

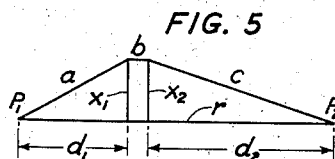
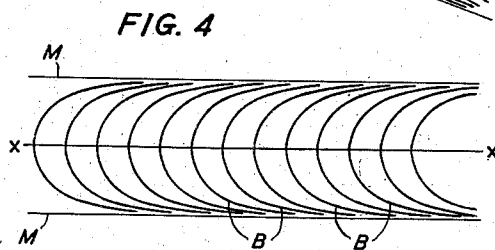
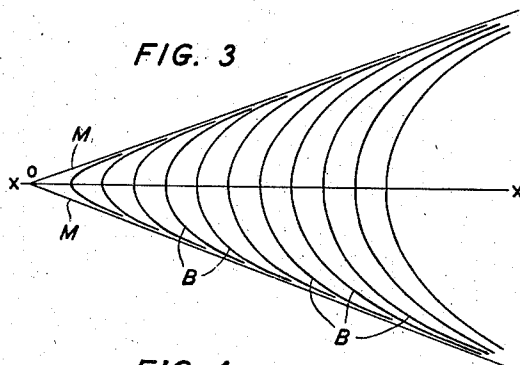
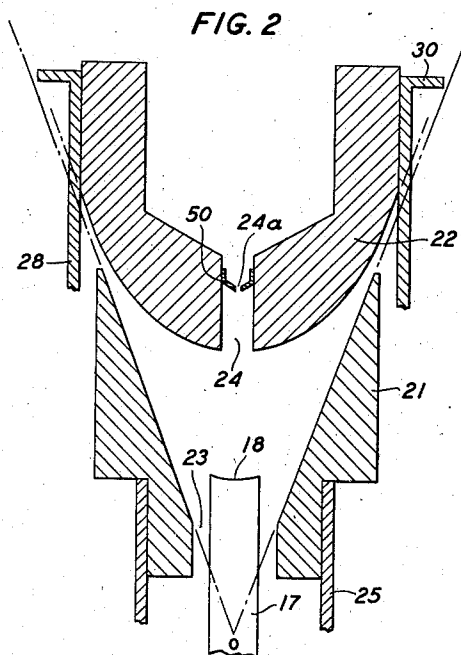
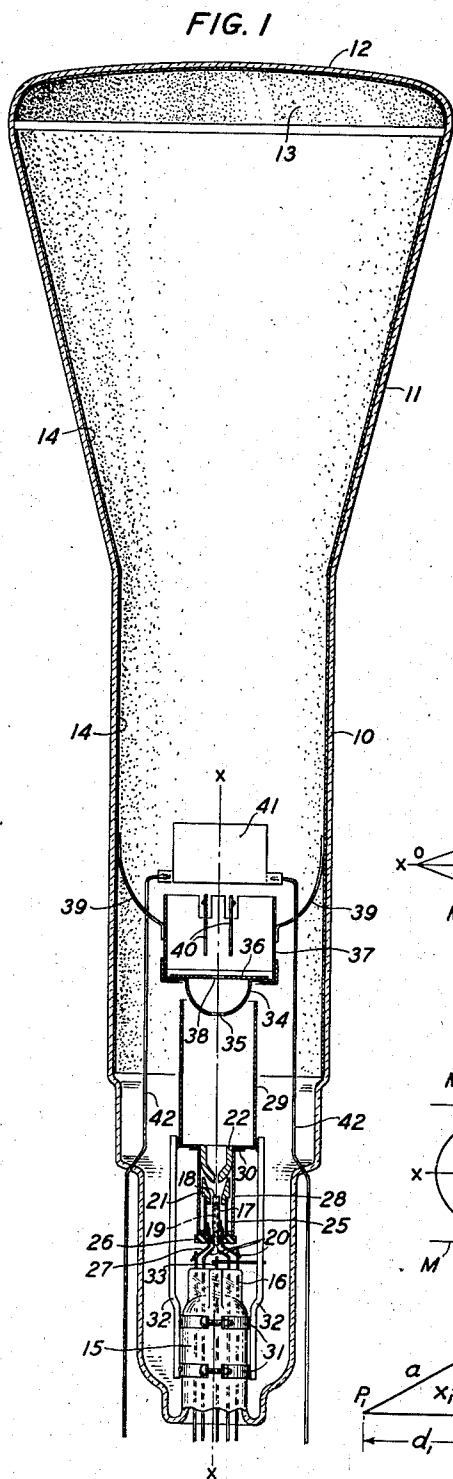
Dec. 30, 1941.

