Aug. 2, 1955 R. J. VAN DE GRAAFF ET AL 2,714,679

HIGH VOLTAGE APPARATUS FOR GENERATING A SUBSTANTIALLY WELL-COLLIMATED BEAM OF CHARGED PARTICLES

Filed July 3, 1952

4 Sheets-Sheet 1

Fig. 1

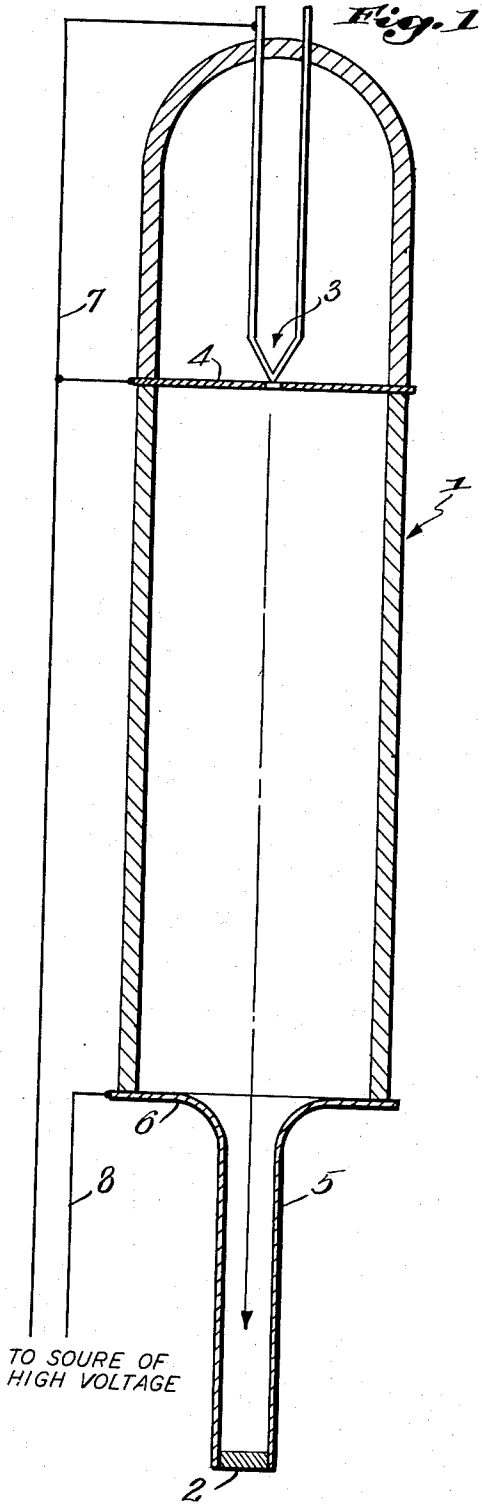
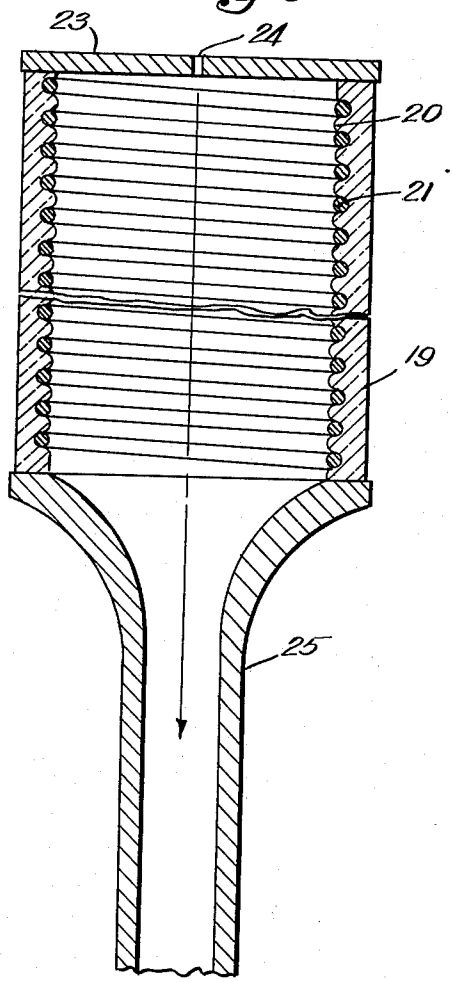


Fig. 3



Inventors
Robert J. Van de Graaff
William W. Buechner
by Evans, Boyd, Townsend, Mull and Cushman
Attys.

