Dec. 23, 1941. R. R. LAW 2,266,773

ELECTRON DEVICE

Filed May 11, 1937 5 Sheets-Sheet 1

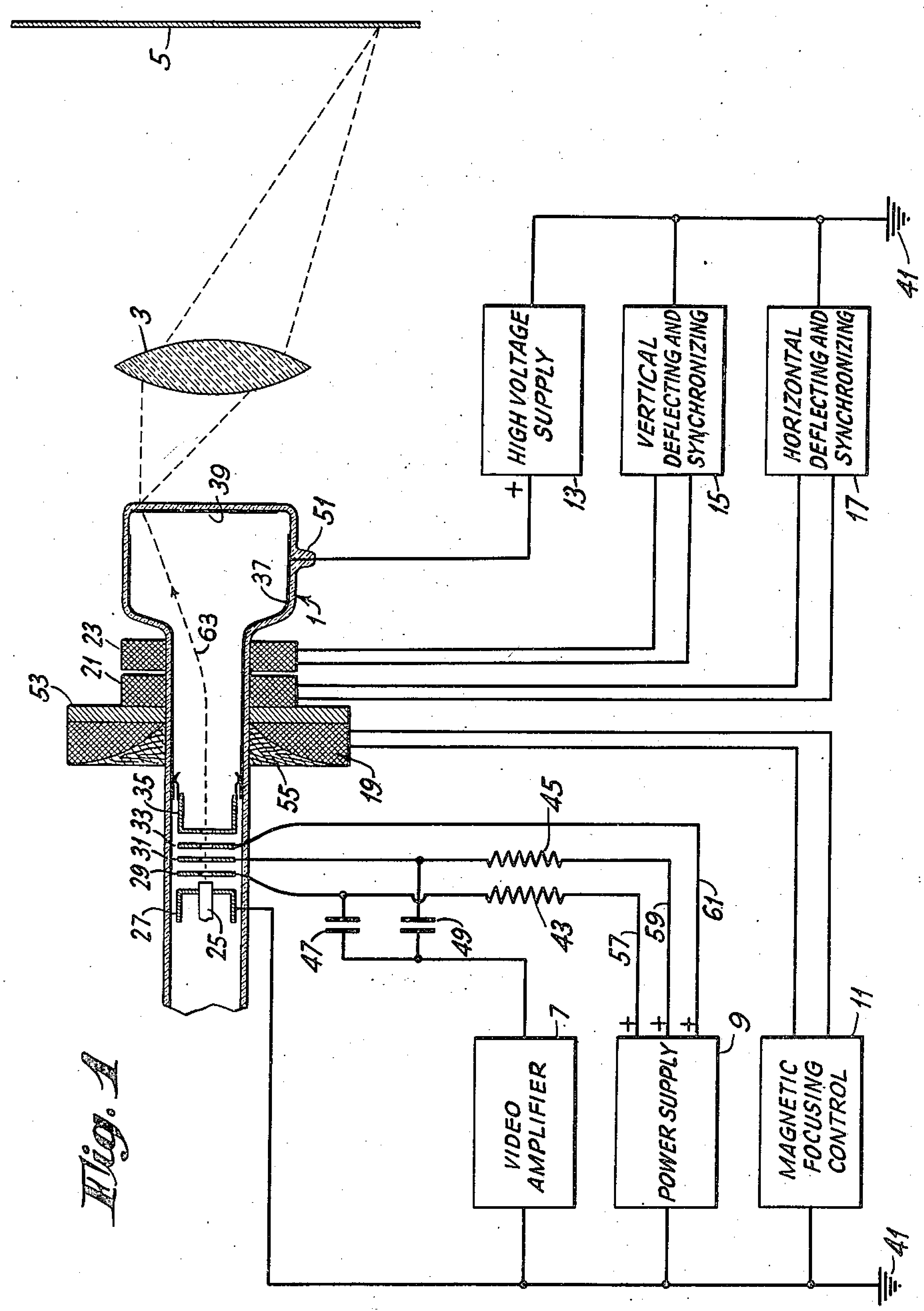

Fig. 1

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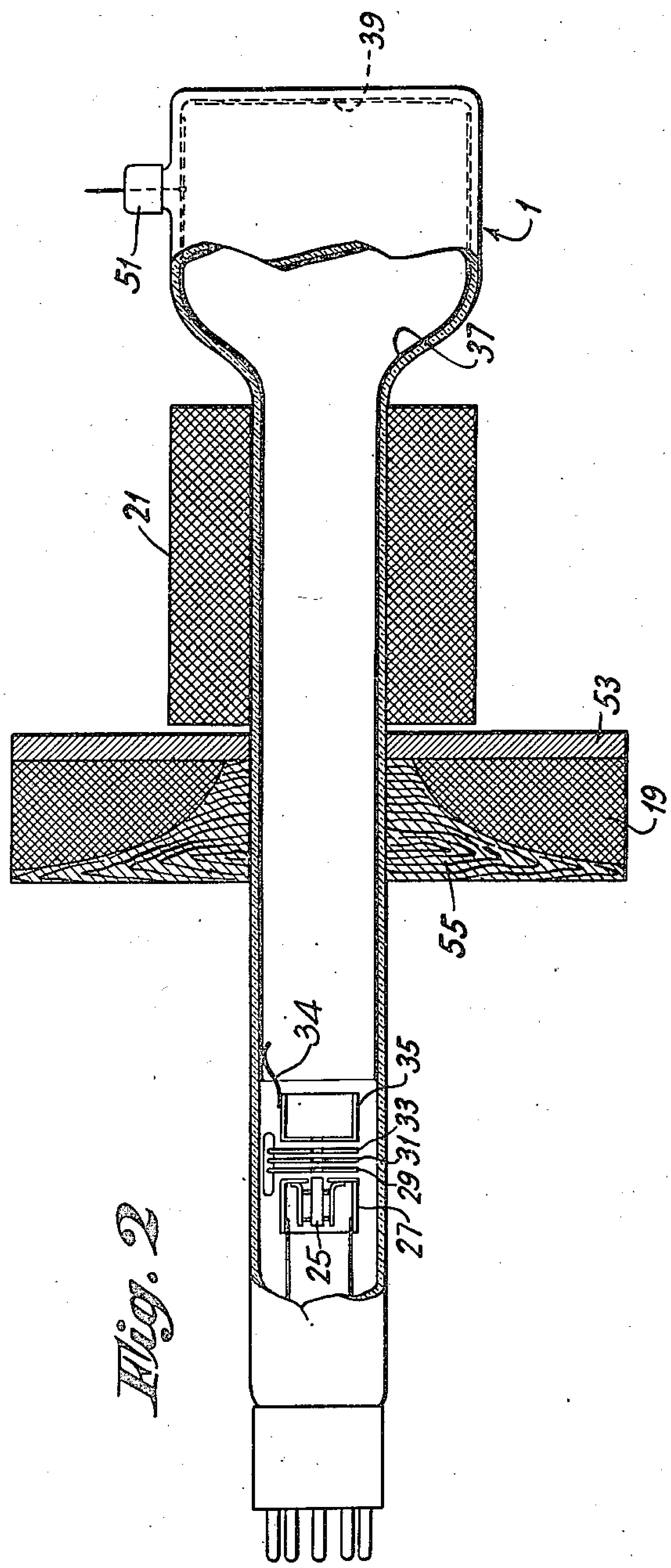

