

Dec. 30, 1941.

J. R. PIERCE

2,268,197

ELECTRON DISCHARGE DEVICE

Filed Feb. 17, 1940

2 Sheets-Sheet 1

FIG. 1

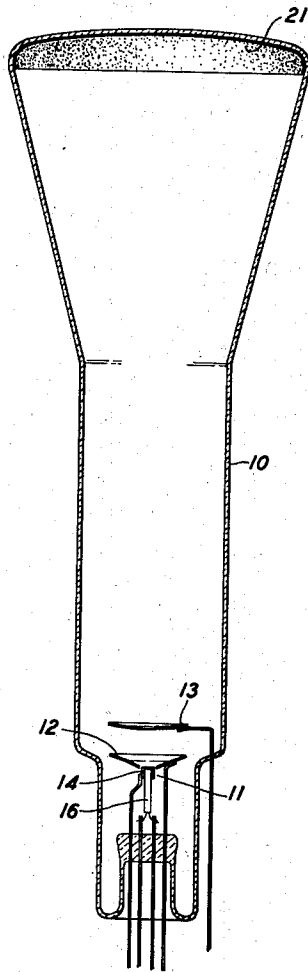


FIG. 2

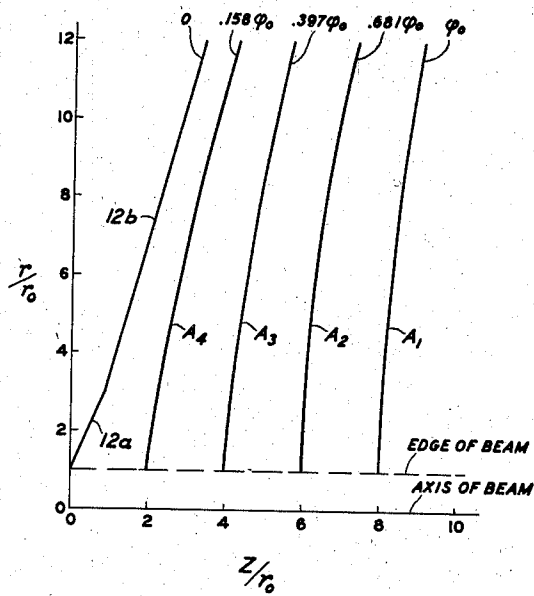


FIG. 6

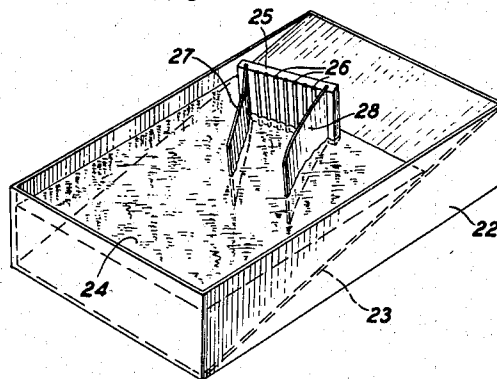
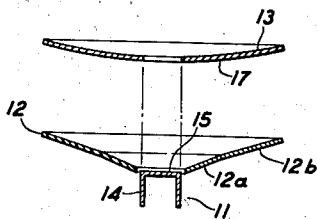


