Oct. 20, 1925. 1,558,437

I. LANGMUIR

ELECTRICAL DISCHARGE APPARATUS

Original Filed Oct. 29, 1913 2 Sheets-Sheet 1

Fig. 1.

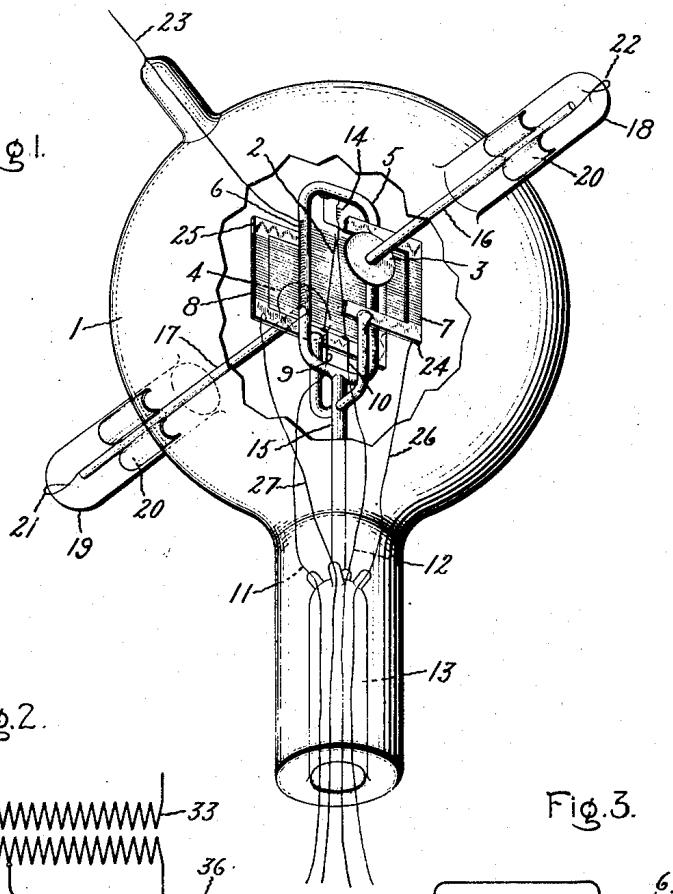


Fig. 2.

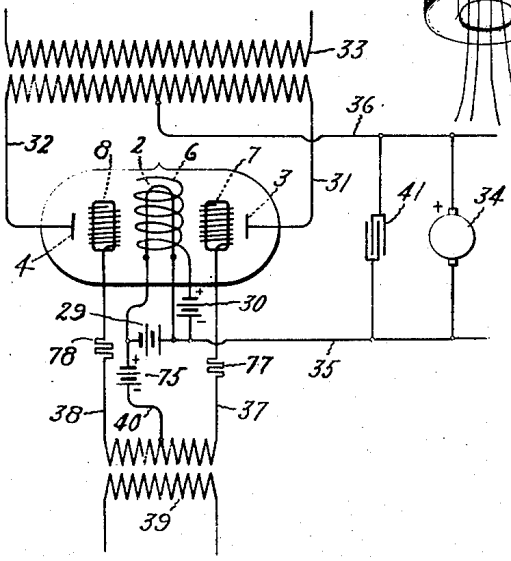
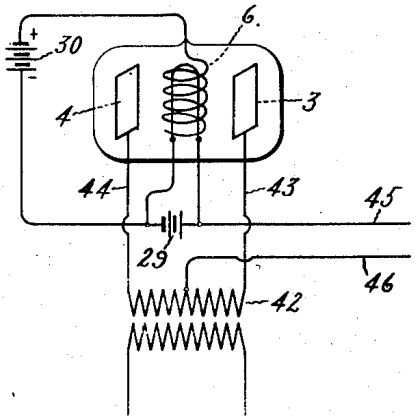


Fig. 3.



Witnesses:
Chas. B. Stokes
J. Ellis Glen.

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney

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Fig. 4.