Fig. 2

Fig. 3

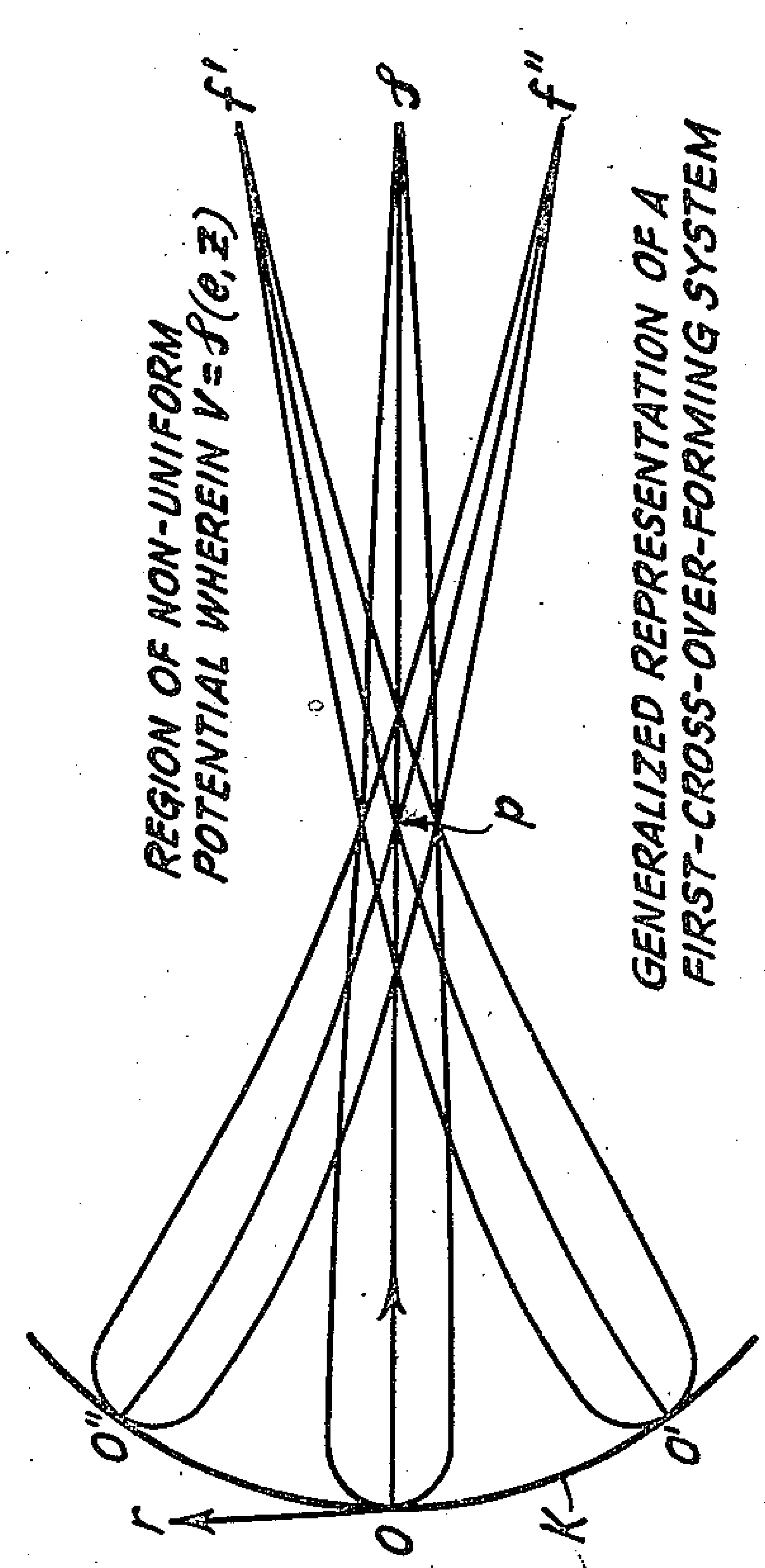

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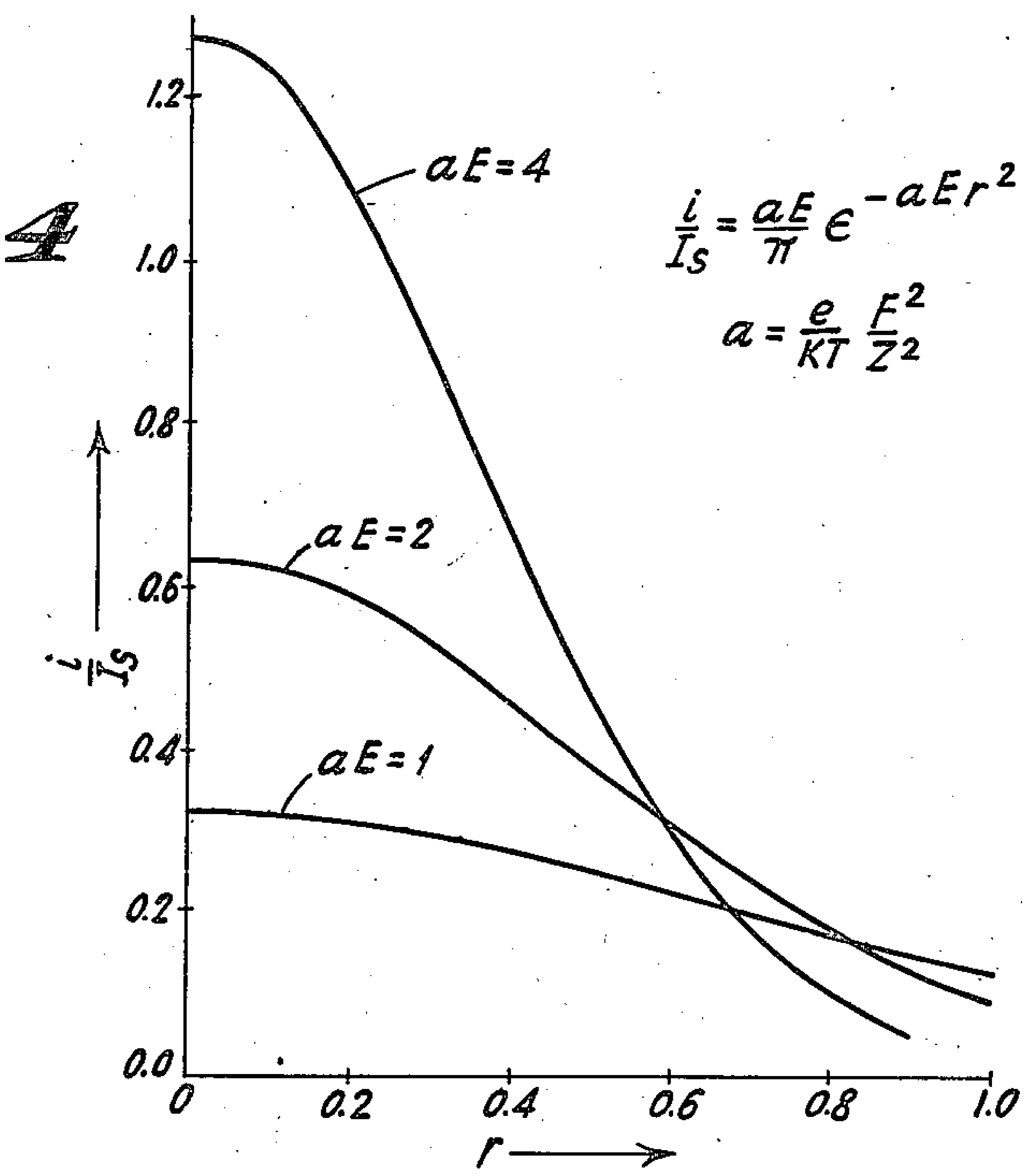
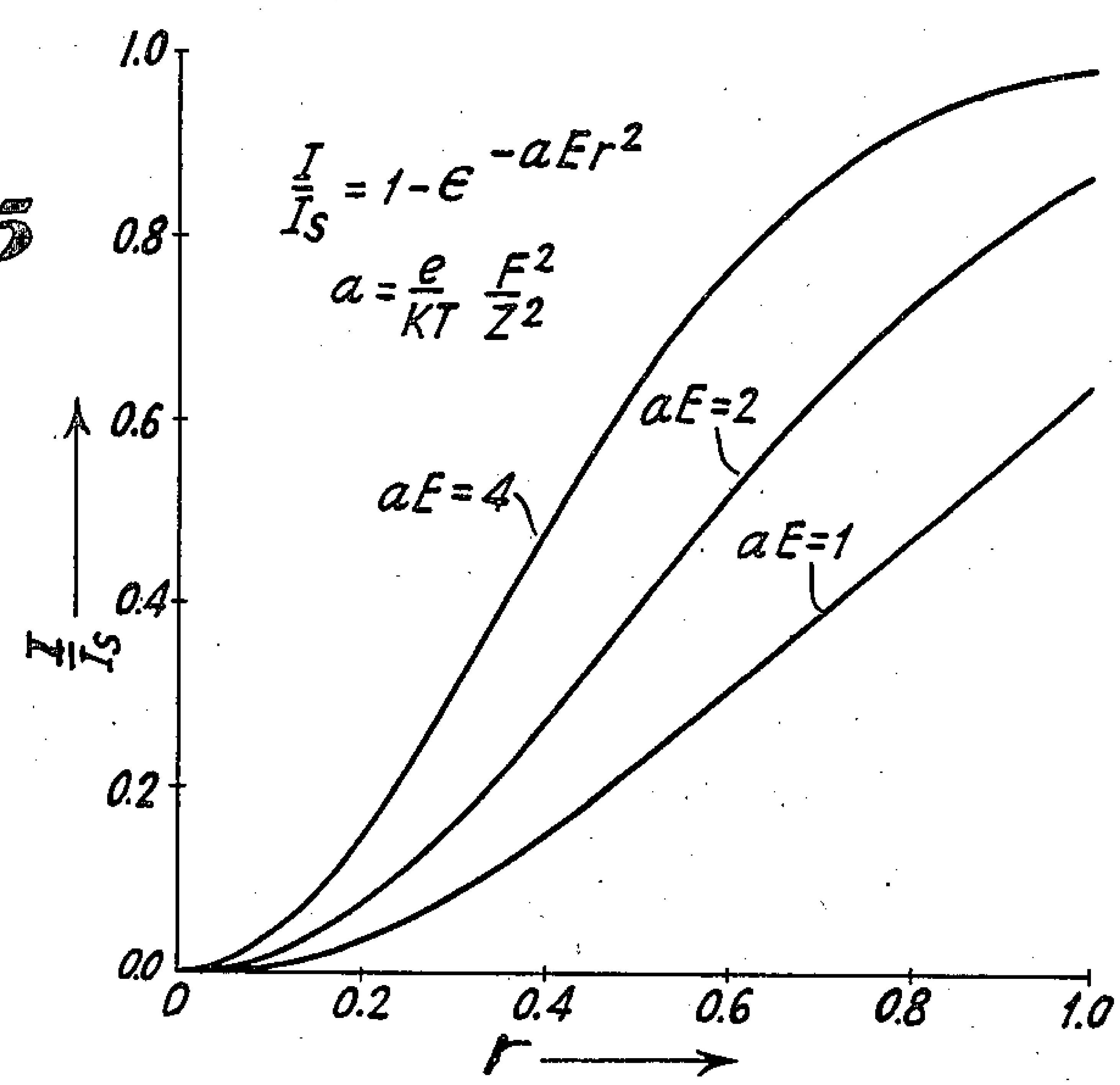
Fig. 4