FIG. 3



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FIG. 7

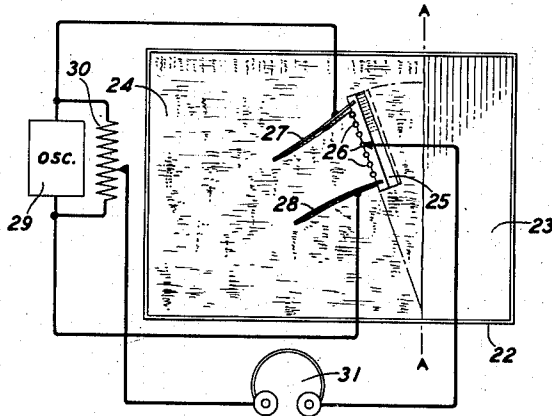


FIG. 5

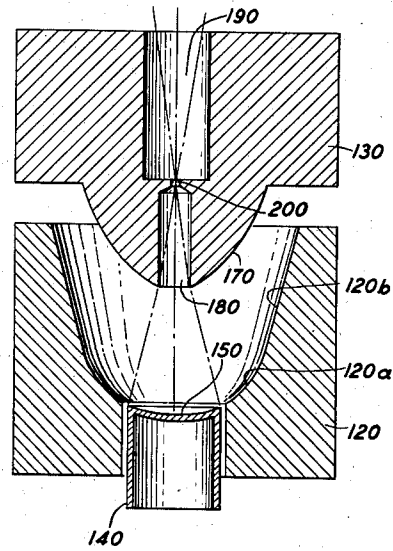


FIG. 8

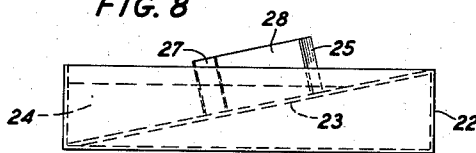
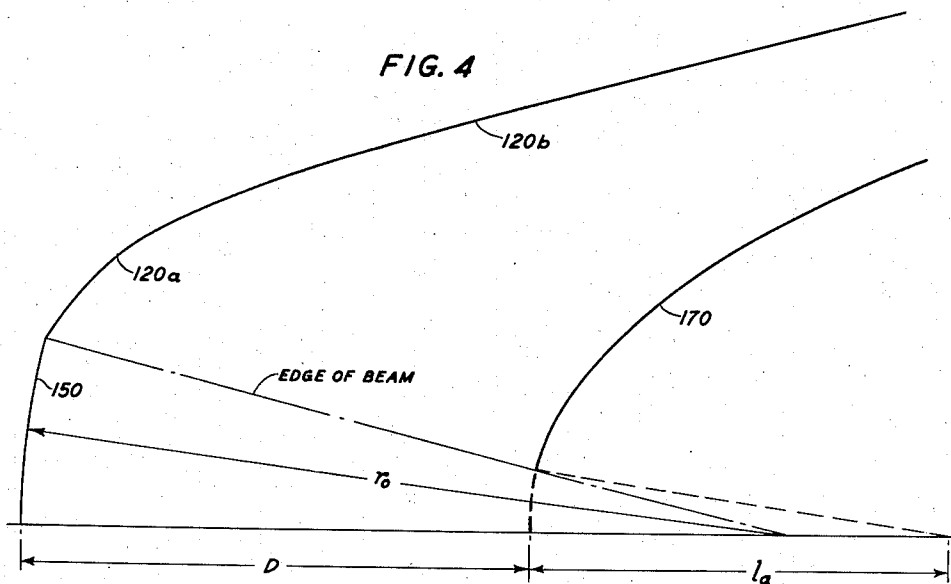


FIG. 4



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2,268,197

ELECTRON DISCHARGE DEVICE

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Application February 17, 1940, Serial No. 319,393

6 Claims. (Cl. 250-162)

This invention relates to electron discharge devices and more particularly to electrode systems for producing a concentrated stream of electrons in electron beam or cathode ray discharge devices.

In my application Serial No. 307,233, filed December 2, 1939, of which this application is a continuation in part, I have disclosed electrode systems for producing a line focus of electron streams in electron beam or cathode ray discharge devices. As described in my prior application identified above, such line focus may be obtained through the use of two or more electrodes having surfaces of such configuration and so spaced that fields of a character which will assure rectilinear motion of the electrons in the beam will obtain between the electrodes. The requisite configurations may be determined by more or less straightforward solutions of space charge equations.

In the case of electrode systems for producing a point focus of electrons, however, the determination, by solutions of space charge equations, of the electrode configurations requisite to assure a desired electron motion throughout the system is a highly complex problem and the mathematical solutions lead only to approximations of the optimum configurations.