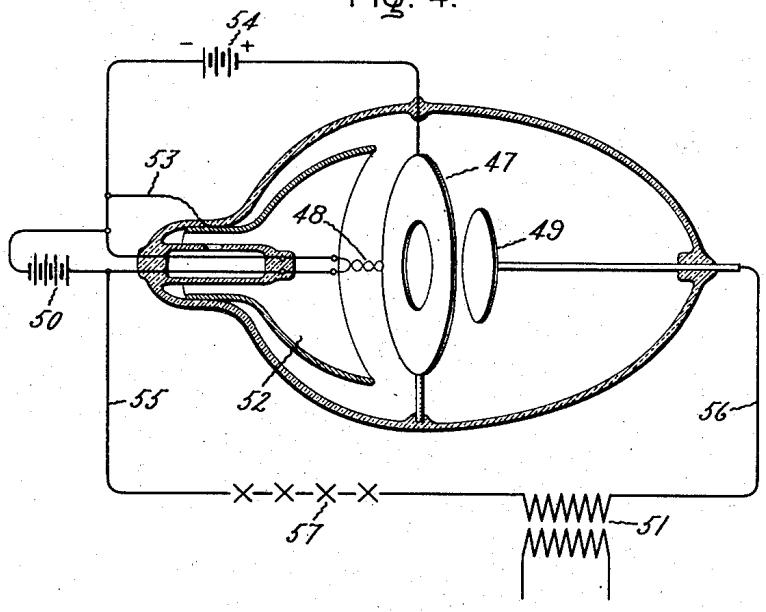
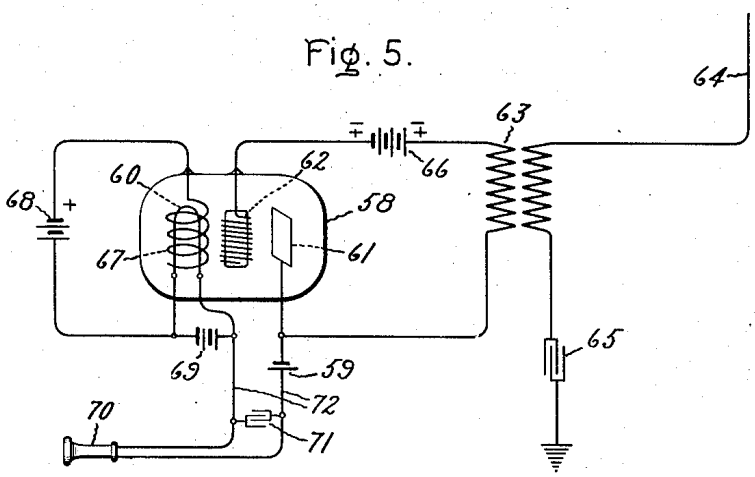


Fig. 5.



Witnesses:
George H. Tilden
J. Ellis Glen.

Inventor:
Irving Langmuir,
by Albert G. Davis
His Attorney.

Patented Oct. 20, 1925. 1,558,437

UNITED STATES PATENT OFFICE.

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

ELECTRICAL DISCHARGE APPARATUS.

Application filed October 29, 1913, Serial No. 797,986. Renewed February 29, 1924.

To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, county of Schenectady, State of New York, have invented certain new and useful Improvements in Electrical Discharge Apparatus, of which the following is a specification.

The present invention relates to electrical discharge apparatus operating with an electron discharge and it concerns particularly the type of device operating without gas ionization and conduction.

Such a device consists essentially of an electron-emitting cathode, and one or more anodes thoroughly freed from gas, located in an envelope evacuated to such a high degree that an electron discharge can take place from the cathode to the anode or anodes without causing appreciable gas ionization by collision with residual gas molecules.