M. S. GLASS

2,268,194

ELECTRON DISCHARGE DEVICE

Filed Dec. 2, 1939



INVENTOR
M. S. GLASS

BY
Walter C. Kiesel
ATTORNEY

UNITED STATES PATENT OFFICE

2,268,194

ELECTRON DISCHARGE DEVICE

Myron S. Glass, West Orange, N. J., assignor to
Bell Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

Application December 2, 1939, Serial No. 307,232

14 Claims. (Cl. 250-162)

This invention relates to electron discharge devices and more particularly to electrode systems for producing concentrated electron streams in electron beam discharge devices such, for example, as cathode ray oscillographs.

In electron beam discharge devices, in general, electrons are emitted from an activated surface or electron source and directed toward an electron receiving element. For example, the electron receiving element may be one or more targets upon which the electron beam may impinge for a desired time or a particular area of which may be impinged upon by the beam. In other devices, the electron receiving element may be a fluorescent screen upon which the electron beam produces a luminous spot or traces a luminous pattern.

Whatever the character of the electron receiving element, production of a current thereto or of a spot or pattern thereon involves three major problems, namely, collimation, focussing and modulation. That is to say, the electrons emanating from the activated surface or source should be concentrated and accelerated toward the electron receiving element in such manner, that they follow approximately paraxial paths, the electron stream should pass through electric fields of such nature that the individual electron paths are such as to produce a sharply defined spot or area upon the electron receiving element, and the rate or density of flow of electrons toward the electron receiving element should be readily controllable.

One general object of this invention is to increase the efficiency and to improve the operating characteristics of electron beam discharge devices.

More specifically, objects of this invention are:

To improve the efficiency of the collimating system in electron beam discharge devices whereby a large percentage of the electrons emanating from the electron source or activated surface are concentrated into the electron beam;

To increase the beam current in electron beam discharge devices;

To improve the electron beam focussing in electron beam discharge devices whereby the beam impinges upon a sharply defined spot or area of small dimensions, upon the electron receiving element;

To enable effective focussing of electron beams of high current density;

To reduce aberration in the focussing system in electron beam discharge devices;

To obtain a small span of voltage variation

upon one or more electrodes of the beam producing system between full intensity and cut-off of the beam current; and

To enable substantially uniform modulation of the rate or density of flow of electrons toward the electron receiving electrode.

In one illustrative embodiment of this invention, a cathode ray device, a specific construction of which is described in the application Serial No. 307,231, filed December 2, 1939, of Sture O. Ekstrand, comprises an electron source, such as a thermionic cathode, a fluorescent screen spaced from the electron source, a collimating system in cooperative relation with the electron source, and a focussing system between the collimating system and the fluorescent screen.

In accordance with one feature of this invention, the collimating system comprises a pair of electrodes having restricted apertures in alignment with the cathode and juxtaposed surfaces of these electrodes are of such configuration as to conform to equipotential boundaries of an electric field of such distribution that electrons flowing therein are turned toward the axis of alignment of the apertures and the cathode.

In accordance with another feature of this invention, the focussing system comprises a pair of electrodes in axial alignment with the electrodes of the collimating system, one of the electrodes being cylindrical and the other being dish-shaped and at the end of the cylindrical electrode toward the screen, and the electrodes of the focussing system are so constructed and arranged that the aberration produced by the focussing system is substantially negligible.

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 drawing in which:

Fig. 1 is an elevational view mainly in section of a cathode ray device illustrative of one embodiment of the invention;

Fig. 2 is an enlarged detail view mainly in section of the cathode and electrodes of the collimating system in the device shown in Fig. 1;

Figs. 3 and 4 are diagrams illustrating equipotential boundaries of electric fields to which surfaces of certain electrodes of the device shown in Fig. 1 conform in accordance with one feature of this invention; and

Fig. 5 is a diagram illustrative of the focussing system in a device constructed in accordance with this invention.