COMPUTED VARIATION OF ELECTRON DENSITY IN A CROSS-OVER

Fig. 5



COMPUTED VARIATION OF THE CURRENT THROUGH A CROSS-OVER DEFINING APERTURE

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Fig. 6

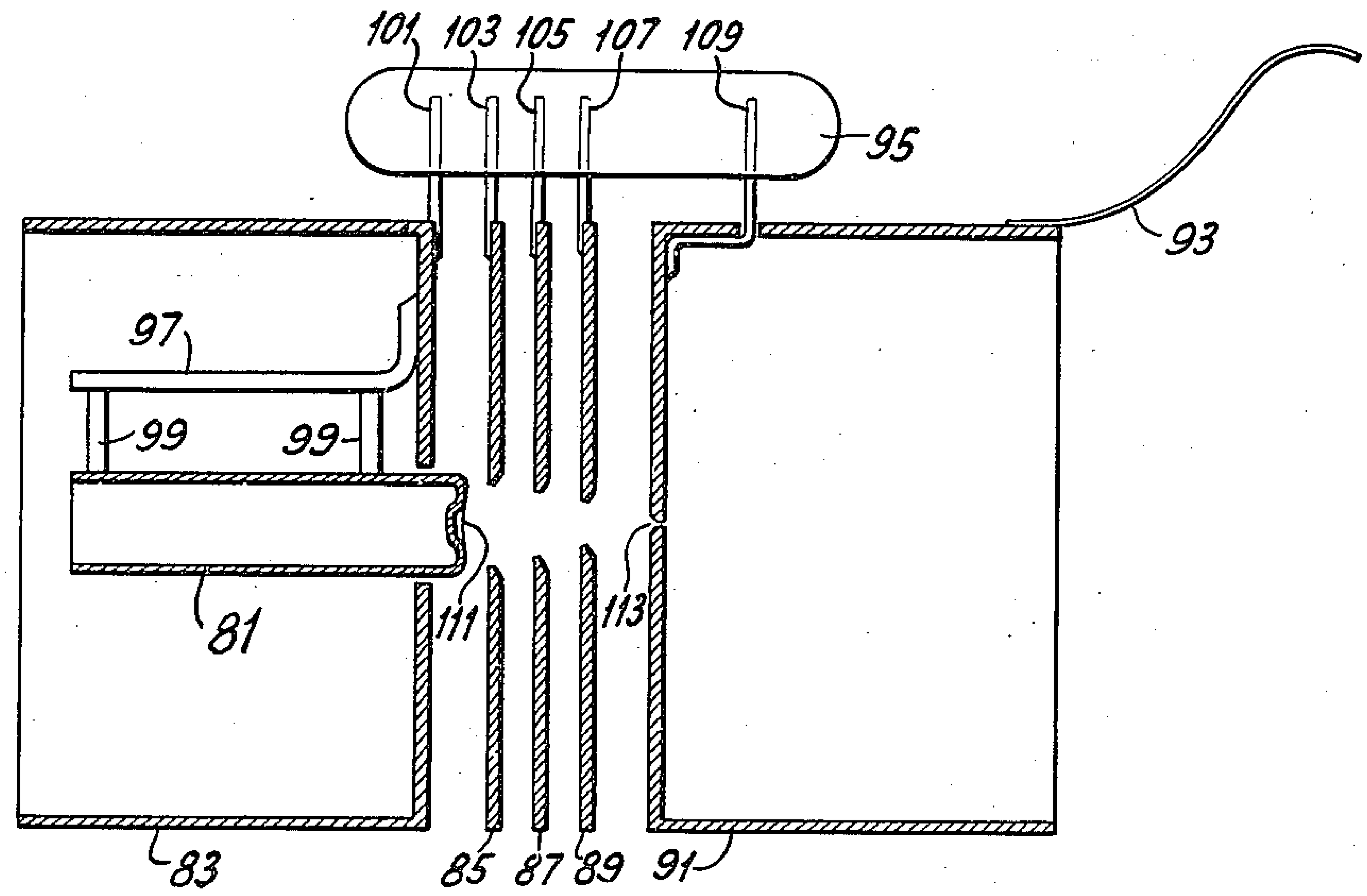
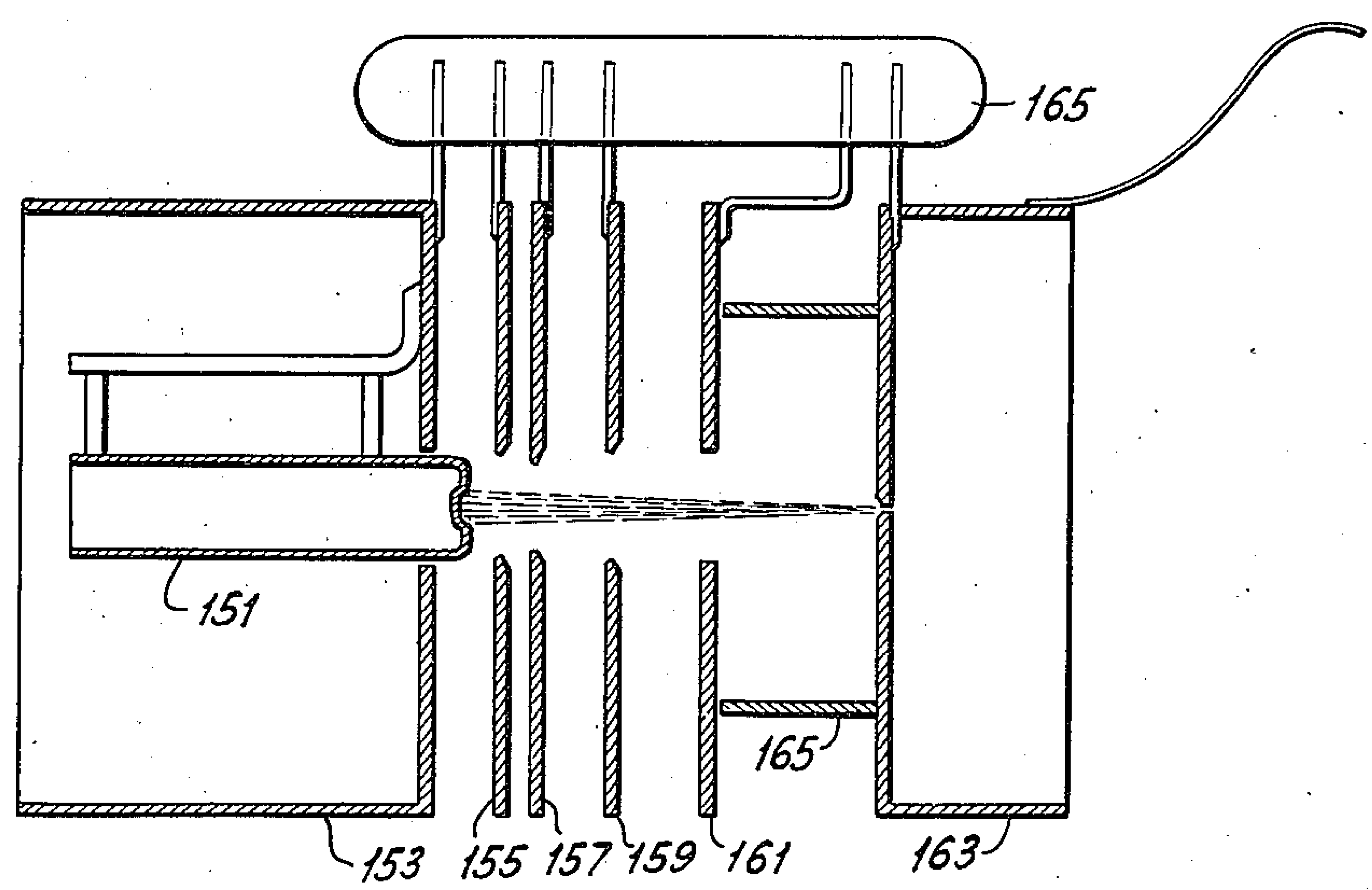