One general object of this invention is to enable the construction of electrode systems for producing a point focus of electrons, having predictable operating characteristics.

Another general object of this invention is to facilitate the determination of electrode configurations in an electrode system for producing a point focus of electrons.

More specific objects of this invention are to simplify, and to increase the efficiency of, electron guns for producing a point focus of electrons.

In one illustrative embodiment of this invention, an electron discharge device comprises an electron source, such as a thermionic cathode, an electron receiving member, such as an anode, target or fluorescent screen, and an electrode system intermediate the electron source and the electron receiving member for concentrating the electrons emanating from said source into a beam of cylindrical or conical form.

In accordance with one feature of this invention, the electrode system aforementioned comprises two or more electrodes having coaxial surfaces defining figures of revolution and of such configuration that electrons emanating from the

cathode traverse rectilinear paths, parallel, diverging or converging.

Another feature of this invention resides in the determination of the configuration of the electrode surfaces whereby the electrostatic fields outside of the electron beam satisfy Laplace's equation and which, over the boundary of the beam, will be consistent with the fields inside the beam requisite for rectilinear motion of the electrons.

A further feature of this invention resides in a method of designing electrodes having such configuration that throughout the electrode system the fields are such that a desired motion and direction of the electrons is realized.

In general, in electrode systems constructed in accordance with this invention, the electron flow in the beam is in accordance with known solutions of space charge equations, for which Poisson's equation and Newton's laws of motion are satisfied, account being taken of electrostatic forces only. For point focus electron guns, the solutions of particular interest are those for electron motion between parallel planes and for motion between concentric spheres. In these cases, the region containing the electron flow, i. e., the region occupied by the electron beam, if rectilinear motion and a point focus are to be realized, is in the form of a right cylinder for parallel rectilinear electron paths and of a cone for converging rectilinear electron paths. The electrodes of the system are made of such configuration that the fields outside of the electron beam satisfy Laplace's equation and, over the cylindrical or conical boundary, are consistent with the solution of the space charge equations inside the beam. Stated in another way, the electrodes are made of such configuration that over the cylindrical or conical boundary of the beam, the fields outside the beam match in potential those inside the beam and have zero gradient normal to the boundary of the beam.

The invention and the foregoing and other 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, partly diagrammatic and partly in section, of a cathode ray discharge device illustrative of one embodiment of this invention;

Fig. 2 is a graph illustrating the form of the generatrices of a number of electrode surfaces in an electrode system constructed in accordance with this invention for producing parallel recti-

linear motion of electrons in electron discharge devices of the beam type, such as illustrated in Fig. 1;

Fig. 3 is an enlarged detail view in section of the electron gun included in the device shown in Fig. 1;

Fig. 4 is another graph illustrating the form of generatrices of electrode surfaces in an electrode system constructed in accordance with this invention for producing a converging electron beam the electrons in which traverse rectilinear paths;

Fig. 5 is a view in section of an electrode system including electrodes opposed surfaces of which are traced by generatrices of the form shown in Fig. 3;

Fig. 6 is a view in perspective of apparatus employed in determining the requisite configuration of electrode systems in accordance with this invention;

Fig. 7 is a top view of the apparatus illustrated in Fig. 6 and showing in addition, diagrammatically, electrical elements employed in utilizing such apparatus; and

Fig. 8 is a side view of the apparatus shown in Fig. 6.

Referring now to the drawings, the cathode ray device shown in Fig. 1 comprises an enclosing vessel 10 within and at one end of which is mounted an electron gun including a cathode 11 and a pair of centrally apertured beam forming electrodes 12 and 13 coaxial with the cathode 10. As shown in Fig. 1, the cathode may be of the indirectly heated type and comprise a cup-shaped metallic member 14, the base surface 15 of which is plane and circular and is coated with a material having good electron emission characteristics, and a heater element 16. It will be understood, of course, that other types of cathodes, for example, filamentary, may be employed.