Referring now to the drawing, the cathode ray

device shown in Fig. 1 is of the construction described in detail in the application of Sture O. Ekstrand identified hereinabove and comprises an evacuated enclosing vessel having an elongated cylindrical portion 10 and a flaring portion 11 terminating in an end wall 12, the inner surface of which is coated to form a fluorescent screen 13. Portions of the inner surfaces of the elongated and flaring portions 10 and 11 respectively of the enclosing vessel may be provided with a conductive coating 14, for example of graphite, as described in Patent 2,096,416, granted October 19, 1937, to Howard W. Wein-

hart. The enclosing vessel is provided at the end thereof remote from the screen 13 with an inwardly extending stem 15 terminating in a press 16 and supporting the electrodes of the device. In order to simplify the drawing, various details of construction of the electrode structure have not been shown, these being shown and described clearly in the aforementioned application of Sture O. Ekstrand.

The electrode structure comprises generally an electron source, a collimating system, a focussing system, and deflector electrodes. The electron source, as shown in Fig. 1, may be an indirectly heated cathode comprising a cylindrical metallic sleeve 17 having a dished or cupped end portion 18, the outer surface of which is coated with a thermionic material, and a heater filament 19 within the sleeve 17, the sleeve and filament being supported by leading-in conductors 20 embedded in the press 16.

The collimating system comprises a modulating electrode 21 and a collimating electrode 22 having central apertures 23 and 24 respectively aligned with the cathode, the electrodes 21 and 22 being coaxial with one another and with the cathode. The electrode 21 may be supported by a metallic cylinder 25 seated upon an insulating spacer 26, and having a leading-in conductor 27 extending therefrom. The electrode 22 may be supported similarly by a metallic cylinder 28 also seated upon the insulating spacer 26, the cylinders 25 and 28 being coaxial with one another and the cathode. The electrode 22 may be provided with a baffle 50, shown in Fig. 2, having a restricted aperture 24a in axial alignment with the aperture 24.

The focussing system comprises a cylindrical electrode 29 coaxial with the cathode, seated upon a flange 30 upon the cylinder 28, and supported from bands or collars 31 clamped about the stem 15 by a plurality of uprights or wires 32 one of which is connected to a leading-in conductor 23 sealed in the press 16. It comprises also a dished or cupped electrode 34 having a central aperture 35 in alignment with the apertures 23 and 24. The electrode 34 may be insulatingly supported from the cylindrical electrode 29.

The electrode 34 has electrically integral therewith a metallic baffle or barrier 36 and a cylindrical shield 37, the baffle or barrier 36 having a central aperture 38 in alignment with the aperture 35 and the shield 37 being electrically connected to the coating 14 by a plurality of resilient metallic fingers 39. A suitable potential may be applied to the electrode 34, baffle or barrier 36 and shield 37 through a leading-in conductor, not shown. The barrier or baffle 36 serves to prevent the potentials of the deflector plates, to be described hereinafter, from affecting the focussing field.

Mounted within the shield 37 are a pair of parallel deflector plates 40 equally spaced on opposite sides of an axis X—X extending through the apertures 35 and 38. A second pair of parallel deflector plates 41 are mounted above the plates 40, at right angles thereto and equally spaced on opposite sides of the axis X—X. The deflector plates 40 and 41 may be supported in part by leading-in conductors 42 sealed in the side wall of the enclosing vessel.

During operation of the device the modulating electrode 21 may be maintained at a negative potential with respect to the cathode, the collimating electrode 22 may be maintained at a positive potential with respect to the cathode, and the electrode 34 may be maintained at a higher positive potential with respect to the cathode. In general, electrons emanating from the emissive portion 18 of the cathode are concentrated into a stream passing into the electrode 22 through the aperture 24, and are focussed into a beam of small cross-sectional dimensions which passes through the aperture 38 and between the deflector plates 40 and 41 and impinges upon the fluorescent screen 13 whereby a luminescent spot is produced upon the screen. The rate or density of electron flow may be varied by varying the potential of the electrode 21 and the beam may be deflected by applying suitable potentials to the deflector plates 40 and 41.