Fig. 7



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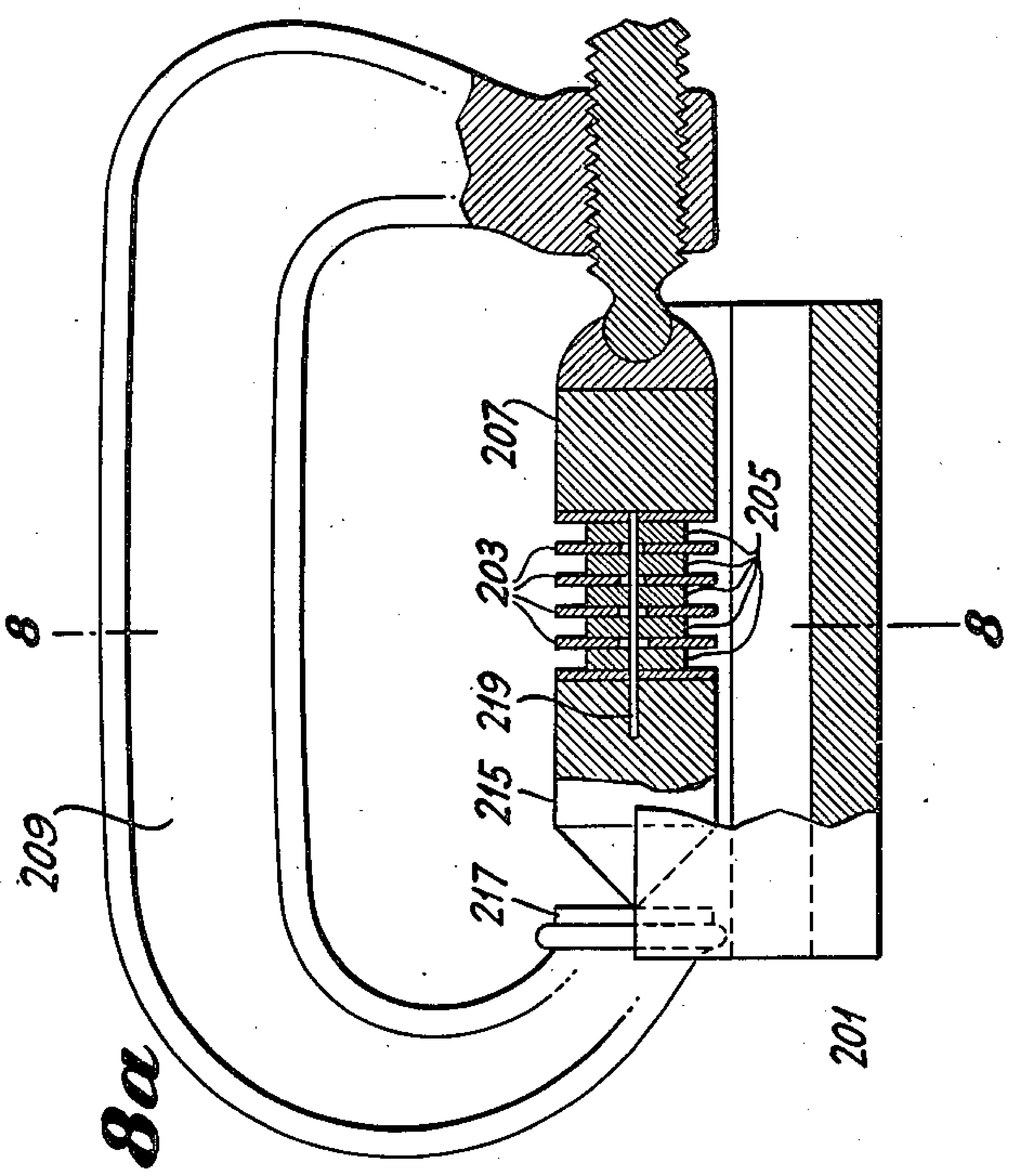

Fig. 8a

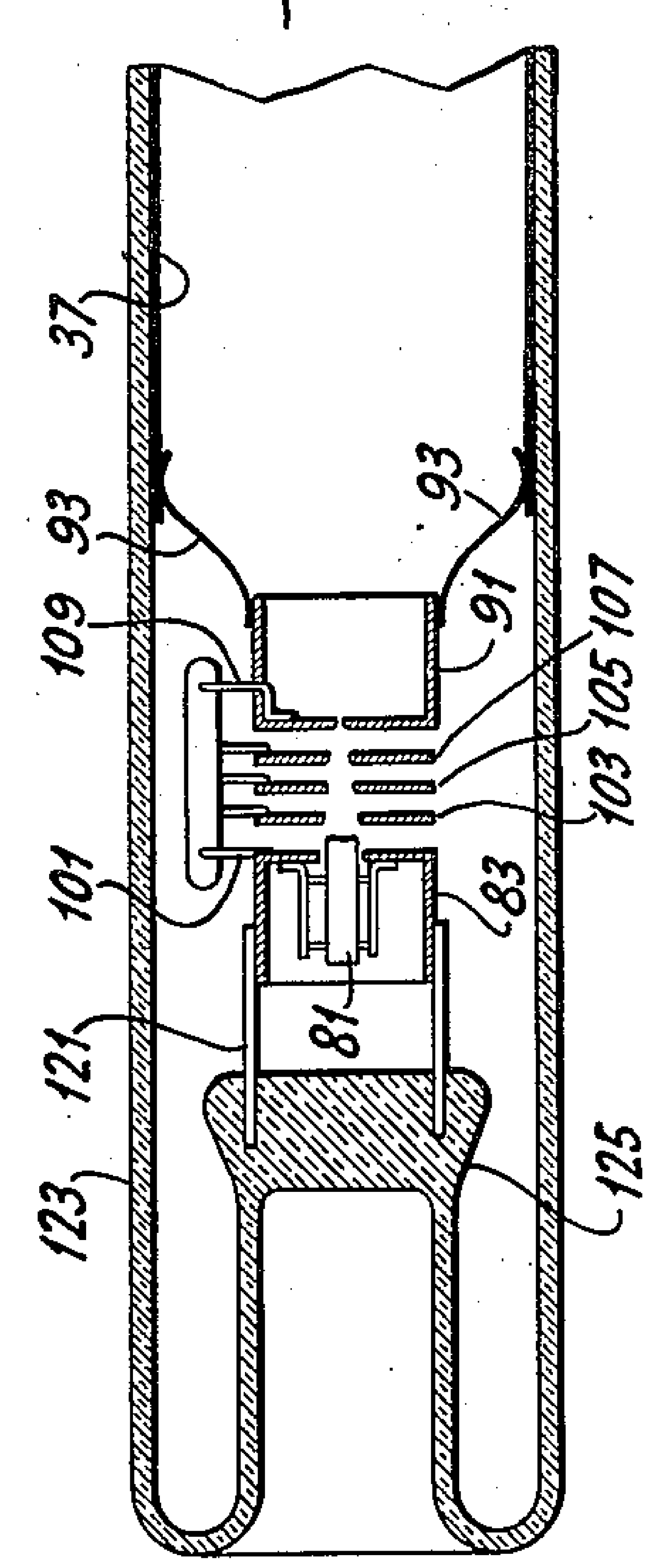

Fig. 9

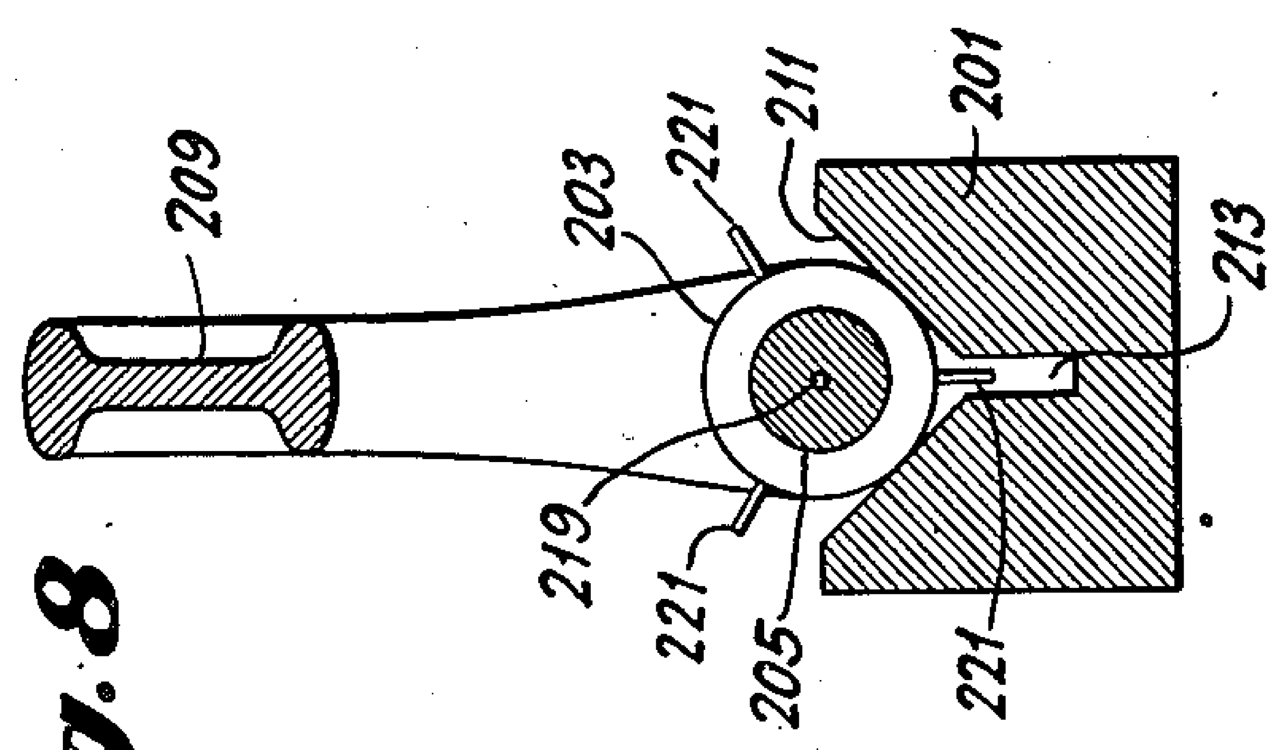

Fig. 8

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2,266,773

UNITED STATES PATENT OFFICE

2,266,773

ELECTRON DEVICE

Russell R. Law, West Orange, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application May 11, 1937, Serial No. 141,910