Aug. 2, 1955 R. J. VAN DE GRAAFF ET AL 2,714,679

HIGH VOLTAGE APPARATUS FOR GENERATING A SUBSTANTIALLY WELL-COLLIMATED BEAM OF CHARGED PARTICLES

Filed July 3, 1952

4 Sheets-Sheet 2

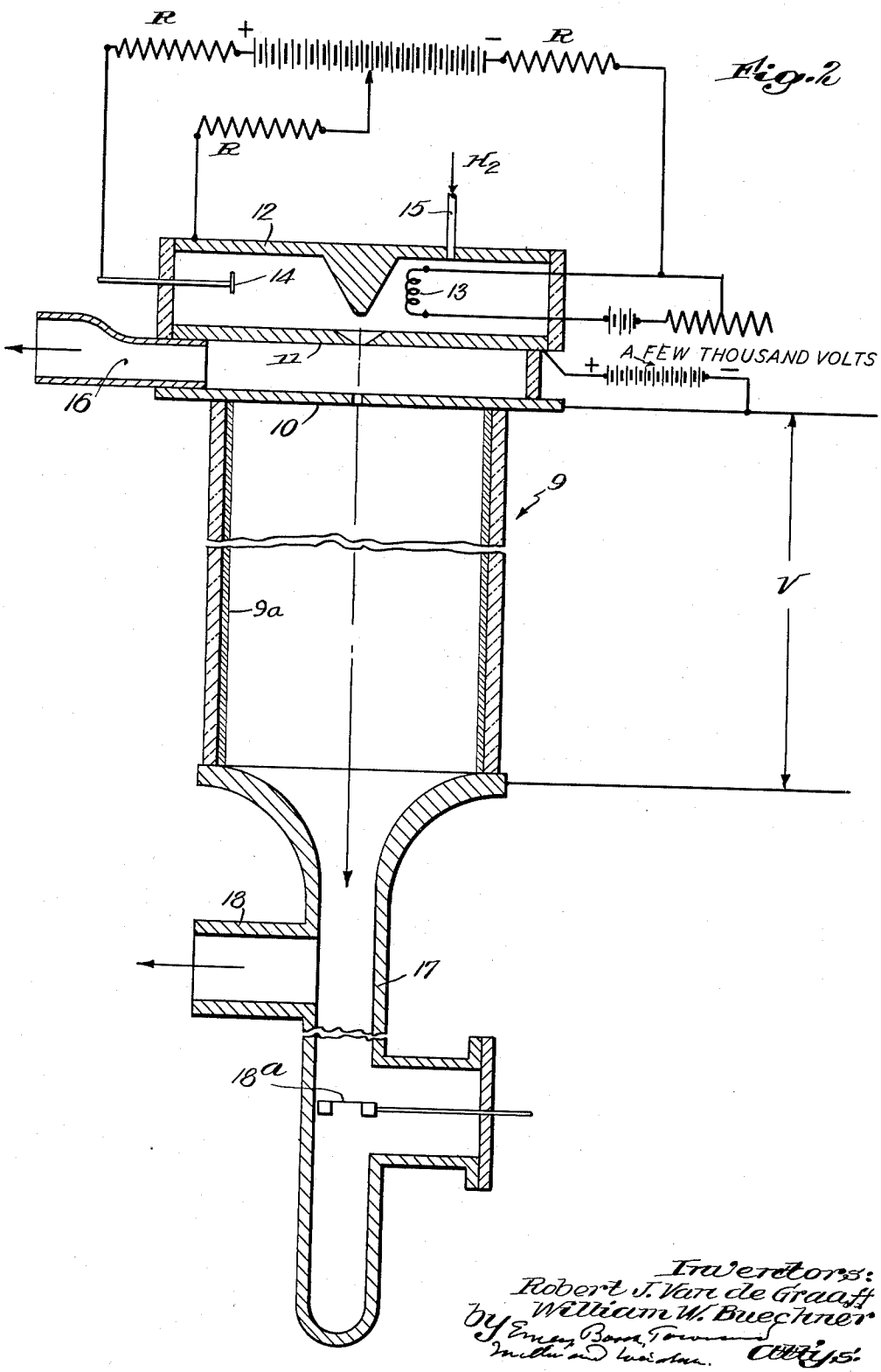


Fig. 2

Inventors:
Robert J. Van de Graaff
William W. Buechner
by Emery, Booth, Townsend, Miller and Laughlin
Attys.