The intensity of the spot produced upon the screen 13 will be dependent, of course, upon the current density of the electron beam and this in turn is dependent upon, among other things, the proportion of the electrons emanating from the surface 18 of the cathode which issue from the aperture 24a. This proportion in turn is determined largely by the nature of the electric fields extant in the vicinity of the cathode and in the region between the cathode and the electrode 22.

In general, it has been ascertained that in order that satisfactory collimation may be attained, the potential gradients in the vicinity of the cathode should be moderately small, the radial gradient of the field should increase progressively with distance away from the cathode and there should be a gradient toward the axis X—X of the electrode system. Thus, the electrons should be accelerated in the direction along the axis and simultaneously subjected to a field which concentrates them toward the axis and counteracts the dispersive effect of space charge.

The field and field distribution are dependent upon the configuration and relative potentials of the electrodes in the region under investigation. The relation between the radial gradient and the potential distribution along the axis of an axially symmetrical system may be expressed by the equation

$$V(x,r) = f(x) - \frac{r^2}{2} f''(x) + \frac{r^4}{2 \cdot 4^2} f^{IV}(x) \mp \dots \quad (1)$$

where $V(x,r)$ is the potential at a point a distance r from a point in the axis, which point is at a distance x from the origin of the system. The potential along the axis is a function, $f(x)$, of distance from the origin. For most practical purposes, terms beyond the r^4 term can be neglected inasmuch as r is quite small.

From Equation 1 it will be seen that a gradient toward the axis exists only if $f''(x)$, the second derivative of the potential as a function of the distance along the axis, is positive. Some fields which would satisfy this condition and also the conditions that there should be a small potential

gradient in the vicinity of the cathode and that the field should increase progressively along the axis, are fields given by the relations

$$E=K\epsilon^x, E=Kx^2, E=Kx^3 \dots E=Kx^n \quad (2)$$

where E is the potential on the axis a distance x from the origin of the system (in the immediate vicinity of the cathode), K is a constant and ϵ is the Napierian base. For fields satisfying the relation given above, it will be noted that for all cases except $E=Kx^2$, the second derivative contains a function of x , so that the radial gradient increases as the electron moves parallel to the axis and acquires greater axial velocity. This is desirable inasmuch as the radial gradient should be smaller in the regions where axial velocity is low in order that the electrons will not cross the axis at an early time in their flight.

Fields having the desired characteristics set forth hereinabove can be obtained, it has been found, by making electrodes of such configuration that they conform to equipotential boundaries of the desired field. Between a pair of electrodes of such construction and operated at suitable potentials, the space between the electrodes would have the desired potential distribution, of course, if the equipotential surfaces were closed surfaces. It has been found that the potential distribution established between equipotential surfaces which are not closed but tend to converge, approach the optimum sufficiently closely for practical purposes.

The configuration of the equipotential surfaces may be determined mathematically in the following manner from Equation 1 given hereinabove. Let a represent a particular value of x . Then

$$V(a,0)=f(a) \quad (3)$$

and the equation for an equipotential line passing through a is

$$V(a,0)=V(x,r) \quad (4)$$

Then

$$f(a)=f(x)-\frac{r^2}{4}f''(x)+\frac{r^4}{64}f^{IV}(x)\mp\dots \quad (5)$$

Equation 5 is a general one for an equipotential line passing through a point at a distance a along the axis from the origin of a system in which the field distribution is such that $V(x,0)=f(x)$. Equipotential surfaces are generated by rotating the equipotential line about the x axis.

In a specific case, let $f(x)=Kx^2$. By substitution in Equation 5,

$$a^2=x^2-\frac{r^2}{2}$$

which may be put into the form

$$\frac{x^2}{a^2}-\frac{r^2}{2a^2}=1 \quad (6)$$

which, of course, is the equation for a hyperbola. Where $a=0$,

$$r=x\sqrt{2}$$

so that the equipotential line of zero potential is a straight line. The equipotential lines of other than zero potential are hyperbolae having the zero potential line as an asymptote. The equipotential surfaces, then, obtained as noted before, by rotating the equipotential lines about the axis are a cone and a family of hyperboloids.