16 Claims. (Cl. 250—27.5)

This invention relates to electronic devices and, in particular, to a cathode ray electron gun and focusing system for cathode ray projection tubes for use in television. To reproduce a picture by television of adequate size, it has been proposed to first produce a small primary image which is in turn projected onto a viewing screen of suitable size by an appropriate optical system. In such a system, the primary image must be very bright to provide sufficient screen illumination and where the primary image is derived from the energy in an electron beam, a beam of high power is required.

Conventional electron guns of the type commonly used in present day cathode ray tubes are not altogether satisfactory due to the inability of such electron guns to give a sufficiently large beam current in the small spot required by the conditions of a small primary image of high line definition.

The design of conventional electron guns for use in cathode ray tubes, such as described in the paper entitled "Theory of Electron Gun" by Maloff and Epstein in the Proceedings of the Institute of Radio Engineers, vol. 22, No. 12, page 1386 et seq. (Dec. 1934), provides a cathode region lens which produces a first cross-over near the cathode at relatively low-voltage and a final focusing electron lens which serves to reimage the first cross-over on the distant fluorescent screen. The use of the term cross-over is in accordance with the terminology used by those skilled in the art and defined on page 1399 of the above referred to article by Maloff and Epstein and locates the points on the axis of an electron beam at which minimum areas of the beam takes place.

In such electron guns, the spot size is dependent upon the control electrode potential, generally the modulation potential superimposed upon a fixed potential, due to changes in the size of the first cross-over which is inherent in such designs. Furthermore, the cross-over is inherently large due to the very pronounced effects of initial velocity of the emitted electrons from the cathode which is present in the formation of a cross-over at low voltage. As a consequence, the first cross-over increases in size with increasing beam current, thereby producing the objectionable defocusing effect known as "blooming," in which the increased spot size has a center portion of relatively high brilliance and a halo of reduced brilliancy surrounding the central portion. Blooming is objectionable since it not only destroys the detail of the picture, but also reduces the contrast range of the reproduced picture. Other distortions arise from the imperfections of the cathode and focusing electrodes alignment and the spherical aberrations present in the electron lenses.

Accordingly, one of the main objects of my invention is to provide a new and improved method and means for producing large images of electro-optically transmitted scenes.

An important object of my invention is to provide an improved cathode ray projection tube having a new and improved electron gun.

Another important object of my invention is to provide an electron gun which will give a high beam current in a small spot whose size is substantially independent of the beam's modulation for use in cathode ray tubes.

Still another important object of my invention is to provide a cathode ray tube with a much reduced spherical aberration by the use of magnetic lenses of special design.

Another object of my invention is to provide an electron gun with an improved first cross-over.

A further object of my invention is to provide an electron gun having a first cross-over electrostatic lens for accurately focusing a large current from a large area cathode into a small cross-over.

A still further object of my invention is to provide an electron gun and focusing system in which the full available second anode voltage is used for first cross-over formation and in which, a small defining aperture is located at the first cross-over for fixing the size and location of the first cross-over.

Another object of my invention is to provide an improved way of mounting and aligning the cathode and the modulating and focusing electrodes and anodes.

Yet another object of my invention is a new method of modulating the beam intensity of a high beam current cathode ray tube.

Other objects of my invention will be readily ascertained by reading the following detailed description together with the drawings.

In the drawings,

Fig. 1 shows schematically in block diagram, a television reproducing system embodying my improved projection tube and method;

Fig. 2 shows diagrammatically one form of my projection tube and focusing system;

Fig. 3 is a diagram for use in explaining the underlying theory of my invention;

Figs. 4 and 5 are graphs illustrating operating characteristics of an electron gun embodying my invention;

Figs. 6 and 7 show in detail two embodiments of the first cross-over forming system in accordance with my invention;

Figs. 8 and 8*a* show diagrammatically in end and elevation view respectively the method of aligning and mounting the electrodes, and

Fig. 9 shows in detail the method of mounting and aligning the elements of one form of my electron gun.

In Fig. 1 is shown a cathode ray tube **1** in register with an optical system **3**, shown conventionally as a single lens although a more complex system may be used, and a viewing screen **5**, which may be of either the opaque or translucent type in accordance with viewing the projected image from the projection side or the rear side of the screen.

A high current beam of electrons **63** is formed by the electron gun comprising the cathode **25**, the electrodes **27**, **29**, **31** and **33** and the anodes **35** and **37**, and projected upon the luminescent screen **39**. Under the impact of the focused beam of electrons light is emitted by the screen **39** which, in turn, is collected by the optical system **3** and focused upon the viewing screen.

The electrodes **29**, **31** and **33** are energized by the electrical energy source **9** and maintained at positive potential with respect to the cathode **25**. The first and second anodes **35** and **37** are energized by the potential source **13**. The specially shaped magnetic focusing coil **19** is energized by the power supply **11** and shielded from the deflecting coils **21** and **23** by a magnetic shield **53**. The deflecting coils are energized by their respective deflector circuits **15** and **17** for causing the beam to trace a path across the screen **39** in mutually perpendicular directions simultaneously and in synchronism with the transmitting scanning apparatus. The intensity of beam current is modulated by the video signals by the amplifier **7** which are simultaneously applied to both electrodes **29** and **31** through the coupling condensers **47** and **49** respectively. Direct coupling can also be used to provide background control or a separate background control tube can be connected to the resistors **43** and **45** at the junction of these resistors and the condensers **47** and **49**, so that the potential of the electrodes **29** and **31** may be varied in accordance with the average integrated light intensity of the entire scene in a similar manner disclosed by the pending Kell application Serial No. 565,226 filed September 26, 1931.

The deflecting and synchronizing circuits, video amplifier and power supplies may take the form shown in the complete television receiver shown in U. S. Patent No. 1,975,056, issued to W. L. Carlson on September 25, 1934, and are not described here in detail since any conventional television receiver may be used with my new and improved projection tube.

The electrodes **29**, **31** and **33** are all energized with positive voltage in a predetermined increasing order by the source **9** as will be pointed out in more detail below. In the leads **57** and **59** are provided resistors **43** and **45** respectively to maintain the proper bias on electrodes **29** and **31** as the beam intensity is varied by the video signals, as described in the Shoenberg et al. application, Serial No. 745,838, filed September 28, 1934.

The electron gun structure together with my improved magnetic lens will now be described in detail. Before describing the electron gun in detail, however, it is necessary to digress for an analysis of the cross-over formation in order to more properly understand how I achieved the aims and objects of my invention.

For a generalized analysis of first cross-over formation we may consider any non-uniform potential field having axial symmetry wherein $E=f(r, z)$. Let the cathode K, Fig. 3, conform to one of the equipotential surfaces defined by $E=f(r, z)$. In the absence of space charge we may so choose this potential function that all electrons leaving the cathode with zero velocity of emission will unite in a common point p at the cross-over. Let us designate the paths of these electrons as principal trajectories. Other electrons leaving the cathode surface with initial velocities of emission will deviate from these principal trajectories by amounts depending upon the magnitude and direction of their initial velocities.

Inasmuch as the non-uniform potential function $E=f(r, z)$ is symmetrical about the axis, it constitutes an electron lens. The action of this electron lens is best illustrated by observing its effect upon a few representative electrons. For example, electrons originating at point o which do not deviate greatly from the principal trajectory will be brought to a common focus at point f. Similarly, electrons originating at adjacent points o' and o'' will be focused at points f' and f'' respectively. For small deviations from the principal trajectory the force tending to restore an electron to its particular principal trajectory is everywhere proportional to its displacement. Furthermore, the displacement is in turn proportional to the initial radial velocity. Neglecting the effects of initial longitudinal velocity, the deviation of the kth electron from its principal trajectory may be expressed by

$$\delta_k=\sqrt{\frac{E\dot{r}_{o_k}}{E}}f(Z)_k \qquad (1)$$

where:

δ_k=deviation of kth electron from its principal trajectory

$E\dot{r}_{o_k}$=initial radial velocity of the kth electron in equivalent volts

E=voltage applied to cross-over-forming system

$f(Z)_k$=function of Z describing the deviation of the kth electron from its principal trajectory.