A pure electron discharge consists of negative charges of electricity, ordinarily called "electrons", moving from a cathode to an anode in a highly evacuated space. These electrons may be emitted by a highly incandescent solid or by certain metals illuminated by ultraviolet light, particularly the alkali metals. As each of these electrons is surrounded by a negative electrostatic field and, also when in motion, by a magnetic field, the motion of the electrons is subject to the influence of both electrostatic and electromagnetic forces. For this reason each of the electrons in a given space is influenced by the field of the other electrons in this space, an effect which will hereinafter be referred to as the "space charge". I have found that the effect of the "space charge" is to limit the current flowing with a given voltage to a value which is independent of the temperature of the cathode above a certain value. This limiting current is dependent upon the geometrical shape of the electrodes, the distance between the electrodes, and other factors. A negatively charged body located in the vicinity of the cathode will reduce the electron discharge current with a given impressed voltage and may also deflect the electrons dependent upon its position and configuration.

Some of the objects of the present invention are: to reduce the effect of the space charge in an electron discharge device; to modify or eliminate the effect of negatively charged bodies in the proximity of the cathode; to increase the discharge current with a given voltage; to furnish electrons having a relatively uniform velocity and to protect the cathode itself from mechanical injury or distortion by electrostatic forces.

With these objects in view the electron discharge apparatus is provided with a conductor located in the vicinity of the cathode and maintained at a predetermined positive potential. This conductor ordinarily assumes the form of a wire grid or grating surrounding the cathode and it is connected to a continuously maintained source of potential, preferably of low voltage.

My invention will be more fully explained in the following description taken in connection with the accompanying drawings in which Fig. 1 shows in perspective a discharge apparatus embodying my invention and suitable for converting direct current into alternating current; Figs. 2, 3 and 5 are diagrams illustrating various electrical systems of connection utilizing an electron discharge device made in accordance with my invention, and Fig. 4 illustrates a modified form of apparatus in which a positively charged plate is used instead of a grid.

In the electron discharge device shown in Fig. 1, the enclosing globe 1 has been shown as partly broken away to disclose the interior arrangement of the electrodes comprising a V-shaped filamentary cathode 2, and plate-shaped anodes 3 and 4. Surrounding the cathode is a frame 5, consisting conveniently of glass, upon which is wound fine wire constituting a grid 6 with closely adjacent turns surrounding the cathode 2. Located respectively between this grid and each of the anodes are grids 7 and 8, the function of which will be hereinafter explained.

The cathode conductor is attached to terminal supports 9 and 10 which are in turn connected to leading-in wires 11 and 12, sealed into the stem 13 of the enclosing globe in the usual manner. The cathode filament is maintained taut by being anchored by its bight by means of the spring 14 attached to the frame 5. The electrodes and grid wires consists preferably of ductile tungsten. The cathode and grids are all carried by glass stems attached to a pedestal 15. The anode stems 16 and 17 consist of tung-

sten or molybdenum and are held in position in the extensions 18 and 19 of the bulb by springs 20, which grip the walls of the bulb. Connection is made to the anodes in the usual manner by the leading-in wires 21 and 22. Connection to the grid surrounding the cathode is made by a leading-in wire 23. The grids 7 and 8 are preferably wound upon metallic frames 24 and 25 consisting, for example, of ferro-chrome which thus short-circuit the turns of the gird. Electrical connection is made thereto by conductors 26 and 27. The relative position of the anodes the cathode and the grids is more clearly indicated in a diagrammatic manner in Fig. 2; Fig. 1 illustrates particularly the structural features.

As shown in Figs. 2 and 3, the cathode 2 is maintained at incandescence by means of a battery 29, or other suitable externally located source of energy. The surrounding grid 6 is attached to the positive terminal of a source of potential, for example a battery 30, the negative terminal of which is connected to the cathode.

The discharge device is evacuated to the highest obtainable vacuum, the electrodes being freed from gas by operating the device while on the pump at a voltage below the value at which harmful gas ionization, as indicated by blue glow, takes place. As gas is driven out of the anode by electron bombardment, the impressed voltage is progressively increased, the removal of gas by the pump being continued. The impressed voltage thus attained before sealing-off should ordinarily be higher than the voltage at which the device is intended to operate. The degree of vacuum in the completed device while depending somewhat upon the character of the device should ordinarily be as low as a few hundred thousandths of a millimeter of mercury, preferably even lower.