Aug. 2, 1955 R. J. VAN DE GRAAFF ET AL 2,714,679

HIGH VOLTAGE APPARATUS FOR GENERATING A SUBSTANTIALLY WELL-COLLIMATED BEAM OF CHARGED PARTICLES

Filed July 3, 1952

4 Sheets-Sheet 3

Fig. 4

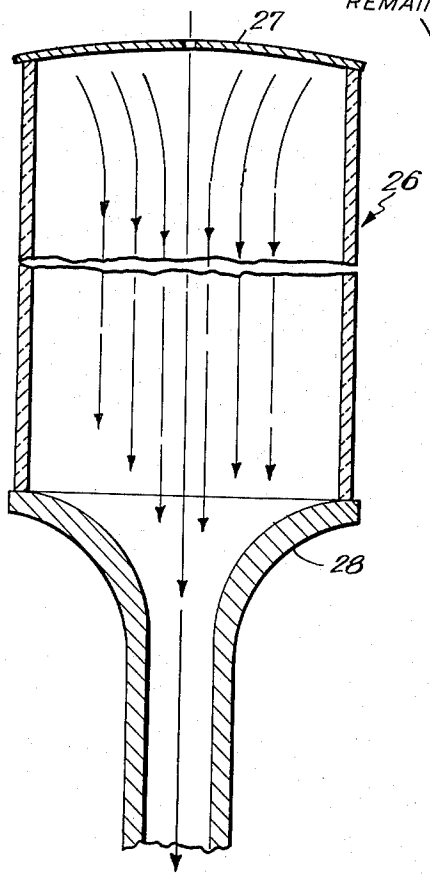


Fig. 5

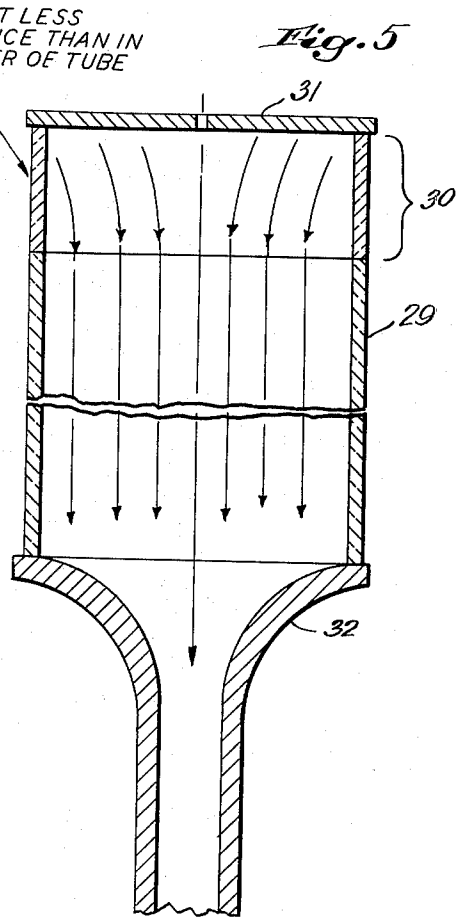


Fig. 6

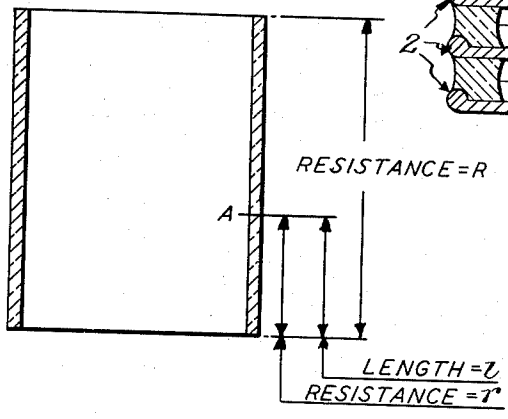
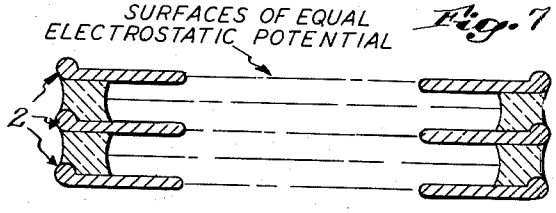


Fig. 7



Inventors:
Robert J. Van de Graaff
William W. Buechner
By Emery, Booth, Townsend, Miller and Laidman. Attys.