Since all the principal trajectories intersect at a common point p which is on the axis of symmetry at the center of the cross-over, the radial position r_k of the kth electron at the cross-over is

$$r_k=\sqrt{\frac{E\dot{r}_{o_k}}{E}}f(Z)_k\frac{1}{\cos\theta_k} \qquad (2)$$

where θ_k is the angle between the kth principal trajectory and the axis of symmetry. In practice θ_k is small so that $\cos\theta_k$ is substantially unity. Furthermore $f(Z)_k$ is substantially the same for all electrons, consequently the radial position of any electron at the cross-over is very nearly

$$r=\sqrt{\frac{E\dot{r}_o}{E}}f(Z) \qquad (3)$$

With reference to any particular potential configuration which forms a cross-over at a specified distance Z from the cathode, the function $f(Z)$ must have the dimensions of Z and is dependent upon some proportionality factor F which defines how the potential E is applied to the system. Equation 3 may therefore be written

$$r=\sqrt{\frac{E\dot{r}_0}{E}}Z\times\frac{1}{F} \qquad (4)$$

Solving Equation 4 for $E\dot{r}_0$

$$E\dot{r}_0=\frac{r^2E}{Z^2}F^2 \qquad (5)$$

If the thermally emitted electrons leaving the cathode surface have a Maxwellian velocity distribution, the current contributed by electrons with initial radial velocity components lying between $\dot{r}_0$ and $\dot{r}_0+\Delta\dot{r}_0$ is:

$$dI(\dot{r}_0)=A\epsilon^{-\frac{m\dot{r}_0^2}{2kT}}\dot{r}_0d\dot{r}_0 \qquad (6)$$

The ratio of the current due to electrons with initial radial velocities lying between $\dot{r}_0=0$ and $\dot{r}_0=\dot{r}_0$ to the total space current is

$$\frac{I}{I_s}=\frac{A\int_0^{\dot{r}_0}\epsilon^{-\frac{m\dot{r}_0^2}{2kT}}\dot{r}_0d\dot{r}_0}{A\int_0^{\infty}\epsilon^{-\frac{m\dot{r}_0^2}{2kT}}\dot{r}_0d\dot{r}_0} \qquad (7)$$

which yields

$$\frac{I}{I_s}=1-\epsilon^{-\frac{m\dot{r}_0^2}{2kT}} \qquad (8)$$

If $\dot{r}_0$ be expressed in equivalent volts

$$\frac{I}{I_s}=1-\epsilon^{-\frac{e}{kT}E\dot{r}_0} \qquad (9)$$

Substituting Equation 5 in 9, the current in the cross-over inside the radius r is

$$I=I_s\left[1-\epsilon^{-\frac{e}{kT}\frac{r^2}{Z^2}F^2E}\right] \qquad (10)$$

where:

e/k=11,606 degrees per volt, characteristic of an electron
T=cathode temperature in degrees Kelvin
Z=cathode-to-cross-over distance
r=radius at cross-over
E=voltage applied to cross-over-forming system
F=a proportionality factor depending on the way in which the potential is applied to the system.

For purposes of subsequent analysis it is convenient to abbreviate Equation 10 as

$$I=I_s[1-\epsilon^{-ar^2E}] \qquad (11)$$

where

$$a=\frac{e}{kT}\frac{F^2}{Z^2}$$

The electron density is also of interest because it gives a physical picture of conditions at the cross-over. By differentiating Equation 11 with respect to r and dividing both sides by $2\pi r$, we see that the current density i is

$$i=\frac{I_s}{\pi}aE\epsilon^{-ar^2E} \qquad (12)$$

These last two equations are sufficient to describe many features of the cross-over. For purposes of illustration let us suppose that a cathode temperature T, a cathode-to-cross-over distance Z, and a potential distribution F are selected such that the coefficient

$$a=\frac{e}{kT}\frac{F^2}{Z^2}=0.001$$

In addition, let the voltage across the first-cross-over-forming system assume the values 1, 2, and 4 kilovolts. The parameter aE then assumes the values 1, 2, and 4 per square centimeter respectively. Let us now see what happens at the cross-over under these conditions. Fig. 4 shows the variation of current density per unit total space current with radius for these three values of applied voltage computed from Equation 12. The current density is seen to be greatest in the center and has the maximum values

$$i_m=\frac{I_s}{\pi}aE$$

amperes per cm.². At the lower value of the parameter aE, in this case when the applied potential is 1 kilovolt, the maximum current density is seen to be only 0.32 I_s amperes/cm.², and it is observed to drop off very slowly with radial distance. At the higher value of the parameter aE, in this case when the applied potential is 4 kilovolts, the maximum current density is 1.27 I_s amperes/cm.², or four times as great, and drops off very rapidly with radial distance away from the center. Thus at the higher voltage, the current density at the center of the cross-over per unit space current is increased because the beam is concentrated into a smaller cross-over.

To define sharply the edge of the first cross-over and prevent radical changes in its size due to defocusing by modulation, it is desirable to use a small defining aperture located at the cross-over. In contemplation of this we become interested in determining how the current through a first-cross-over-defining aperture depends upon the size of the aperture and the parameter aE. Figure 5 illustrates how the current through a cross-over-defining aperture varies with the radius of the defining aperture. These plots are computed from Equation 11 for the same values of the parameter aE.

In Fig. 5 it will be observed that larger and larger fractional parts of the total space current may be concentrated into a cross-over of given size as the parameter aE is increased. For example, if as before a=0.001 per square cm., 50% of the total space current may be concentrated into a cross-over-defining-aperture 1.68 mm. in diameter with a potential of 1 kilovolt. At 2 kilovolts, 50% of the total space current may be concentrated into a 0.84 mm. aperture. Thus at higher and higher values of voltage, a given fractional part of the total space current can be concentrated into a smaller and smaller cross-over-defining-aperture.

In addition to the effects of different voltages applied to the cross-over-forming system, it is evident that any alteration in cathode temperature, cross-over-forming system geometry, or potential distribution factor which may alter the coefficient a will have an effect analogous to a change in voltage insofar as concentration of the beam at the cross-over is concerned. For example, the curves of Figs. 4 and 5 might be taken to represent a case wherein the applied voltage was constant at one kilovolt and the coefficient a assumed the values 0.001, 0.002, and 0.004 per square cm., respectively. In the light of these observations we would conclude that the cathode temperature T should be kept as low as possible consistent with satisfactory emission, the voltage E applied to the first-cross-over-forming system should be as high as possible and the potential distribution should be adjusted to give a large value of F.

The design of a complete electron gun in accordance with my invention requires a consideration of certain other factors in addition to the theory of first cross-over formation. First, we must recall that the electrons issuing from the first cross-over are to be reimaged on the distant screen by a final focusing lens. The usable aperture of the final focusing lens is limited by its aberrations. As a consequence, the spread of the beam emerging from the first cross-over must be kept within the limits imposed by the available aperture of the final focusing lens. Second, the available voltage may be apportioned to the two functions of first-cross-over formation and final focusing in any desired manner. That is, we may use only a part of the available voltage for first-cross-over formation, reserving the remainder for final focusing; or, the entire available potential may be used for first-cross-over formation and final focusing may be accomplished by a magnetic lens or an electrostatic lens of the retarding-electrode type.

The significance of these two considerations may be evaluated in the following manner. The useful beam current in a cross-over of radius r is given by Equation 11. For purposes of analysis we may suppose the cathode current to be space-charge limited according to the conventional three-halves-power law. In this event

$$I_s \propto \frac{(\text{Cathode diameter})^2}{(\text{Cathode-to-cross-over-distance})^2}E^{3/2}$$

Inasmuch as the spread of the beam is directly proportional to the ratio of the cathode diameter to the cathode-to-cross-over distance, this ratio is limited by the permissible beam spread for any particular potential distribution. In practice, therefore, $I_s \propto E^{3/2}$.

If we use full second-anode voltage for first-cross-over formation the object and image spaces of the final focusing lens will have the same index of refraction and the magnification will depend simply upon the ratio of object to image distance. On the other hand, if the first cross-over if formed at some voltage E_1 which is a fractional part of the total voltage E_2, final imaging may give a demagnification due to the differing indices of refraction in the object and image spaces. Because of this demagnification, we should be willing to accept a larger first cross-over at low voltage. This characteristic may be readily analyzed if we neglect the shift in position of the equivalent thin lens and consider the magnification to be

$$m=\frac{\text{Image distance}}{\text{Object distance}}\sqrt{\frac{E^1}{E^2}}$$

In this event, a first cross-over formed at low voltage might be

$$\sqrt{\frac{E_1}{E_2}}$$

times as large and still give the same final spot size. To illustrate, suppose that the object and image distances are equal, let the required final spot size be 1 mm., and let the available voltage be 10 kilovolts. If all the voltage is used for first cross-over formation, $E_1=E_2=10$ kilovolts and the magnification is unity. The first-cross-over-defining aperture should then be 1 mm. in diameter. If on the other hand the first cross-over were formed at some lower voltage, say $E_1=2$ kilovolts, the magnification would be

$$\sqrt{\frac{E^1}{E^2}}=\sqrt{\frac{2}{10}}=0.45$$

and the first-cross-over-defining aperture would be

$$\frac{1}{0.45}=2.22 \text{ mm}$$

in diameter for the same final spot size. The ratio of the current through the final aperture to the total space current in the two cases is, however, seem to be the same for both cases. That is $r^2E=(2.22)^2(2)=(1)^2(10)=\text{constant}$. That is, the ratio of beam current to total space current is theoretically the same for either a high or a low voltage first cross-over.

