric discharge device having two electrodes only constituted respectively by a substantial linear filamentary cathode which is adapted to emit electrons when heated, a substantially cylindrical anode located symmetrically about said cathode and means for producing a magnetic field substantially at right angles to an electrostatic field between said electrodes.

31. An electron discharge device comprising an evacuated envelope, electrodes therein constituted exclusively by an electron-emitting cathode, and an anode enclosing said cathode and means for producing a magnetic field in such direction with respect to the general course of electron current between said electrodes that when a constant voltage is applied to said electrodes and the magnetic field strength is progressively increased, the effective electron emis-

sion from said cathode is substantially unchanged up to a definite value of field strength, while with a small increase above said value the effective emission is reduced substantially to zero.

32. An electron discharge device comprising an envelope having the space therein evacuated to a pressure so low that an electron discharge therein may occur without material ionization, a cathode adapted to emit electrons independently of the impressed voltage, a cylindrical electrode located substantially symmetrically about said cathode, means for producing a flow of load current between said electrodes, and means for producing a magnetic field substantially at right angles to the load current between said electrodes, said device having no electrode which may exert an electric field tending to deflect said electrons into a direction parallel to said magnetic field.

33. The method of controlling the current in an electric circuit which consists in producing a substantially pure electron discharge in said circuit, impressing a magnetic field substantially at right angles to said discharge, and varying the strength of said field in response to the current to be controlled between a critical value sufficiently high to cause a decrease of current and a greater value at which substantially no current will pass.

In witness whereof, I have hereunto set my hand this 27th day of January, 1920.

ALBERT W. HULL.