Aug. 2, 1955 R. J. VAN DE GRAAFF ET AL 2,714,679

HIGH VOLTAGE APPARATUS FOR GENERATING A SUBSTANTIALLY WELL-COLLIMATED BEAM OF CHARGED PARTICLES

Filed July 3, 1952 4 Sheets-Sheet 4

Fig. 8

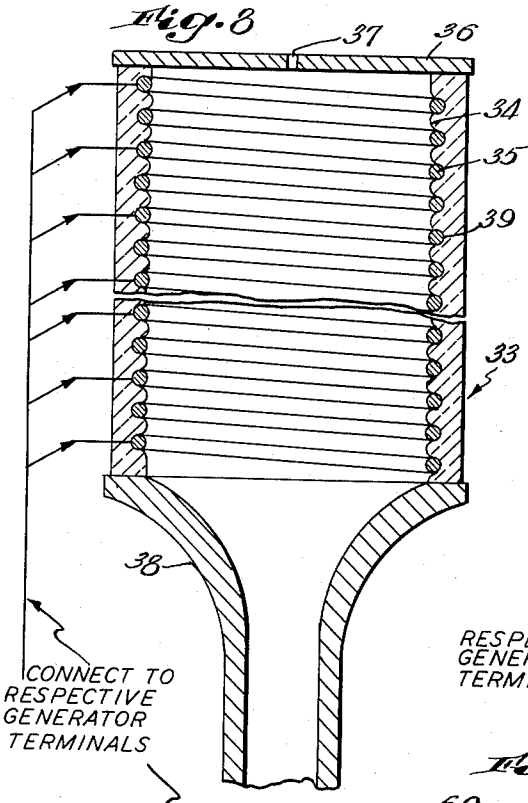


Fig. 9

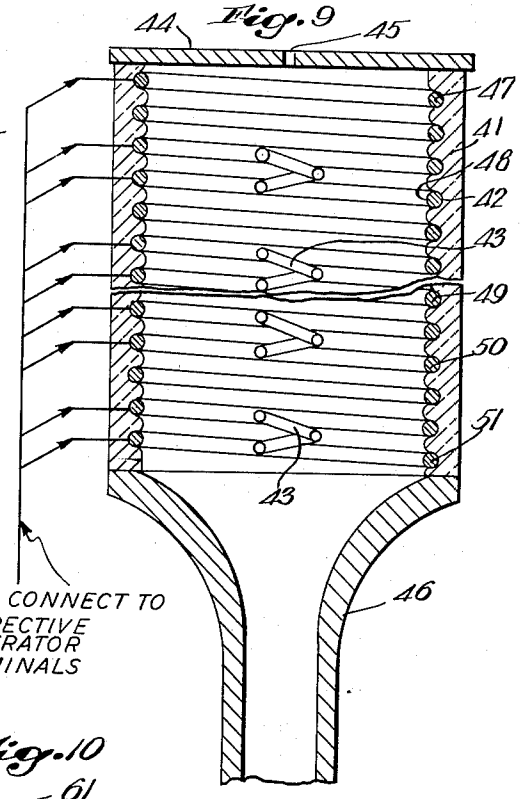
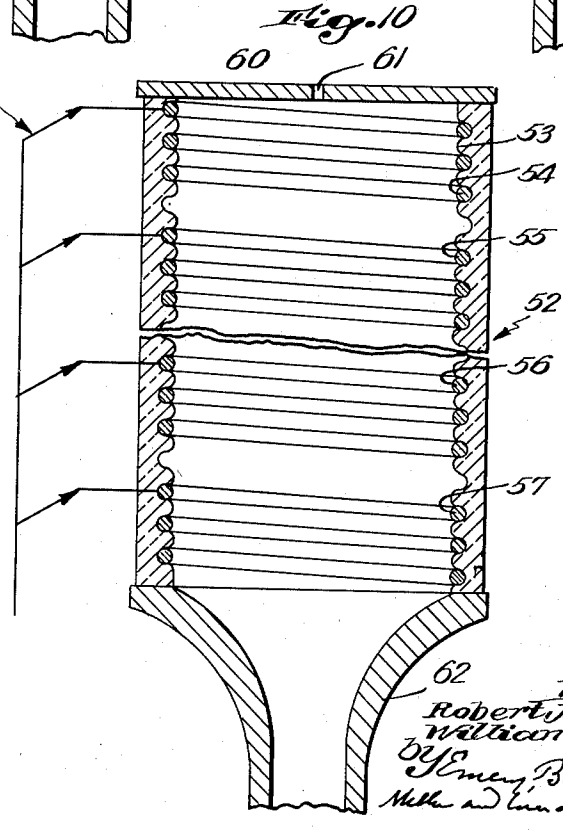


Fig. 10



Inventor
Robert J. Van de Graaff
William W. Buechner
By Emery, Booth, Townsend, Miller and Lunsford
Atty's.

United States Patent Office 2,714,679 Patented Aug. 2, 1955

2,714,679

HIGH VOLTAGE APPARATUS FOR GENERATING A SUBSTANTIALLY WELL-COLLIMATED BEAM OF CHARGED PARTICLES

Robert J. Van de Graaff, Belmont, and William W. Buechner, Arlington, Mass., assignors to High Voltage Engineering Corporation, Cambridge, Mass., a corporation of Massachusetts

Application July 3, 1952, Serial No. 297,036

1 Claim. (Cl. 313—85)

This invention relates to high-voltage acceleration tubes, and in particular to apparatus for practicing or carrying out the method disclosed and claimed in our co-pending method application, Ser. No. 128,084 (now Patent No. 2,608,664), filed November 18, 1949, as a true division of the parent application, Ser. No. 617,036, filed September 18, 1945, now Patent No. 2,517,260.

In our said Patent No. 2,517,260 there is disclosed and claimed certain apparatus for practicing or carying out the said method.

In the present application we disclose a high-vacuum electronic tube or envelope, the lengthwise extending or lateral wall thereof being otherwise constructed than of alternate, closely spaced annular metallic electrode disks or rings and annular disks or rings of insulating material such as glass or porcelain, but by which herein disclosed several tubes or envelopes, nevertheless, the said method may be effectively and completely carried out.

The said several different apparatus for carrying out said method will be better understood in detail by reference to the following description when taken in connection with the accompanying illustration of said several apparatus.