As shown clearly in Fig. 3, the electrode 12 comprises two frusto-conical sections 12a and 12b of unequal angles and the surface 17 of electrode 13 facing the electrode 12 is curved. The configuration of these electrodes, which serve to form the electrons emanating from surface 15 of the cathode into a parallel rectilinear beam, will be described fully hereinafter.

The electron discharge device includes also an electron receiving element upon which the electron beam impinges, which may be of any of a number of forms and types. For example, it may be a fluorescent screen, an anode or a secondary electron emissive target. In the particular embodiment of this invention illustrated in Fig. 1, the electron receiving element is a fluorescent screen or coating 21 on the inner surface of the end wall of the vessel 10 remote from the electron gun.

The device may include one or more electrodes or other means for affecting the electron beam produced by the electron gun. For example, it may include sweep or deflector plates or coils for controlling the direction of the generated electron beam or one or more electrodes for controlling or varying the intensity of the beam or for focussing or accelerating the beam emanating from the electron gun. In order to simplify the drawings, such beam affecting means have been omitted therefrom.

In the embodiment of the invention shown in Fig. 5, the electron gun is adapted to produce a converging electron beam and comprises generally the same electrodes as the gun shown in Figs. 1 and 2, but having different forms and surface

configurations. The electron emissive surface 150 of the cathode member 140 is dishd to conform to a segment of a sphere. The beam forming electrode 120 is provided with a dishd surface 120a, 120b of a particular configuration described hereinafter. The other beam forming electrode 130 is provided with a surface 170 of a particular configuration also described hereinafter and with a pair of coaxial cylindrical apertures or bores 180 and 190 connected by a restricted passageway 200.

One of the principal desiderata in electron beam or cathode ray discharge devices is the attainment of a high beam current in relation to the emission of the cathode. In the optimum case, all of the electrons emanating from the cathode, as from the surface 15 in Figs. 1 and 3 and from the surface 150 in Fig. 5, would be concentrated into the beam issuing from the second beam forming electrode, such as 13 or 130. The beam current will be dependent upon the fields extant in the region traversed by the beam and these fields in turn will be dependent upon the configuration of the electrode surfaces.

In accordance with a feature of this invention, the electrode configurations are made such that substantially optimum beam current is realized. Thus, in the case of an electron gun for producing a parallel rectilinear beam, the electrode surfaces in the gun are made such that the electrons emanating from the cathode are confined within a cylindrical boundary of substantially the same diameter as the emissive surface (15 in Figs. 1 and 3) of the cathode and these electrons traverse parallel rectilinear paths normal to this emissive surface. In the case of an electron gun, such as shown in Fig. 5, for producing a converging beam, the electrode surfaces are made of such configuration that the electrons emanating from the emissive surface 150 are confined within a conical boundary and traverse rectilinear paths.

The motion of the electrons within the beam requisite to obtain confinement of the electrons within the boundary set, as previously noted, is dependent upon the fields in the region traversed by the beam. In general, the fields necessary for the desired motion can be determined from known solutions of the space charge equations for which Poisson's equation and Newton's laws of motion are satisfied, taking into account electrostatic forces only. As noted hereinabove, the condition necessary for the desired rectilinear electron flow within the beam is that the fields outside of the electron beam satisfy Laplace's equation and are consistent with the solution of the space charge equations within the beam, over the cylindrical or conical beam boundary or, stated in another way, over the cylindrical or conical boundary of the beam, the field outside the beam shall match in potential the field inside of the beam and have zero gradient normal to the boundary of the beam.