If we assume the total cathode current to be space charge limited and to vary approximately as the three-halves power of the voltage, we immediately see the benefit to be derived from using high voltage for first-cross-over formation for any given value of the coefficient a. For since the ratio of beam current to total space current for a given final spot size is independent of voltage, the total space current and likewise the beam current vary approximately as the three-halves-power of the voltage applied to the first-cross-over forming system. To return to our preceding example where 10 kilovolts are available, we would expect an increase in beam current of $(5)^{3/2}$ or approximately 10 fold when we changed from a 2-kilovolt first-cross-over forming voltage to one of the 10 kilovolts. Provided the permissible cathode emission density is not exceeded, it is desirable to use all available voltage for first cross-over formation.

In Fig. 6 I have shown one electron gun built in accordance with my invention based on the theory I have evolved above.

This electron gun uses full available voltage for first cross-over formation and has a first-cross-over-defining aperture located at the first cross-over. This first-cross-over-defining aperture serves to fix the size of the electron object imaged on the screen by the final focusing lens. The relative voltages applied to the intermediate electrodes **85**, **87**, and **89** determine the potential distribution in the first-cross-over-forming system. Modulation of the beam current is accomplished by varying the potentials on electrodes **85** and **87**. Inasmuch as full second-anode voltage is used for first-cross-over formation, the final focusing-lens object and image space have the same index of refraction and the final spot size is given by

$$\text{Final spot size}=\text{First cross-over-defining aperture size}\times\frac{(\text{Image-distance})}{(\text{Object distance})}$$

The minimum image distance is fixed by the available deflecting power. The maximum object distance is determined by the available aperture of the final focusing lens and the spread of the beam. It is, therefore, desirable to keep the spread of the beam low. It has been pointed out already that the spread of the beam emerging from the first-cross-over increases with cathode diameter. Consequently, the cathode should be as small as is consistent with the total desired space current at a practical emission density. If we assume 0.5 ampere per square centimeter to be the maximum permissible emission density, then for an electron gun, from which a total space current of 4 milliamperes is desired, the minimum permissible cathode diameter is about 1 mm.

The spherical indentation on the cathode improves the performance of the first-cross-over forming system. Such a curved surface, limited-area cathode also possesses advantages in assembly in that a suitable spacer may be interposed between the cathode and the first control grid element for accurately positioning the cathode without contaminating the active emitting surface.

Although final focusing may be accomplished by either magnetic or retarding type electrostatic lenses, the electron gun illustrated in Fig. 2 uses a magnetic lens. This choice was based on experimental study which showed that larger aberration-free apertures could be obtained with magnetic lenses than with conventional concentric-cylinder electrostatic lenses. The magnetic final-focusing lens illustrated in Fig. 2 is wound on a spool of special shape in order to provide a more advantageous flux distribution. The shape is such to provide an annular magnetic coil whose inside diameter varies parabolically with the vortex of the parabola toward the axis of the tube. This new and unconventional design of a magnetic focusing lens has made it possible to obtain very small spherical aberration even with relatively large beam diameter. An iron-end plate **53** serves to shield the magnetic lens from the deflecting coils and to prevent interaction between the focusing and deflecting fields. Inasmuch as the spread of the beam emerging from the first-cross-over forming system illustrated in Fig. 6 is about 6 degrees for a beam diameter of 6 mm., the effective object distance should not exceed 60 mm. since the minimum image distance must be about 160 mm. to give adequate deflection sensitivity, the first-cross-over-defining aperture must be about 0.1 mm. in diameter to give a 0.25 mm. spot on the screen. The choice of this final-spot size is based on a consideration of the picture size and number of scanning lines. The picture size is, in turn, influenced by the optical system used for projection.

In this gun the indirectly heated cathode **81** is supported from the Wehnelt cylinder **83** by three nichrome uprights **97** spaced 120° around the axis of the cathode **81** and tabs **99**. The indirectly heated cathode has a spherical depression **111** which is coated with electron emitting material. In register and in spaced relation to the cathode are four accelerating electrodes **85, 87, 89** and **91**. Each of the electrodes is apertured and the aperture size decreases continually from electrode to electrode with electrode **91** having the smallest aperture **113**. The electrode **91** is in the form of an annular cylinder closed at the end nearest the cathode. Three tungsten wires **93** fastened to the other end of the electrode **91** may contact to the coating **37** of the tube **1**, as shown in Fig. 1. The coating of the bulb which serves as a second anode is a conducting layer and may be, for example, aquadag or a thin layer of silver, or a thin layer of silver which is coated with aquadag, to reduce internal illumination and stray light. The electrodes are held rigidly in alignment and coaxial with one another by the heavy studs **101, 103, 105, 107** and **109** imbedded in glass heads **95**. It will be understood that Fig. 6 is a cross-section, only one of the three beads and series of studs being shown. The other two beads and series of studs are spaced around the periphery of the electrodes at an angle of 120 degrees with each other. In one such gun the apertures had the following sizes and voltages applied:

Electrode	Diameter of aperture	Voltage
83	0.152	0
85	0.086	100
87	0.067	200
89	0.52	2,000
91	0.004	10,000

The voltages are all measured with respect to the cathode and all voltages are positive. The high voltage applied to the electrode **91** is through the contact cap **51**, the conducting layer **37**, and the tungsten wire **34** of the tube **1**, as shown in Fig. 1. The entire electrode assembly of the gun shown in Fig. 6 is supported by three heavy rigid wires **121** spaced approximately 120° apart as shown in Fig. 8 by element **221**. These heavy wires are imbedded in the press **125** of the tube wall structure **123**.

It will thus be seen that my electron gun structure has a rigid unitary assembly supported from the glass press **125** and prevented from moving under mechanical agitation by the rigid construction and the spring leads **93**, which further help to center and position the structure. Accordingly, a projection tube constructed as I have described, may be subjected to heavy mechanical shock without in any way affecting the alignment of the elements with respect to one another or with respect to the fluorescent screen within the tube. The aperture **113** is positioned right at the cross-over point in accordance with the theory which I have outlined above.

An alternative form of electron gun is shown in Fig. 7 in which, however, an additional electrode is provided. In this type of gun the apertures are no longer uniformly reduced in size as the order of the aperture position is increased from the cathode. The first-cross-over-defining aperture, however, is of the same size as that shown in Fig. 6. In the structure shown in Fig. 7, however, the spacing between the electrodes is no longer uniform and the combination of the non-uniform spacing and change in voltage distribution produces the same potential proportional factor so that the cross-over area is substantially the same as that for the system shown in Fig. 6. One such form of gun shown in Fig. 7 had the following aperture sizes, spacing distances and potentials:

Electrodes	Apertures' diameter in inches	Spacing from preceding aperture	Voltage
		Inches	
153	0.152	0.00	0
155	0.125	0.08	0
157	0.105	0.03	100
159	0.125	0.08	2,000
161	0.125	0.10	10,000
163	0.004	0.20	10,000

The electrode **163** has a cylindrical extension **165** coaxial with the aperture for collecting any secondary electrons which might be emitted by the first-cross-over-defining aperture being impacted by the beam.

In order to accurately align the electrodes, I have devised the following method which is simple in practice and provides an improved electron gun structure in which no insulating materials are interposed in the region of the focusing fields produced between the electrodes. To this end, a V-block 201 has a slot 213 cut at the apex of the V perpendicular to the base. The electrodes 203 and spacers 205 are alternately stacked and maintained adjacent to each other on a spacer support rod 219 which passes through the apertures provided in the spacers and the electrodes. The stacked spacers and electrodes are then laid in the V 211 of the block end and blocks 207 and 215 placed one at each end of the stacked array. The faces of the end blocks engaging the stacked elements have centrally located holes so that the spacer rod 219 may be placed therein for preliminary alignment. The C clamp 209 is then placed about the assembled elements and end blocks and tightened. The amount of pressure is so adjusted that the elements are maintained in position by relatively small frictional forces between the faces of the electrodes and the washers. The electrodes are then tapped lightly from above so that each of the electrodes is in contact with both faces of the V 211. The end blocks as well are tapped so as to make contacts with both faces of the V, and when this has been done, the C clamp is then tightened up with considerable pressure. The faces of the C clamp with which the end block 215 is in contact, has a copper face 217, the purpose of which is to provide a certain amount of elasticity to take up expansion, as will be described hereinafter. The electrodes 203 may have the short stud members 221 spot welded thereto prior to the assembly or after the array has been firmly clamped. When the array has been firmly clamped, the C clamp together with the array is removed and glass beads made molten and affixed around the heavy studs, as shown in Fig. 6.