In the drawings:

Fig. 1 is a vertical or longitudinal, central cross section of a high-voltage, high-vacuum tube, the wall whereof is entirely composed of a semi-conductor and by which tube the said method may be practiced:

Fig. 2 is a similar section of a high-voltage, high-vacuum tube, the wall whereof is entirely composed of an insulator coated on the inside surface, or on both the inside surface and the outside surface with a material of suitable conductivity;

Fig. 3 is a similar section of a high-voltage, high-vacuum tube, the wall whereof is composed from end to end of a glass tube, the inner face of which is made as a helical corrugation in which is received a helical resistor;

Fig. 4 is a similar section of a high-voltage, high-vacuum tube, the wall whereof is like that of Fig. 1 or that of Fig. 2, but wherein the upper end portion of the substantially uniform electrostatic field is slightly warped by reason of the fact that the top metallic plate is concaved downward to substantially the extent indicated;

Fig. 5 is a similar section of a high-voltage, high-vacuum tube, the wall whereof may be like that disclosed in Fig. 1 or that in Fig. 2, but the resistance in the upper end of the tube is somewhat less than in the remainder of the said tube as indicated by brackets to cause a slight warping effect;

Fig. 6 is a diagram to be referred to in explaining the electrical action;

Fig. 7 is a representation in vertical cross section of a small part of the high-voltage, high-vacuum tube shown in our said Patent 2,517,260, shown for purfposes of explanation;

Fig. 8 is a longitudinal or vertical section similar to that of Fig. 3, but wherein the means provided to correct a slight distortion in the electrostatic field consists of one

long continuous conductive coil from the cathode end to the anode end of the high-voltage, high-vacuum tube, the corrections being made by providing in this particular case electrical connections at various intervals from the coil to corresponding electrodes of the high voltage generator;

Fig. 9 is a section similar to that of Fig. 8, but wherein there are provided a large number of short coils, all respectively connected to the next adjacent ones by resistors; and

Fig. 10 is a section similar to that of Fig. 9, but wherein the series of short coils are entirely unconnected with each other, but are therefore each connected to an appropriate different terminal of the electrostatic generator.

Referring in order to the figures of the drawings illustrating a number of different high-voltage, high-vacuum tubes, and by each of which the method disclosed and claimed in our said co-pending method application, Ser. No. 128,084, and first to Fig. 1, therein is shown a high-vacuum tube 1 by which the method herein referred to is carried out, and which may be of two different constructions, respectively shown in Figs. 1 and 2. The cylindrical wall of the tube 1 is, according to Fig. 1, entirely a semi-conductor, or, according to the construction shown in Fig. 2 is an insulator coated on the inside surface or on both the inside surface and the outside surface with a material of suitable conductivity.

With either construction Fig. 1 or Fig. 2, the current which flows along or through the wall in the direction from the anode 2 to the cathode end 3 of the tube 1 may have a value appropriate for the particular application. For example, the current may be approximately 100 microamperes when such a tube is used with two million volts for accelerating electrons for producing high-energy X-rays.

At the upper end of the tube 1 is a plane or plate 4 of conducting material such as a suitable alloy, for example, Fernico, or Kovar, and at the lower end of the tube 1 is secured a small-diameter tube 5 having an upper plane, flat or plate-like end 6 of conducting material such as mentioned above, and having at its lower end the anode 2.

The total resistance (Fig. 1) of the tube 1 constituting a semi-conductor, or (Fig. 2) of the conducting coating in the second construction, will be approximately 2×10^{10} ohms. A suitable wall material is the conducting glass manufactured by Corning Glass Works.

The source of charged particles is the cathode 3.

A possible conducting material for applying as a coating to an insulating tube of glass or porcelain of Fig. 2 would be a thin application of metal evaporated or spattered onto the surface, the thickness of the coating being such as to give the required resistance.

The tube structure 1 is with either construction connected to the high-voltage source in a manner depending upon the nature of such source. In Fig. 1 the lines 7, 8 extending from the cathode 3 and the anode 2 and labeled on the drawings Fig. 1, "To Source of High Voltage" indicate schematically a generalized means or manner of connection, as, for example, copper wires.

In principle, the type of high-voltage source used is immaterial. It may be a battery, a transformer, or a high-voltage electrostatic generator, for example. In many cases of the construction Fig. 1 or of the construction Fig. 2, the actual connection of the voltage to the tube is accomplished automatically in the manner of mounting the tube. For example, in an electrostatic accelerator of the belt type, the end of the tube 1 containing the target or anode 2 would automatically be placed at ground potential, since it would be supported by the high-pressure tank. The cathode end of the tube 1 would be enclosed by the high-voltage terminal of the generator, and would be at terminal potential, which might be either positive or negative, depend-

ing upon whether the tube 1 is used for accelerating positive ions or electrons.