The system shown in Fig. 2 is adapted particularly for the conversion of direct current into alternating current and for this purpose the anodes 3 and 4 are connected by means of conductors 31, 32 to the primary winding of a transformer 33. Energy is supplied by a direct current source of energy 34, for example, a dynamo, or a battery connected at its negative terminal by means of conductor 35 to the cathode and at its positive terminal by means of conductor 36 to an intermediate point upon the primary of the transformer 33. The grids 7 and 8 are connected by means of the conductors 37 and 38, to a source of alternating current 39 having the frequency desired for the alternating current to be produced by the device. This source has been diagrammatically indicated as a transformer altho of course any suitable alternating current source may be used. The cathode 2 is connected by means of a conductor 40 to an intermediate point on the secondary of the transformer 39.

The operation of the system above described is as follows:—When the cathode 2 is brought to incandescence it emits electrons, which travel under the influence of the impressed electromotive force to a positive electrode. When, however, a conductor, located between the cathode and an anode between which electrons are passing, is negatively electrified, the electrons are repelled in accordance with the degree of negative charge, thereby decreasing or interrupting entirely the discharge current. On the other hand, when a conductor, located between an electron-emitting cathode and an anode, is positively electrified the discharge is assisted and the current increased. Some of the electrons go to the positively charged conductor, but when this conductor has a relatively small obstructing surface, as in the case when a fine filament serves as the grid or other conducting body, very little energy will be absorbed thereby. For example, a tungsten wire having a diameter of about .0004 to .0010 of one inch wound with about 100 turns to the inch may be used but the turns per inch vary widely. When the impressed electromotive force between cathode and anode is high the amount of energy lost by the absorption of electrons by a grid having a relatively low positive charge is negligible.

As the grids 7 and 8 are made alternately negative and positive by the alternating source 39, the discharge current, or stream of negative charges, passes in turn to anodes 3 and 4, thereby setting up an alternating current in the primary of the transformer 33, and in that manner repeating in the divided output circuit, acting as the primary of the transformer, with amplified energy the electric waves in the divided input circuit, acting as the secondary of the transformer 39. If desired, a condenser 41 may be provided in order to absorb current variations and to neutralize the inductive effect of the transformer and provide a more rapid rise and fall of current. At any given instant either of input electrodes 7 or 8 will be negatively charged, and being in close proximity to the cathode, will tend to reduce the electron current flowing. However, when a positive field is established in the vicinity of the filament by the grid 6, this grid screens the cathode from the negative field, and assists the flow of electron current, thus making possible the combination of two repeating elements in a single electron discharge apparatus. The electrons are emitted by the cathode at variable speed but all being subject to the same static field which greatly increases the speed of all an equal amount, the differences of speed rep-

resent a relatively small fraction of the impressed resultant speed. As the positive field near the cathode opposes the current-reducing effect of the space charge, the distance between the cathode and the anodes may be increased without sacrifice of efficiency.

Some energy is lost by the absorption of the electrons by the positively charged grid 6 but as its surface is small and the positive potential may be made relatively small as compared with the voltage impressed between the cathode and the anodes, this loss will form but a relatively small proportion of the total amount of energy in the output circuit.

It is desirable that the rise of static potential of the grid becoming negative, should be rapid so as to shut off the flow of electron current completely to its corresponding anode. This result can be effected by making the alternating source 39 of high potential but this also increases the positive charge on the companion grid. A high positive grid potential increases the absorption of energy by the grid. By including a battery 75 or other source of potential in the conductor 40 connected to the cathode and an intermediate point of the secondary of the transformer 39, with its negative terminal connected to the transformer, the potential on the grid negatively charged is increased, and the potential on the grid positively charged is diminished, providing, of course, that the potential of the source 75 does not exceed the potential of the source 39. If desired resistances 77, 78, may be included in the grid circuits 37, 38, or these resistances may be replaced by a single resistance in conductor 40 to reduce current flow therein without reducing the potential. In some cases such resistances may make a separate superimposed negative potential unnecessary.