Suitable means may be provided for holding a C clamp to leave the ends of the separators to manipulate the beads and the gas flame. During the process of affixing the beads to the studs 221, the electrodes and end blocks absorb considerable heat from the flame used to make molten the glass and to heat the studs 221. Considerable expansion, therefore, of the assembly takes place, but by the use of the copper disk 217, this expansion is prevented from causing warping or distortion of the electrodes, since the copper disk which is soft, yields before the electrodes, which are of solid metal. The use of the copper disk to take up the expansion has the further advantage of preventing excessive pressures building up between the electrodes and the insulating spacers, and thus, avoids crushing of the spacers, which, if not prevented, would result in misalignment of the electrodes.

When the assembly has been cooled, the C clamp is released and the support rod 219 removed, which permits the spacers to drop out, leaving a unitary electrode structure with the only insulating material in the form of the glass beads outside of the region of the electrostatic fields used for focusing.

In place of a V block, parallel cylindrical rods appropriately spaced may be used for aligning the elements, the spacing between the rods being less than the diameter of the electrodes. This method of assembly has the further advantage of avoiding distortions which arise from the usual jig method of assembling electrodes. Where the jig method is used, the jig itself must be heated by the gas flame in order to appropriately fix the electrodes with respect to one another. Such heating, due to unequal expansions of the jig structure, warps the jig structure and introduces undesirable misalignments. The use of my method, however, avoids in the first place, the use of costly jigs and such misalignments.

While by suitable adjustment of the potentials of the electrodes 29, 31 and 33, a linear modulation characteristic may be provided, I prefer to adjust the potentials of these electrodes to provide an approximately square-law modulation characteristic. By providing such a characteristic so that the beam current varies as the square of the modulation potential, an improved contrast ratio of light to dark portions of the picture is obtained. This is desirable since it results in a picture having better viewing qualities. The stray light from the room which limits the density of the darkest portions is rendered ineffective by the increased intensity values of the lighter portions of the picture. A further advantage results, likewise, whenever there is a tendency for the material comprising the fluorescent screen, to depart from linear conversion of electronic energy to light energy, or where saturation effects of the screen at high beam current values are present. Under such circumstances, the non-linear modulation characteristic of the beam tends to compensate for the non-linear conversion characteristic of the screen which has generally a curvature of opposite sign to that of the modulation characteristic. Thus, the overall effect is one calculated to reproduce the transmitted image with identical density values of the original image.

Having described my invention, what I claim is:

1. A cathode ray tube comprising an envelope, a cathode, a shield electrode concentric with and surrounding said cathode, and displaced longitudinally from said cathode and said shield and in the order named, a plurality of apertured disk electrodes of uniform diameter with decreasing effective apertures in register with said cathode, each of said disk electrodes being adapted to be maintained at positive potential, an anode supported from the wall of the envelope, and a fluorescent screen supported by the envelope normal to the axis of the cathode.

2. A cathode ray tube comprising an envelope, a cathode, a shield electrode concentric with and surrounding and supporting said cathode, and displaced longitudinally from said cathode and said shield and in the order named, a plurality of modulating disk electrodes adjacent to and in register with said cathode, a plurality of focusing disk electrodes in register with said modulating electrodes, said focusing electrodes having decreasing effective apertures, an anode supported on the wall of the envelope, and a fluorescent screen supported by the envelope normal to the axis of the cathode.

3. A cathode structure for electron devices comprising an apertured cup-shaped electrode, a plurality of supporting members equi-spaced within the cup-member and affixed to the planar wall of the cup, a metallic cylinder positioned coaxial with the cup-member and projecting through the aperture, and a plurality of support members engaging the metallic cylinder and each of the supporting members.

4. A cathode structure for electron devices comprising an apertured cup-shaped electrode, a plurality of supporting members equi-spaced within the cup-member and affixed to the planar

wall of the cup, a metallic cylinder closed at one end positioned coaxial with the cup member and projecting through the aperture, and a plurality of support members engaging the metallic cylinder closed at one end and each of the supporting members, and a recess in the exterior of the closed end of the metallic cylinder, and electron emissive material deposited in the recess of the metallic cylinder.

5. An electrode structure for a cathode ray tube comprising a cylindrical electrode planarly closed at one end, said end being apertured, a cathode supported from within the cylindrical electrode and projecting through the aperture, a plurality of apertured disk electrodes in register with the cathode, an apertured cup-shaped electrode in register with the cathode and the apertured disk electrodes, stud members affixed to each of the electrodes, and supporting means engaging the studs and holding the electrodes in predetermined spaced relation.

6. The method of assembling disk electrodes wherein spacers are used, which comprises the steps of alternating stacking spacers and the electrodes, lightly compressing the stacked spacers and electrodes, aligning the spacers and electrodes between guides, compressing under great pressure the aligned electrodes and spacers, affixing radial support arms to each of the electrodes, said radial arms being equally spaced around the periphery of the electrodes, molding a vitreous body about the radial arms to maintain the electrodes in predetermined spaced relationship, totally releasing the compression and subsequently removing the spacers.

7. The method of reducing spherical aberration in electron optical systems, which comprises the steps of producing electrons from a source, directing the electrons through progressively increasing accelerating fields to produce cross-over, terminating the acceleration at the point of cross-over, directing the electrons passing the cross-over point toward a fluorescent screen, and producing intermediate the cross-over point and the fluorescent screen an electromagnetic field whose intensity varies parabolically as a function of the distance between the cross-over point and screen.

8. The method of reducing spherical aberration in electron optical systems, which comprises the steps of producing electrons from a source, directing the electrons through progressively increasing accelerating fields to produce cross-over, terminating the acceleration at the point of cross-over, directing the electrons passing the cross-over point toward a fluorescent screen, producing intermediate the cross-over point and the fluorescent screen an electromagnetic field whose intensity varies parabolically as a function of the distance between the cross-over point and the screen, producing two mutually perpendicular deflecting fields for moving the electrons directed toward the fluorescent screen over predetermined scanned areas, and electromagnetically shielding fields from the produced deflecting fields.

9. An electrode structure for a cathode ray tube comprising a cylindrical electrode planarly closed at one end, said end being apertured, a cathode supported from within the cylindrical electrode and projecting through the aperture, a plurality of apertured disk electrodes in register with the cathode, said disk electrodes being equispaced from each other and having progressively decreasing apertures, an apertured cup-shaped electrode in register with the cathode and the apertured disk electrodes, stud members affixed to each of the electrodes, and supporting means engaging the studs and holding the electrodes in predetermined spaced relation.

10. An electrode structure for a cathode ray tube comprising a cylindrical electrode planarly closed at one end, said end being apertured, a cathode supported from within the cylindrical electrode and projecting through the aperture, a plurality of apertured disk electrodes in register with the cathode, said disk electrodes having equal apertures of the same size and being spaced from each other with progressively increasing distances, an apertured cup-shaped electrode in register with the cathode and the apertured disk electrodes, stud members affixed to each of the electrodes, and supporting means engaging the studs and holding the electrodes in predetermined spaced relation.

11. The method of assembling and uniting the parts of an electron gun having at least two electrodes which comprises supporting said electrodes on an arbor in substantial axial alignment and longitudinally spaced, welding metal anchoring tabs at the adjacent ends of the electrodes with the tabs in alignment, and then forming rigid insulator links between the said adjacent tabs by applying insulator beads in a viscous state to said tabs, allowing said beads to harden and then removing the arbor.

12. The method of assembling and uniting the parts of an electron gun having at least two cylindrical electrodes, which comprises supporting said electrodes bearing metal anchoring tabs welded to their adjacent ends on an arbor in axial alignment and longitudinally spaced, and then forming rigid insulator links between said adjacent tabs by applying insulator beads in a viscous state to said tabs to bridge the same, and allowing said beads to harden and then removing the arbor.

13. The method of assembling and uniting the parts of an electron gun having at least two electrodes which comprises welding metal anchoring tabs at the adjacent ends of the electrodes, supporting said electrodes on an arbor in substantial axial alignment and longitudinally spaced, and then forming insulator links by applying insulator beads in a viscous state to bridge said tabs and allowing said beads to harden, and then removing the arbor.

14. The method of assembling and uniting the parts of an electron gun having at least two cylindrical electrodes which comprises welding metal anchoring tabs to the ends of the electrodes, supporting said electrodes substantially coaxially on a common rigid support with the tabs on one electrode spaced from but substantially aligned with and adjacent to the tabs on the other electrode, forming rigid insulator links by applying insulator beads in a viscous state to adjacent tabs to bridge the same, allowing said beads to harden, and then removing said electrodes from said common support.

15. The method of supporting and insulating electrodes in exact spaced relationship such that a field can be established between them which has desired directing properties upon electrons traversing said field, wherein said electrodes, provided with tabs at their adjacent ends, are first mounted on jigs in the desired spaced relationship and then adjacent pairs of tabs are bridged by applying viscous beads which are allowed to solidify before said jigs are removed.

16. The method of assembling electrodes hav-

ing parallel disc portions with aligned passages for an electron stream which comprises the steps of alternately stacking spacers and the electrodes, aligning the electrodes, clamping the electrodes to maintain said alignment, affixing radial supporting arms to each of the electrodes, said radial arms being equally spaced around the periphery of the electrodes, molding a vitreous body about the radial arms to maintain the electrodes in predetermined spaced relationship, totally releasing the clamping force on the electrodes, and subsequently removing the spacers.

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