For the case of parallel electron motion between two equipotential boundaries, such as electrode surfaces, assuming electron flow in the z direction, within the electron flow, Poisson's equation may be written as,

$$\frac{\partial^2 \phi}{\partial z^2} = \frac{j}{p_0 \sqrt{2 \frac{e}{m} \phi}} \quad (1)$$

$$\frac{\partial \phi}{\partial y} = \frac{\partial \phi}{\partial x} = 0 \quad (2)$$

ϕ being potential with respect to the plane of zero electron velocity, j the current density, ρ_0 the permittivity of a vacuum, e the electron charge, m the electron mass, and x and y the directions normal to the direction of electron flow and to each other.

In the case of such parallel electron flow in a beam of constant circular cross-section between a pair of aligned equipotential surfaces, wherein the flow is parallel to the axis of alignment of the surfaces, the field outside the beam must be an axially symmetrical solution of Laplace's equation which, over the boundary of the beam, satisfies the conditions

$$\phi = f(z) \quad (3)$$

and

$$\frac{\partial \phi}{\partial r} = 0 \quad (4)$$

where z is distance along the beam, $f(z)$ is a solution of Equation 1, supra, and r is distance normal to the beam boundary.

If $\phi = 0$ and

$$\frac{\partial \phi}{\partial z} = 0 \text{ at } z = 0 \quad (5)$$

corresponding to space charge limited flow from a cathode located at $z = 0$, the correct solution of Equation 1 is

$$\phi = f(z) = Az^{4/3} \quad (5)$$

where

$$A = \left(\frac{j}{2.33 \times 10^{-6}} \right)^{2/3}$$

In an electron gun for producing a converging electron beam occupying a conical region, the field outside the beam must be an axially symmetrical solution of Laplace's equation, for which the potential gradient normal to the conical beam boundary is zero, and for which the potential along the beam boundary varies in accordance with a solution of the space charge equations for rectilinear electron motion between concentric spheres. The requisite potential variation along the beam boundary may be expressed by the relation

$$\phi = K(\alpha^2)^{2/3} \quad (6)$$

where

$$K = \left(\frac{i}{29.34 \times 10^{-6}} \right)^{2/3}$$

i being the current which would flow between complete concentric spheres and α^2 is a function of the ratio

$$\frac{r}{r_0}$$

r being the distance from the center of curvature of the emissive surface of the cathode and r_0 the cathode radius. Particular values of α^2 can be obtained in ways known in the art.

In both the cases of electron motion noted above, i. e., in those producing parallel rectilinear beams and converging beams, the potential variation along the beam boundary will be dependent upon the configuration of the emissive surface of the cathode and of the opposed surfaces of the beam forming electrodes. The determination of the requisite configurations by solution of the space charge equations is a highly complex problem and leads to only more or less unsatisfactory approximations of the optimum configurations. In accordance with a feature of this invention, however, the determination of the requisite electrode surface configuration is greatly facilitated.

It will be appreciated that in both the cases mentioned, the beam and the surfaces of the electrodes of the gun will be figures of revolution. Hence, any sector of the field bounded by planes passing through the axis of symmetry and the electrode surfaces will be fully illustrative of the fields between the electrodes.

Typical apparatus which may be employed in determining the requisite electrode configuration of the electrode surfaces in accordance with this invention is illustrated in Figs. 6, 7 and 8 and comprises a tank 22 having an inclined bottom surface 23 of insulating material, and containing a body of electrolyte 24, such as water. Resting upon the inclined surface 23 is a linear strip of insulation 25 having thereon a plurality of parallel conductors 26. The insulating strip 25 has attached thereto a pair of pliant metallic strips 27 and 28, which may be fitted in slots in the insulating strip, as shown in Fig. 7.

As illustrated in Fig. 7, a potential is impressed across the metallic strips 27 and 28, as by an oscillator 29 across the terminals of which a calibrated potentiometer 30 is connected. An indicating device, such as a telephone receiver 31, is connected to a sliding connection on the potentiometer 30 and is adapted to be connected individually to each of the conductors 26.

The insulating strip 25 represents the beam boundary in an electrode system the axis of symmetry (A—A) of which is represented by the thin edge of the electrolyte 24, i. e., the water line upon the inclined surface 23. The metallic strips 27 and 28 represent sections of the opposed surfaces of the electrodes 12 and 13.