In the system illustrated by Fig. 3, an electron discharge tube is employed to rectify alternating current furnished by the primary of a transformer 42, the terminals of which are connected to the anodes 3 and 4, respectively, by conductors 43 and 44. The conductor 45 of the direct current consumption circuit is connected to the cathode 2 and the conductor 46 of the direct current circuit is connected to a point of intermediate potential upon the secondary of the transformer 42. It will be observed that the electrodes 3 and 4 will be in turn made positive and negative, current passing from the cathode to the positive electrode. Here likewise the electrode which is connected to the opposite terminal of the source, and hence is negative, would act to cut down the current passing from the cathode to the positive electrode. This effect, however, is prevented by the positively charged grid 6.

In the case of a rectifier having a plurality of electrodes functionating as anodes, the current-reducing effect of the electrodes when negatively charged is especially marked as the drop of potential in the direct current load will reduce the potential of the positive electrode which is taking current. As no current is flowing to a negative electrode, it will have the full potential of the source. For this reason also the mechanical distortion of the cathode located in the unsymmetrical field would be serious were the positive grid 6 not present, whereby the cathode is screened and protected.

The positively charged body need not necessarily be grid-shaped. Fig. 4 illustrates somewhat diagrammatically a rectifying device in which a plate 47 is located between an electron-emitting cathode 48 and an anode 49. Heating current is supplied the cathode conductor by a battery 50, and a source of energy for example, a transformer 51 is connected between the cathode and the anode. Surrounding the cathode is a concave dished plate 52, which is maintained negatively charged, conveniently by connecting it to the cathode by means of a conductor 53. This ring serves to modify the static field so as to focus the electrons into a fairly well-defined stream which passes through an aperture in the plate 47 to the anode.

By maintaining the plate 47 positively charged, for example, by means of a battery 54, the passage of the electrons from the cathode to the anode is assisted. The potential of the battery 54 and hence the charge on the plate 47, may be only a fraction of the potential between supply conductors 55, 56. The electrons will be attracted to the plate 47 but will largely pass through the aperture in the same as this represents the center of static attraction. By making the potential of the plate 47 relatively low the loss of energy by the absorption of electrons on the part of the plate 47 will be relatively small, and will be more than compensated by the increase in discharge current. The rectified current may be utilized by load devices 57. If it is desired to utilize both half waves of the alternating current, two sets of the devices illustrated are used in any well-known manner, such, for example, as that disclosed in Arsem Patent #929,371, or Alexanderson Patent #996,445.

As indicated in Fig. 5 the positively charged conductor may be used to advantage in a device for amplifying or repeating weak variable currents, such as signals in radio-telegraphy, or telephony. The repeater or electron discharge tube 58 is provided with a local source of energy, for example a battery 59, which may be of very low voltage, and is connected between the

cathode 60 and the anode 61. The grid 62 and the cathode 60 are connected to the secondary of a transformer 63, the primary of which is included in the antenna circuit. The latter has as usual an aerial antenna 64, and a grounded condenser 65. The grid 62 may be maintained at a definite potential by a battery 66. The cathode is surrounded by a grid 67, maintained at a perdetermined positive potential with respect to the cathode by a battery 68. When the cathode is heated by a local source of energy 69, a current will tend to flow from the cathode to the anode but this current is either prevented from flowing or is greatly reduced when the field of the grid 62 is negative. As the electrons are drawn away from the cathode 60 by the positive field furnished by the grid 67, a very low voltage may be used in the plate circuit, in fact, I prefer in some cases to use but a single cell for the battery 59, as indicated. A negative potential on the grid 62 on the other hand may be made relatively high. The current variations in the electrode circuit 72 due to the signal impulses impressed upon the grid circuit, are correspondingly great. The signals may be received by a telephone 70, or other suitable receiver, connected in shunt with a condenser 71.

The sensitiveness of this arrangement is especially marked as the electrons leave the grid 67 at substantially uniform velocity and hence are all affected to an equal extent by the variations in the negative charge of the grid 62.

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

1. A discharge apparatus operating with an electron discharge comprising a highly evacuated envelope, an electron-emitting cathode, an anode, a conductor therein located near the cathode, means for maintaining said conductor at a substantially uniform positive potential with respect to said cathode, and separate means within said envelope for varying the electron discharge between said cathode and anode.