If, as another specific illustration, $f(x)=Kx^4$,

$$a^4=x^4-3x^2r^2+\frac{3}{8}r^4 \quad (7)$$

It can be shown that for practical purposes of electrode design the r^4 term is negligibly small, so that Equation 7 may be written as

$$r^2=\frac{x^4-a^4}{3x^2}; r=\sqrt{\frac{x^4-a^4}{3x^2}} \quad (8)$$

When $a=0$, $r=0.577x$. For this case, as for the first case noted above, the zero equipotential boundary is generated by a straight line and the other equipotential surfaces are generated by curves asymptotic to the straight line.

A diagram illustrating the equipotential lines plotted from equations derived as above is shown in Fig. 3, which illustrates the case where

$$f(x)=Kx^6$$

In this figure, M, M are the equipotential lines of zero potential and the curves B , asymptotic to M , M , are the equipotential lines for other than zero potential. For other cases, that is, where

$$f(x)=Kx^n$$

and n is an integer, 2 or greater, the equipotential lines will be similar to those shown in Fig. 3 differing therefrom principally in the curvature, as to curves B , and in slope, as to lines M, M .

For the case where

$$f(x)=K\epsilon^x, \epsilon^a=\epsilon^x\left(1-\frac{r^2}{4}+\frac{r^4}{64}\mp\dots\right)$$

As noted heretofore, the r^4 terms, and higher order terms of r are negligibly small for practical purposes. Disregarding these terms, then,

$$\frac{r^2}{4}=1-\epsilon^{a-x}; r=\pm 2\sqrt{1-\epsilon^{(a-x)}} \quad (9)$$

This, it will be apparent, is the equation for a family of curves which, at large values of x , become asymptotic to the lines $r=\pm 2$, parallel to the x axis. Fig. 4 is a diagram showing the equipotential lines for this case. It will be noted that, inasmuch as the limiting lines ($r=\pm 2$) are parallel to the axis, the diameter of the system is definitely established, at $x=0$, the potential is unity, instead of zero as in the cases previously considered, and the system has no real origin or zero electrical boundary.

For any particular electrode system, the field distribution, and hence the configuration of the electrodes used, will be determined by practical mechanical design considerations. Thus, curves for low powers of x must be extended to relatively large radial distances before they approach convergence and, as a result, large diameter electrode systems would be necessary. Conversely, curves for higher powers of x approach convergence at relatively small radial distances so that smaller diameter electrode systems may be utilized.

A suitable relation for devices of generally the size commonly employed is the one wherein $f(x)=Kx^6$. The field distribution in a collimating system satisfying this relation is such that the radial gradient at any point in the collimating field is proportional to the square of the distance from the axis and to the fourth power of the distance along the axis. Hence, the radial gradient is small in the vicinity of the cathode and increases very rapidly as the electrons approach the central portion of the electrode 22 toward the cathode.

The particular spacing between the surfaces of the cathode 19 and electrode 22 is dependent upon the operating characteristics desired. Thus,

in a specific arrangement of electrodes illustrated in Fig. 2, the inner surface of the electrode 21, which, as noted before, is utilized as the modulating electrode, conforms to the conical surface generated by rotating the line M in Fig. 3 about the axis X—X. The vertex O of the cone is the origin of the system. The vertex of the surface of the electrode 22 toward the cathode is located 9 units ($\frac{9}{16}$ of an inch in a specific case) from the vertex O and conforms to the surface generated by rotation of the curve B in Fig. 3 having its vertex 9 units from the vertex O. In a particular case, it may be desired to have the voltage required on the modulator electrode 21 to suppress the electron beam about $\frac{1}{20}$ as great as the voltage on the electrode 22. For this voltage relation, the cathode emitting surface 18 should be slightly more positive (with respect to the modulating electrode) than the equipotential boundary of the field immediately in front of the cathode. Hence, the cathode should be positioned substantially $9 \times 20^{1/5}$ units from the origin of the system.

The dimensions of the aperture 24a in the electrode 22 will depend upon the beam desired and the dimensions of the electrodes. For the particular structure described in the preceding paragraph, an aperture 10 to 15 mils in diameter has been found satisfactory to produce a small well-defined spot on the screen 13.

It may be remarked that the configuration of the portion 18 of the cathode is of some import. For large area cathodes and high current electron beams the surface 18 should be of such shape as to coincide with an equipotential boundary of the field. For small cathodes and low current beams, the surface 18 may be plane without introducing material distortion effects.