Inasmuch as the inclined surface 23 is of insulating material, no potential gradients will exist in the electrolyte normal to either this surface or the surface of the electrolyte. Likewise, inasmuch as the strip 25, representing the beam boundary, is of insulating material, no potential gradients will exist normal to this surface. Hence, it will be seen that two of the conditions,

$$\frac{\partial \phi}{\partial y} = \frac{\partial \phi}{\partial x} = 0$$

given by Equation 2 or Equation 4, supra, requisite for the establishment of a field which will result in rectilinear electron flow are satisfied.

The potential associated with current flow in a uniform electrolyte satisfies Laplace's equation, thus fulfilling the condition that the potential outside of the beam must satisfy Laplace's equation. There remains to be determined, then, only the electrode configurations which will result in the prescribed potential distribution along the beam boundary.

The requisite potential distribution along the beam boundary can be determined from Equations 5 and 6 hereinabove. The electrode configurations necessary to establish this potential distribution may then be determined by bending or forming the strips 27 and 28 and measuring the potential at the conductors 26. The proper distribution will obtain when the strips 27 and 28 are of such form that, as indicated by the absence of any signal in the receiver 31, the potential at each conductor 26 matches the proper potential indicated by the calibrated potentiometer 30. The requisite electrode surfaces, then, will be surfaces of revolution the generatrices of which are of the form of the strips 27 and 28, determined as described, corresponding to the prescribed potential distribution along the insulating strip 25.

It will be understood that in determining the requisite electrode configuration for an electron gun for producing a parallel rectilinear beam, the insulating strip 25 should be mounted parallel to the water line or axis of symmetry A—A. In determining the requisite electrode configurations for an electron gun to produce a converging electron beam, the strip 25 should be mounted so that an extension of the surface thereof which represents the beam boundary will intersect the axis A—A at the center of curvature of the emissive surface (150 in Fig. 5) of the cathode and will make, with the axis, an angle corresponding to the angle of the conical beam boundary desired in any particular instance. The configuration of the electrode surfaces will vary, of course, with the included angle of the conical beam boundary.

It may be noted that the configurations of the electrode surfaces will be dependent upon the potential and spacing thereof, both of which will be dictated by exigencies of a practical structure and device. However, these configurations are not dependent upon the absolute magnitude of the potentials involved nor on the units in which distance is measured. The electrode shapes for any desired potential and spacing of the electrodes can be determined in the manner described hereinabove.

Some suitable generatrices for various electrode surfaces in a device, such as shown in Fig. 1, for producing a parallel beam of electrons are illustrated in Fig. 2. In such a device, it is convenient to use two beam-forming electrodes, one (12) at cathode or zero potential, and one (13) at a positive potential ϕ_0 or a fraction of ϕ_0 with respect to the cathode. In Fig. 2, the ordinates are measured in the ratio

$$\frac{r}{r_0}$$

where r is the distance from the axis of the beam and r_0 is the radius of the emissive surface 15 of the cathode. The abscissae are measured in the ratio

$$\frac{z}{r_0}$$

where z is distance along the beam from the cathode.

In Fig. 2, the line O is the generatrix of the surface 12a, 12b of the electrode 12 in Fig. 1, if the electrode 12 is operated at zero or cathode potential. It will be noted that the portion 12a of this generatrix is a straight line which makes an angle of 67.5 degrees with the normal to the cathode surface 15. This relationship has been found to be necessary in order that the electron flow will be normal to the cathode surface 15 near the edge thereof. A satisfactory electron gun will be realized if the generatrix of the portion 12b of the surface of electrode 12 is a straight line making an angle of 74 degrees, 5 minutes with the normal to the cathode surface 15. Although, in an exact determination of the configuration of electrode surfaces 12a and 12b it will be found that the generatrix is not composed of two exactly straight lines, the departure from exactness introduced by using a generatrix of the form shown by line O in Fig. 2 is negligible for practical purposes.