The said tube 1 of either the construction Fig. 1 or the construction Fig. 2 would, if suitably connected to a voltage source, create throughout its interior volume an electric field that is uniform and is essentially the same as that produced in and by the apparatus originally disclosed by us in the application of Van de Graaff and Buechner, Ser. No. 617,036, filed September 18, 1945, now Patent No. 2,517,260.

In the tube shown at 1 in Fig. 1, on the contrary, the wall itself acts as a resistor, and thus the conducting metallic disks 2 are entirely dispensed with. In the original disclosure in the said Van de Graaff and Buechner application, Ser. No. 617,036, now Patent 2,517,260, the electrode disks 2 introduce into the tube the potentials established by the resistor. The function of shielding from the adverse effects of stray electric fields and charged particles, also accomplished by the said metallic electrode disks 2, is not required when the wall of the tube 1 is itself semi-conducting, as in the type of constructure in Fig. 1 or when the wall of the tube is an insulator coated inside or both inside and outside with a material of suitable conductivity.

Fig. 2 shows a vacuum tube wall 9 of insulating material coated on the inside surface with a material of suitable conductivity, as indicated at 9*a*. At the upper end of wall 19 are three spaced metal plates 10, 11, 12, the plates 10, 11 each having a central opening downwardly through which passes the beam or stream of charged swift particles. Between the plates 11, 12, entering at opposite sides through an annular glass wall, are the hot cathode 13 for emitting electrons and the anode 14. Hydrogen gas under pressure on the order of 10^{-2} mm. is admitted through the small pipe 15. The cathode 13 and the anode 14 are connected, as indicated, to a battery or generator, or other source of current, providing about 300 volts. In the indicated circuit are provided resistors R. From between the plates 10, 11 leads a pipe 16 to a vacuum pump.

The parts, other than the tube wall 9, are made some of glass and the rest of metal, the material in all cases being indicated by the proper crosshatching according to the Patent Office chart for draftsmen.

The hydrogen ions issue downwardly through the central openings in the metal plates 11 and 10 to produce the desired initial beam of positive ions. The hydrogen gas, after use, is discharge mainly through the said pipe 16. By reversal of polarity in the apparatus shown in Fig. 2 either negative electrons or positive ions may be emitted. The said beam or stream of charged swift particles (electrons or positive ions) is accelerated and focused by the substantially uniform electrostatic field that extends lengthwise parallel with the longitudinal wall 9 of the tube and throughout the cross-sectional area of said tube wall 9. As indicated, the electrode plate 10 at the top of the tube wall 9 and the metal tubing 17 of reduced diameter at the lower end of the wall 9 are suitably electrically connected to a source of high voltage. The tubing 17 is connected as indicated at 18 to a main vacuum pump. Within said tubing 17 is provided a target 18*a*, which is here indicated as a thin aluminum foil.

As will be explained in connection with Figs. 4 and 5, the step of warping of the substantially uniform electrostatic field, near the upper end of the tube wall 9 occurs with, or as the result of, using either of the constructions shown in said Figs. 4 and 5, to be described in detail. As has already been made clear in the original application, Ser. No. 617,036, now Patent 2,517,260, warping occurs when desired at the upper part of the said substantially uniform electrostatic field.

Focusing occurs in the use of the apparatus shown in Fig. 2, it being accomplished or effected by the action of the substantially uniform electrostatic field itself.

Fig. 3 shows a tube wall, the top electrode plate, and a part of the lower contracted end that contains a target, but does not show the construction above said top electrode plate nor the entire construction of the said lower contracted end, as the structure above the said top electrode plate may be substantially the same as what is fully shown in Fig. 2 and fully described with respect to Fig. 2 in the just preceding pages hereof, or it may be substantially the same as what is shown in Fig. 1 and fully described with respect thereto. Likewise the construction below the broken-away part of the lower contracted end may be substantially the same as what has already been described and shown in connection with either Fig. 1 or Fig. 2.

Referring to the tube wall construction shown in Fig. 3, it is composed from end to end of a glass tube 19, the inner face of which is made as a helical corrugation 20 received in which is a helical resistor 21 that may be made of one piece, or may be made of a series of pieces, the adjacent ends of which are connected in each case by a resistor such as indicated in Fig. 9. The helical resistor or resistors 21 may be made of material such as, for example, a thin layer of carbon deposited on a base of insulating material.

The source of charged swift particles in the construction shown in Fig. 3 may be the same as in Fig. 2 or in Fig. 1. In either case the top of the tube wall 19 is closed by a metallic plate 23 having a small central opening 24 for the downward emission of the beam or stream of charged swift particles, either electrons or positive ions, and the said metallic plate 23 is electrically connected as in Fig. 1, or as in Fig. 2 with the metallic tubular portion of reduced diameter 25 and thereby is established and maintained a continuous beam or stream of charged swift particles downward through a substantially uniform electrostatic field extending throughout substantially the entire cross sectional area of the tube and parallel to the longitudinal wall thereof and thereby the beam or stream of charged swift particles is focused.