2. An electrical discharge apparatus, comprising an electron-emitting cathode, an anode, an envelope therefor, said electrodes and the space in said envelope being freed from gas to a degree permitting a substantially pure electron-discharge to take place therein without gas ionization, a conducting body in said envelope located near the cathode, and a source of potential having its positive terminal connected to said body and its negative terminal directly to the cathode.

3. An electron discharge device comprising a highly evacuated container, a cathode adapted to be heated to incandescence independently of the operating current of the device, an anode, a conductor located in part at least between said cathode and anode, means for maintaining said conductor at a uniform positive potential with respect to the cathode, and independent means for establishing an electrostatic field to control an electron discharge between cathode and anode.

4. An electrical discharge apparatus comprising an evacuated container, an electron-emitting cathode, a cooperating anode and a conductor in part surrounding the cathode, means for maintaining said conductor at a uniform positive polarity with respect to the cathode, and means for producing a negative charge in the vicinity of said cathode.

5. The combination of an electron discharge device comprising an evacuated container, an electron-emitting cathode, an anode, a conductor coiled about said cathode but spaced apart therefrom, and a source of potential having its positive terminal connected to the said conductor and its negative terminal connected directly to the cathode.

6. The combination of an electron-discharge apparatus comprising a cathode, means for heating said cathode, cooperating anodes located on opposite sides of said cathode, a grid surrounding the cathode but spaced apart therefrom, a source of potential having its positive terminal connected to said grid, grids located respectively between said surrounding grid and the anodes, and a source of alternating potential connected to said intermediate grids.

7. The combination of a discharge device, comprising an envelope, an electron-emitting cathode and an anode, a conductor located near said cathode, means for maintaining said conductor at a positive potential with respect to said cathode, a second conductor located near said cathode, and means for maintaining said second conductor at a negative potential with respect to said cathode.

8. The combination of an enclosing envelope, an incandescent cathode, a plurality of anodes, a charge-controlling conductor surounding said cathode in part at least, a source of potential having a positive terminal connected to said conductor and a negative terminal connected to the cathode, a transformer, connections between the terminals of said transformer and said anodes, a source of unidirectional current connected between said cathode and an intermediate point on said transformer primary, charge-controlling conductors located between said cathode and said anode, and means for charging said conductors alternately negative and positive.

9. The combination of an enclosing envelope, an incandescent cathode, a plurality of anodes, a charge-controlling conductor

surrounding said cathode in part at least, a source of potential having a positive terminal connected to said conductor and a negative terminal connected to the cathode, a transformer, connections between the terminals of said transformer and said anodes, a source of unidirectional current connected between said cathode and an intermediate point on said tranformer primary, charge-controlling conductors located between said cathode and said anodes, a source of alternating current connected to said charge-controlling conductors and a source of direct current connected at the positive terminal to said cathode and at the negative terminal to a point of intermediate potential on said alternating current source.

10. The combination with an electron discharge device comprising a cathode and a pair of input electrodes enclosed in an evacuated envelope, a transformer secondary having its terminals connected to said input electrodes, a source of direct current having its positive terminal connected to said cathode and its negative terminal connected to an intermediate point in said transformer secondary, and means for impressing an alternating potential upon said transformer secondary.

11. The combination with an electron discharge device comprising a cathode provided with means for heating it to incandescence and a pair of input electrodes enclosed in an evacuated envelope of a transformer secondary having its terminals connected to said input electrodes, a source of direct current having one terminal connected to said cathode and its other terminal connected to an intermediate point in said transformer secondary, and means for impressing an alternating potential upon said transformer secondary.

12. The combination with an electron discharge device comprising a cathode provided with means for heating it to incandescence, a pair of anodes and a pair of input electrodes enclosed in an evacuated receptacle, said input electrodes being located between said cathode and said anodes, means for maintaining both of said input electrodes normally at a definite potential with respect to said cathode which is different than that of the cathode, and means for charging said input electrodes alternately negative and positive.