The surface 17 of electrode 13 will be a surface of revolution generated by lines of the form shown by the curves A₁ to A₄ in Fig. 2, the particular line used being dependent upon the rela-

tive magnitude of the potential (ϕ_0 or the indicated part thereof in Fig. 2) it is desired to apply to the electrode 13.

Typical generatrices for the electrode surfaces, one at zero potential and the other at a positive potential in a gun, such as illustrated in Fig. 5, for producing a converging electron beam are shown in Fig. 4. In this figure, which illustrates the generatrices in a gun for producing a beam confined within a conical boundary whose elements make an angle of 14 degrees with the axis of symmetry of the electrode system, r_0 is the radius of curvature of the cathode surface 150 and D is the axial distance between the cathode surface 150 and the surface 170 extended to intersect the axis. It will be understood, of course, that the form of the generatrices will be dependent upon the angle of the conical beam boundary desired.

In both cases, i. e., parallel and converging electron beams, the aperture in the positive electrode, 12 or 120, into which the beam enters will exert a diverging lens action upon the beam. The magnitude of the diverging effect can be calculated from the formula for focal length of a lens formed by a circular aperture, namely,

$$f = \frac{4V}{E_1 - E_2} \quad (7)$$

where E_1 and E_2 are the fields on the two sides of the aperture and V is the potential at the aperture.

In the case of a parallel electron beam produced by electrodes having surfaces of the configurations illustrated in Figs. 1 and 2, the potential and field to the left (in Fig. 2) of the aperture in the electrode 13 are given by Equation 5, supra. To the right of the aperture the space may be considered field free for practical purposes. Thus, the focal length of the lens formed by the aperture, taking D as the value of z at the aperture, will be

$$f = -\frac{4\phi}{\phi'} = -\frac{4AD^{1/3}}{\frac{4}{3}AD^{1/3}} = -3D \quad (8)$$

Inasmuch as the electron paths are parallel between the cathode and the aperture, the focal distance just after passing through the aperture is equal to the focal length f . Thus, the electron paths beyond the aperture will appear to diverge from a point a distance $3D$ behind the aperture or $2D$ from the cathode surface.

In the case of a converging beam, the focal distance beyond the aperture can be determined from Equation 8 and using for ϕ and ϕ' values obtained from a plot of

$$\frac{\phi}{V} \text{ versus } \frac{z}{D}$$

When the beam reaches the end of the aperture 180 toward the cathode surface 150, it is converging toward the center of the curvature of the cathode, a distance $r_0 - D = r_a$ away. After passing through the aperture, the beam will converge toward a point a distance l_a beyond the aperture, l_a being given by the relation.

$$\frac{1}{r_a} + \frac{1}{l_a} = \frac{1}{f} \quad (9)$$

The point of cross-over will be a distance l_a beyond the inlet end of the aperture or a distance $l = l_a + D$ from the cathode.

It may be remarked that accurate results for focal length determined by the equation given above will be obtained only if the cathode

to electrode 130 distance is several times the diameter of the aperture 180.

It may be noted further that for a value of

$$\frac{D}{r_0} = 0.29$$

the beam emerging from the aperture will be substantially parallel.

Although specific embodiments of the invention have been shown and described, it will be understood, of course, that they are but illustrative. For example, although electron guns utilizing but two beam-forming electrodes have been shown, it will be understood that guns employing more than two such electrodes may be constructed in accordance with this invention. Furthermore, although the electrode 12 has been described as maintained at cathode potential, it may have a variable potential applied thereto, to modulate the electron beam. Various other modifications may be made in the devices shown and described without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electron gun for electron discharge devices comprising an axially symmetrical electrode system including a cathode having an electron emissive surface and including also means for directing electrons emanating from said surface, in the presence of substantially complete space charge, along rectilinear paths lying within a boundary of revolution traced by a linear generatrix extending normal to said surface at the periphery thereof, said means comprising a pair of spaced electrodes having opposed, coaxial centrally apertured surfaces of revolution flaring away from said emissive surface, and said opposed surfaces corresponding to equipotential boundaries of a field which satisfies Laplace's equation between said opposed surfaces, for which the potential gradient is zero normal to said boundary of revolution and for which along said boundary of revolution the potential increases exponentially as a function of distance from said emissive surface.