Fig. 4 shows a tube wall 26 which may be like that shown or described with respect to Fig. 2, or it may be like either of the constructions shown in or described with respect to Fig. 1 and the said method claimed in said application Ser. No. 128,084 is carried out just as in and by the constructions disclosed in said Figs. 1 and/or 2, excepting that in the construction shown in Fig. 4 the upper end portion of the substantially uniform electrostatic field is slightly warped, as indicated by the lines of arrows, by reason of the fact that the top metallic plate 27 is concaved downward to substantially the extent indicated.

Fig. 5 shows a tube wall 29 which may be like that shown or described with respect to Fig. 2, or it may be like either of the constructions shown in or described with respect to Fig. 1 and Fig. 2 and the said method claimed in said application No. 128,084 is carried just as in and by the constructions disclosed in said Fig. 1 and Fig. 2, excepting that in the construction shown in Fig. 5 the resistance in the upper end of the tube 29 is somewhat less than in the remainder of the said tube. The extent of such lessened resistance in Fig. 5 is indicated by the bracket 30. Such lessened resistance is effected by making a suitable change in the composition or structure of the upper end portion of the said tube 29 in a known manner or in any other suitable way.

Thus, in the use of the structure shown or indicated in or described with respect to Fig. 5 the upper end portion of the substantially uniform electrostatic field is slightly warped (that is, made slightly convergent) as indicated by the lines or arrows.

The other steps of the said method claimed in said application, Ser. No. 128,084, are all carried out in and by the apparatus of Fig. 5, as in the apparatus of Figs. 1, 2 and 3.

In said Figs. 1 and 2 of this present application there

are no electrode rings with fixed potentials assigned to them. There are no arbitrary fixed potentials at all, except at the cathode and the anode. In view of the fact that in said Figs. 1 and 2 of this application the inner surface of the tube is of conductive material, no electrical charge accumulates on this inner surface, and any electrical charge can move freely throughout the inner surface of the tube. Consequently, the potential distribution along the tube takes a natural and very effective form; it increases in proportion to the distance from the low-potential end of the tube. That is to say, it increases in a constant fashion, and so the force will be constant throughout the tube.

In the case of Figs. 1 and 2 of this present application, the desired effect is achieved by removing all disturbing influences and accurately controlling the potential distribution by providing no arbitrary fixed potentials excepting at the cathode and the anode and by causing a current constantly to flow from the anode to the cathode.

Referring to the several constructions disclosed in the drawings of said Figs. 1 and 2, and their descriptions, the electrical action is as follows:

The constantly flowing current through the conductive glass or the conductive coatings on the glass of said Figs. 1 and 2 establishes an electrical potential at a given point which is completely determined by the potentials at the ends of the tube and the proportion of the total resistance which lies to one side of that point at which the electrical potential is measured. In Fig. 6 of this present application, if R is the total resistance and r is that proportion of the total resistance which lies between A (the point at which the potential is to be measured) and the grounded electrode, and if the other electrode is given a potential of, say 2,000,000 volts, then the potential A will be

$$\frac{r}{R}\times 2{,}000{,}000$$

If further r is exactly proportional to the length l there will be a uniform increase of potential from the grounded end of the tube to the upper electrode.

It can be shown by electrostatic theory, and we here state, that if the potential gradient is uniform at the bounding surface of the rectilinear tube of arbitrary (but constant) cross section, the field within the tube is also uniform.

Electrons are therefore accelerated down the tube because the constantly flowing current established an electrostatic field. In this example the field is further made uniform.

We compare this construction just described, with Fig. 7 of this present application, in which a small part of the tube of our said U. S. Patent 2,517,260 is shown for purposes of explanation. An electrostatic potential is established for each of the electrodes 2 thereof, by its connection to the appropriate plane of an electrostatic generator. This electrostatic potential will be the same at all points on the surface of and within the material of a particular electrode.

Although the electrode is not infinitely thin, it can be seen from considerations of symmetry that some of the equipotential surfaces lying in the evacuated region are plane. These plane equipotential surfaces are shown in Fig. 7. Equipotential surfaces between the plane ones shown are slightly curved and are not shown. Thus the accelerating force on an electron on the axis of the tube will be strictly longitudinal, and the force on one near the axis will be approximately longitudinal.

The method which is expressed by the claims of our said method application, Ser. No. 128,084, is effectively carried out by the apparatus shown in our said U. S. Patent No. 2,517,260, wherein there is a multiplicity of thin, alternately arranged metallic electrodes and insulation rings constituting the wall of the acceleration tube. Such method is also carried out by each apparatus shown

or described in Figs. 1 and 2 of this present application, where the electrode rings and alternating thin glass or porcelain insulation rings are entirely dispensed with, and instead a cylindrical wall is provided, which is either entirely a semi-conductor, or is an insulator coated on the inside surface or on the inside and outside surfaces with a material of suitable conductivity, such as a thin coating of metal evaporated onto the surface, the thickness of the coating being such as to give the required resistance or such as conducting glass manufactured by Corning Glass Works, there being a plane of conducting material at the cathode end of the acceleration tube and another at the anode end thereof, these being connected to the source of high voltage. The current flows along or through the wall of the acceleration tube in the direction from the anode to the cathode.