13. An electron-discharge device comprising an evacuated vessel containing a cathode adapted to be heated to incandescence independently of the operating current of the device, an anode, a discharge controlling electrode and a fourth electrode near said cathode, means for producing a current between said cathode and said anode, and means for maintaining said fourth electrode at a definite potential with respect to said cathode.

14. A device of the audion type comprising a thermionic cathode, an anode and an auxiliary electrode, means for supporting said auxiliary electrode, said cathode being filamentary in form, and a planary supporting frame therefor parallel to one of said electrodes and comprising spaced parallel members.

15. Parallel supporting members, and a filamentary thermionic cathode insulatingly supported at a plurality of points thereby, a grid frame at each side of said cathode, and an arbor for supporting said members and said frames.

16. A device of the audion type comprising parallel grids, a support therebetween comprising spaced parallel members, and a cathode extending between said members and supported thereby.

17. The combination in an electron discharge device of an evacuated receptacle containing an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a constant positive potential with respect to the cathode, and means for varying the potential of the grid nearest the anode with respect to the cathode.

18. The combination in an electron discharge device of an evacuated receptacle containing an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a positive potential with respect to the cathode, means for maintaining the grid nearest the anode at a negative potential with respect to the cathode, and means for varying the potential of the grid nearest the anode with respect to the cathode.

19. The combination of an electron discharge device comprising an electron emitting cathode, an anode, and two grids interposed between cathode and anode, means for maintaining the grid nearest the cathode at a constant positive potential with respect to the cathode, means for varying the potential of the grid nearest the anode with respect to the cathode, and means for impressing upon the anode a positive potential of greater value than that impressed upon the grid nearest the cathode.

20. The combination of an electron discharge device comprising an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining one of said grids at a constant positive potential with respect to the cathode, and means for varying the potential of the other grid with respect to the cathode.

21. The combination of an electron dis-

charge device comprising an electron emitting cathode, an anode and two grids interposed between cathode and anode, means for maintaining one of said grids at a constant positive potential with respect to the cathode, means for varying the potential of the other grid with respect to the cathode, and means for impressing upon the anode a positive potential of greater value than that at which the first of said grids is maintained.

22. An evacuated vessel containing a filament electrode and a cold electrode, a second cold electrode located between the filament and the first cold electrode, and a third cold electrode located between the filament and second cold electrode.

23. An evacuated vessel containing a filament electrode and a plate electrode, a grid electrode interposed between the filament and the plate electrode, and a second grid electrode interposed between the first grid electrode and the filament.

24. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode surrounding said cathode and a second grid electrode outside of said first grid electrode, a stem through which leading-in conductors for at least two of said electrodes are sealed, and a support for all of said electrodes arising from said stem.

25. An electron discharge device comprising an evacuated vessel, an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and a support for all of said electrodes arising from said stem.

26. An electron discharge device comprising an evacuated vessel, an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, and a support of insulating material within said vessel for supporting all of said electrodes.

27. An electron discharge device comprising an electron emitting cathode, an anode, a pair of grid electrodes located in different planes between said cathode and said anode, an evacuated vessel, and a support of insulating material for supporting the cathode and grid electrodes in desired spaced relation within said vessel.

28. In an electron discharge device in which a stream of electrons passes from one point to another, a plurality of grids located in different planes and successively passed by the electron stream.

29. In an electron discharge device in which a stream of electrons passes from one point to another, a plurality of grids which are successively passed by the electron stream.

30. An electron discharge device comprising an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, an evacuated container, and supporting means for supporting all of said electrodes from a single point in said container.

31. An electron discharge device comprising an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, an evacuated container and supporting means for supporting all of said electrodes from a single point in said container, said supporting means being arranged to insulate all of said electrodes from one another.

32. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and means for supporting a plurality of said electrodes from said stem.

33. An electron discharge device comprising an evacuated vessel containing an electron emitting cathode, a grid electrode, a second grid electrode interposed between said cathode and the first grid electrode, a stem through which leading-in conductors for a plurality of said electrodes are sealed, and means for supporting all of said electrodes from said stem.

In witness whereof, I have hereunto set my hand this 27th day of October 1913.

IRVING LANGMUIR.