In a collimating system constructed as described above, it has been found that a very large proportion, up to 95 per cent, of the electrons emanating from the cathode are directed into paraxial paths and constitute a concentrated beam passing through the aperture 24, which may be focussed into a sharply defined spot of small dimensions on the screen 13. The beam may be modulated without substantial alteration in the definition or size of the spot.

As pointed out heretofore, the electrons issuing from the aperture 24 come under the influence of the fields of a focussing system comprising the electrodes 29 and 34. In focussing electrons, the problems are similar to those encountered in connection with collimation and considered heretofore. In general, focussing involves the determination of the paths of individual electrons so that the electrons are directed toward the axis of the system and produce a sharply defined spot of small cross-sectional area upon the electron receiving element, for example, the screen 13. The focussing obtained is dependent, of course, upon the potential distribution in the focussing field.

The potential distribution in the focussing field requisite for the attainment of a high degree of focussing may be obtained, as in the case of collimation, by making the surfaces of the electrodes of the focussing system of such configuration as to coincide with equipotential boundaries in the focussing field. Illustrative potential distributions which are suitable have been described heretofore in the description of the collimating system.

It will be noted that for potential distributions up to the order of $E=Kx^3$ along the axis X—X

of the system there is substantially no inherent aberration in the focussing system, the lens action of the aperture 35 being substantially negligible. For higher order distributions, aberration terms appear in the formulae for field distribution. However, as will be pointed out hereinafter, such aberration may be substantially eliminated.

Although, as will be apparent from the preceding discussion of the collimating system, a variety of potential distributions may be employed to produce excellent focussing, a particularly suitable distribution for structural and space considerations is that represented by the relation $E=Kx^2$ wherein, as illustrated in Fig. 4, the asymptotic boundary is a cylinder. For this case, as shown in Fig. 1, the electrode 29 is a cylinder and the electrode 34 conforms to an equipotential surface of the form, substantially hemispherical, shown in Fig. 4.

The determination of requisite potential ratios for a focussing system may be accomplished in accordance with the following considerations with particular reference to Fig. 5. In this figure, x_1 and x_2 are regions distances x_1 and x_2 from the origin of the system and it is assumed that the potential distribution along the axis is equal to $f(x)$ between these points. Assume that the electron stream entering the focussing system originates at a point P₁, e. g. in the limiting aperture 24a, on the axis a distance d_1 from x_1 , traverses the path indicated generally by the line a, b, c, and returns to the axis at point P₂ a distance d_2 from x_2 . x_1 in the device shown in Fig. 1 is approximately at the end of the cylinder 29 toward the cathode. In view of the small values of r encountered in practice it may be assumed for practical purposes that electrons enter the field at x_1 with axial velocities corresponding to the potential $f(x_1)$ and that the axial velocity is the same for all electrons irrespective of the distance r at which they enter the field. Between x_1 and x_2 the average value of r is substantially a constant.

It can be shown, then, that for any systematic potential distribution along the axis of an axially symmetrical system the following general relation exists:

$$\frac{\sqrt{f(x_2)}}{d_2} + \frac{\sqrt{f(x_1)}}{d_1} = -\frac{1}{4} \int_{x_1}^{x_2} \left[-f''(x) + \frac{r^2}{8} f^{IV}(x) \mp \dots \right] \frac{dx}{\sqrt{f(x)}} \quad (10)$$

This equation, it will be noted, involves the four quantities x_1 , x_2 , d_1 and d_2 . Knowing any three of these quantities enables solution for the fourth. The quantities d_1 and d_2 will be established by the mechanical requirements and geometry of the focussing system employed. d_2 is approximately the distance between the aperture 35(x_2) and the screen 13(P₂). d_1 is dependent upon the geometry of the system and may be estimated from experience. x_1 represents the position in the potential field corresponding to the energy of the introduced electrons, i. e., substantially at the end of the electrode 29 nearest the cathode and its value is readily determinable from the equations for the axial field distribution employed. x_2 , then, may be considered as the quantity for which the equation is to be solved.