Fig. 3 of this present application discloses a tube wall composed of glass (not Corning glass). If such glass wall were a perfect insulator, that is, if it had uniform dielectric properties, the electrostatic field within the tube would be uniform. Actually no insulator is perfect; that is, no insulator has absolutely uniform dielectric properties. Also, charge may accumulate at some points on the wall of the tube, thus somewhat distorting the field. To correct such distortion the helical conductor represented by numeral **21** in Fig. 3 is provided.

We will now refer to Figs. 8, 9 and 10 of this application, which also constitute structures for carrying out the steps of the method claimed in our said method application Ser. No. 128,084. By each of these structures the steps of the method claims will be carried out, and these structures, Figs. 8, 9 and 10, are each very different in structure from that shown in our said Patent No. 2,517,260, and they also differ materially among themselves.

In the construction shown in Fig. 8, the means provided to correct the distortion in the electrostatic field, consists of one long continuous conductive coil **35** from the cathode end to the anode end of the acceleration tube. If that coil **35** had uniform resistance throughout its length the field within the tube would be uniform. However, the resistance will vary slightly, so that field will not be perfectly uniform, though substantially so.

In said Fig. 8 the wall of the tube is represented at **33**. It is composed of glass, as in Fig. 3. Its inner surface is formed as a helical corrugation **34**, in which is received a single long helical resistor **35**. There is provided a top metallic plate **36** having a small central opening **37** having the same purpose as the plate **23** with opening **24** of Fig. 3, and the metallic tubular portion **38** of reduced diameter, as in Fig. 3 and for the same purpose.

By connecting various substantially spaced points on the said long continuous coil **35** to appropriate different terminals on the electrostatic generator, as indicated on the drawing Fig. 8, the uniformity of the electrostatic field will be made more nearly exactly uniform.

In Fig. 9 of the drawings there are provided resistors **43** and top metallic plate **44** with opening **45** as in Fig. 8 and the metallic tubular portion **46** of reduced diameter, and a large number of short coils, such as **47** to **51**, all respectively connected to the next adjacent by resistors **43**. Some of said short coils may be connected up to an appropriate different terminal of the electrostatic generator, as indicated at the left of said Fig. 9. Each of such coils is properly termed an electrode.

In Fig. 10 there is provided the glass tube or wall **52**, corrugated as shown at **53**, and a series of short coils, such as **54** to **57**, but they are entirely unconnected with each other. They are not, as in Fig. 9, connected by resistors. Therefore, they must necessarily be and are each connected to an appropriate different terminal of the electrostatic generator, as indicated at the left of said Fig. 10, and when so connected, they are properly termed electrodes. If the separated coils within the glass walled tube

52 were neither connected to each other by resistors nor to appropriate terminals of the generator, they would not, of course, control the electric field within the tube at all.

In all three Figs. 8, 9 and 10, the connections to the electrostatic generator provide a coarse control of the electrostatic field within the tube, whereas the single long coil in Fig. 8 and the coils in Fig. 10 provide a less coarse control of the electrostatic field within the acceleration tube.

The electrical function of the connections from the separate, small coils or from the continuous coil is to improve and hence more nearly perfect the uniformity of the electric field within the acceleration tube. The various short coils described with reference to Fig. 3 and as disclosed in Figs. 9 and 10, generally act as do the thin electrode rings of our said Patent No. 2,517,260, but the difference is that the coils also provide a fine control of the electrostatic field within the tube in addition to the coarse control provided by the connections to the generator.

Having thus disclosed several embodiments of apparatus by each of which may be practiced the method disclosed in our said co-pending allowed method application, Ser. No. 128,084, it is to be understood that although specific terms are employed, they are used in a generic and descriptive sense, and not for purposes of limitation, the

scope of the invention being set forth in the following claim.

We claim:

High-voltage apparatus for generating a substantially well-collimated beam of charged particles, comprising a high-voltage high-vacuum acceleration tube having at one end portion a charged-particle source including means for injecting charged particles into said tube along the longitudinal axis thereof, and at the other end portion a member to which said charged particles are to be delivered as a substantially well-collimated beam, the lateral wall of the said tube from end to end consisting entirely of a semiconductor, the resistivity and cross-sectional area of said lateral wall being substantially constant throughout the length thereof.

References Cited in the file of this patent

UNITED STATES PATENTS

2,005,021	Brash et al.	June 18, 1935
2,095,930	Houtermans et al.	Oct. 12, 1937
2,145,727	Lloyd, Jr.	Jan. 31, 1939
2,206,558	Bennett	July 2, 1940
2,215,155	Kallmann	Sept. 17, 1940
2,358,553	Beldi	Sept. 19, 1944