2. An electron gun for electron discharge devices comprising an axially symmetrical electrode system including a cathode having a plane, circular electron emissive surface, and a pair of spaced electrodes opposite said emissive surface, said electrodes having opposed surfaces of revolution conforming to equipotential boundaries of a field which satisfies Laplace's equation between said opposed surfaces, for which the potential gradient is zero normal to a boundary, all elements of which are normal to said emissive surface at the periphery thereof, and for which, in said boundary, $\phi = Az^{4/3}$, where ϕ is potential, z is distance from said emissive surface and

$$A = \left(\frac{j}{2.33 \times 10^{-6}} \right)^{2/3}$$

j being the current density.

3. An electron gun for electron discharge devices comprising an axially symmetrical electrode system including a cathode having an electron emissive surface conforming to a segment of a sphere, and a pair of spaced electrodes opposite said emissive surface, said electrodes having opposed surfaces of revolution conforming to equipotential boundaries of a field which satisfies Laplace's equation between said opposed surfaces, for which the potential gradient is zero normal

to a boundary, all elements of which are normal to said emissive surface at the periphery thereof, and for which, in said boundary, $\phi = K(\alpha^2)^{2/3}$, where K is a constant and α^2 is a function of

$$\frac{r}{r_0}$$

r_0 being the radius of curvature of said emissive surface and r distance from the center of curvature of said emissive surface.

4. The method of determining the configuration of electrodes in an electrode system, requisite for establishing rectilinear motion of electrons between said electrodes and within a boundary of predetermined form, which comprises immersing a pair of formable metallic strips and an insulating strip in an electrolyte bounded at one surface by an insulating surface, locating said metallic and insulating strips on said insulating surface in the relation in which the electrodes are to be mounted in said system with respect to the electron beam, the insulating strip corresponding to said boundary, impressing a potential between said metallic strips, measuring the potential at a plurality of points along said insulating strip, and altering the form of said metallic strips until the potential along said insulating strip varies in accordance with a predetermined relation corresponding to rectilinear motion of electrons in said electrode system.

5. The method defined in claim 4 which comprises altering the form of said metallic strips until the potential along said insulating strip varies in accordance with the relation $\phi = Az^{4/3}$ where ϕ is potential,

$$A = \left(\frac{j}{2.33 \times 10^{-6}} \right)^{2/3}$$

z is distance from the origin of said system, and j is current density.

6. The method of constructing an electron gun for producing a converging conical electron beam, said gun comprising an emissive surface corresponding to a segment of a sphere and a pair of spaced electrodes coaxial with said emissive surface and having opposed surfaces, which method comprises immersing a pair of formable metallic strips and an insulating strip in a wedge-shaped body of electrolyte bounded on one face by an insulating surface, locating said metallic and insulating strips on said insulating surface in the relation in which the electrodes are to be mounted in said gun, the insulating strip corresponding to the boundary of said beam, impressing a potential between said metallic strips, measuring the potential at a plurality of points along said insulating strip, altering the form of said metallic strips until the potential along said insulating strip varies in accordance with the relation $\phi = K(\alpha^2)^{2/3}$ where ϕ is potential, K is a constant and α^2 is a function of

$$\frac{r}{r_0}$$

r_0 being the radius of curvature of said emissive surface and r distance from the center of curvature of said emissive surface, constructing electrodes having surfaces the generatrices of which correspond to the form of said metallic strips as thus altered, and mounting said electrodes and an emissive surface in the relation in which said metallic strips were mounted in said electrolyte.

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