The case where the potential distribution is as shown in Fig. 4 ($f(x)=Kx^2$) may be used as

a specific illustration. For this case, Equation 10 may be written in simplified form as

$$2\left(\frac{\epsilon^{\frac{x_2}{d_2}} + \epsilon^{\frac{x_1}{d_1}}}{\epsilon^{\frac{x_2}{d_2}} + \epsilon^{\frac{x_1}{d_1}}}\right) = \left(1 - \frac{r^2}{8} + \frac{r^4}{64} \mp \dots\right) \left(\frac{x_2}{\epsilon^2} - \frac{x_1}{\epsilon^2}\right) \quad (11)$$

which defines a focussing system with axial potential distribution of $E = K\epsilon^x$. The terms in r are almost negligibly small and represent aberration. In a specific case, let $d_1 = 4$ units, $d_2 = 20$ units and $x_1 = 4$ units. Then, neglecting the terms in r and solving Equation 11, $x_2 = 5.022$. Then, the ratio of the voltages upon the electrodes 34 and 29 required to produce a focus on the screen 13 is

$$\frac{\epsilon^{x_2}}{\epsilon^{x_1}} = 2.77$$

As pointed out above in connection with Equation 11 the r terms represent aberration and are very small. The inherent aberration may be reduced, if necessary, by increasing the diameter of the cylindrical electrode 29 and thus thereby decreasing the relative magnitude of the beam diameter.

For the specific case ($f(x) = K\epsilon^x$) described above, the length of the cylindrical electrode 29 is not of particular import with respect to the focussing action of the field although it does enter into the magnitude of the inherent aberration and affects the image and object distances. In general, increasing the length of this cylindrical electrode decreases the aberration. This may be seen from the following: if the calculations for focussing given above are generalized by letting $E = \epsilon^{Kx}$ instead of $E = K\epsilon^x$, the equation for the equipotential surfaces is

$$r = \pm \frac{2}{K} \sqrt{1 - \epsilon^{K(a-x)}} \quad (12)$$

which, it will be noted, is the same as Equation 9 except for the introduction of the factor K in the exponent for the ϵ term. The equation for the path of the electron then becomes

$$\frac{2}{K} \left[\frac{Kx_2}{\epsilon^{\frac{x_2}{d_2}} + \epsilon^{\frac{x_1}{d_1}}} \right] = \left[\frac{Kx_2}{\epsilon^{\frac{x_2}{d_2}} + \epsilon^{\frac{x_1}{d_1}}} \right] \left[1 - \frac{r^2 k^2}{8} \pm \dots \right] \quad (13)$$

which, it will be noted, is the same as Equation 11 except for the introduction of the factor K at various points in the equation.

From Equation 13, it will be apparent that if K is considerably less than unity, the magnitude of the aberration term is greatly reduced. Small values of K obtain if the exponential field extends along a long cylinder. Hence, increasing the length of the focussing cylinder 29 decreases the aberration.

Although a specific embodiment of the invention has been shown and described, it will be understood, of course, that it is but illustrative. For example, in the collimating system, the electrodes may have surfaces conforming to equipotential boundaries of a field other than that corresponding to the relation of $f(x) = Kx^6$ and in the focussing system, the electrodes may have surfaces conforming to equipotential boundaries of a field other than that corresponding to

$$f(x) = \epsilon^{Kx}$$

The particular field distribution selected for any specific device will be dependent upon mechanical considerations. It will be understood further that various modifications may be made in the specific embodiment disclosed without departing

from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. An electron discharge device comprising an electron source, an electron receiving element spaced from said source, and an electrode system between said source and said element, said system including a pair of spaced electrodes in axial alignment with said source and having opposed surfaces conforming to equipotential boundaries of a field corresponding to a predetermined exponentially increasing potential distribution along the axis of alignment.

2. An electron discharge device comprising an electron source, an electron receiving element spaced from said source, and an electrode system between said source and said element, said system including a pair of spaced electrodes in axial alignment with said source, and having opposed surfaces conforming to equipotential boundaries of a field corresponding to a potential which increases progressively toward said element along the axis of alignment and the second derivative of which as a function of the distance along said axis is positive.

3. An electron discharge device in accordance with claim 2 wherein said electron source comprises a cathode having an electron emissive surface conforming to an equipotential boundary of said field.

4. An electron discharge device in accordance with claim 2 wherein said opposed surfaces conform to equipotential boundaries of a field corresponding to a potential which increases along said axis according to the relation

$$E = Kx^n$$

where E is the potential, K is a constant, x is the distance along said axis with respect to the origin of the system and n is 2 or greater.

5. An electron discharge device in accordance with claim 2 wherein said opposed surfaces conform to equipotential boundaries of a field corresponding to a potential which increases along said axis according to the relation

$$E = K\epsilon^x$$

where E is the potential, K is a constant, ϵ is the Napierian base, and x is the distance along said axis with respect to the origin of the system.

6. An electron discharge device comprising an electron source, an electron receiving element spaced from said source, and an electrode system between said source and said element including a pair of spaced electrodes in alignment with each other and with said source, said electrodes having opposed surfaces conforming to equipotential boundaries of a field corresponding to a potential which increases progressively toward said element along the axis of alignment and which has a gradient toward said axis which increases with distance parallel to said axis and toward said element.

7. An electron discharge device comprising an electron source, an electron receiving element spaced from said source, and an electrode system between said source and said element including an electrode in axial alignment with said source and having a central aperture and a second electrode between said source and said first electrode and in axial alignment therewith, the surface of said second electrode toward said source conforming to a second or higher order curve of the distance along the axis of alignment from the origin of the system, and the surface of said

first electrode toward said first surface conforming to a boundary substantially asymptotic to said first surface.

8. An electron discharge device in accordance with claim 7 wherein said first surface conforms to an equipotential boundary of a field corresponding to a potential which increases along the axis of alignment according to the relation

$$E = Kx^n$$

where E is the potential, K is a constant, x is the distance from the origin of the system, and n is 2 or greater, and said surface of said first electrode is substantially conical.

9. An electron discharge device in accordance with claim 7 wherein said first surface conforms to an equipotential boundary of a field corresponding to a potential which increases along the axis of alignment according to the relation

$$E = Ke^x$$

where E is the potential, K is a constant, e is the Napierian base and x is the distance from the origin of the system, and said second surface is cylindrical.

10. An electron discharge device comprising an electron source, a collimating system including a pair of electrodes in axial alignment with said source, said electrodes having opposed surfaces conforming to equipotential boundaries of a field corresponding to a potential which increases progressively away from said source along the axis of alignment and the second derivative of which as a function of distance along said axis is positive, an electron receiving element, and a focussing system between said collimating system and said electron receiving element, said focussing system including a pair of electrodes in axial alignment with said source and said first electrodes and having opposed surfaces conforming to equipotential boundaries of a field corresponding to a potential which increases progressively along said axis toward said element and the second derivative of which as a function of the distance along said axis is positive.

11. An electron discharge device in accordance with claim 10 wherein said electron source com-

prises a cathode having an electron emissive surface conforming to an equipotential boundary of said first field.

12. An electron discharge device in accordance with claim 10 wherein the electrode of the focussing system nearest said source is electrically integral with the electrode of said collimating system furthest from said source.

13. An electron discharge device in accordance with claim 10 wherein the opposed surfaces of said first electrodes conform to equipotential boundaries of a field corresponding to a potential increasing along said axis according to the relation

$$E = Kx^n$$

and wherein the opposed surfaces of said second electrodes conform to equipotential boundaries of a field corresponding to a potential increasing along said axis according to the relation

$$E = Ke^x$$

where E is the potential, K is a constant, e is the Napierian base, x is the distance along said axis and n is 2 or greater.

14. An electron discharge device comprising a cathode, an electron receiving element spaced from said cathode, a beam forming system adjacent said cathode including a centrally apertured collimating electrode in axial alignment with said cathode and having the surface thereof toward said cathode conforming to a surface of revolution generated by a curve of at least a second order function of distance along the axis of alignment, said beam forming system including also an electrode having a conical surface extending from immediately adjacent said cathode surface and asymptotic to said first surface, and a focussing system between said collimating system and said element including an elongated cylindrical electrode coaxial with said first electrodes and a second electrode at the end of said cylindrical electrode toward said element, having a substantially hemispherical surface facing toward said collimating system and having also a central aperture in axial alignment with said cathode.

MYRON S. GLASS.