Oct. 5, 1948.

A. LEVIALDI

THERMIONIC DISCHARGE TUBE WITH ELECTRONIC VELOCITY FILTER

2,450,602

Filed Aug. 17, 1944

2 Sheets-Sheet 1

Fig. 1.

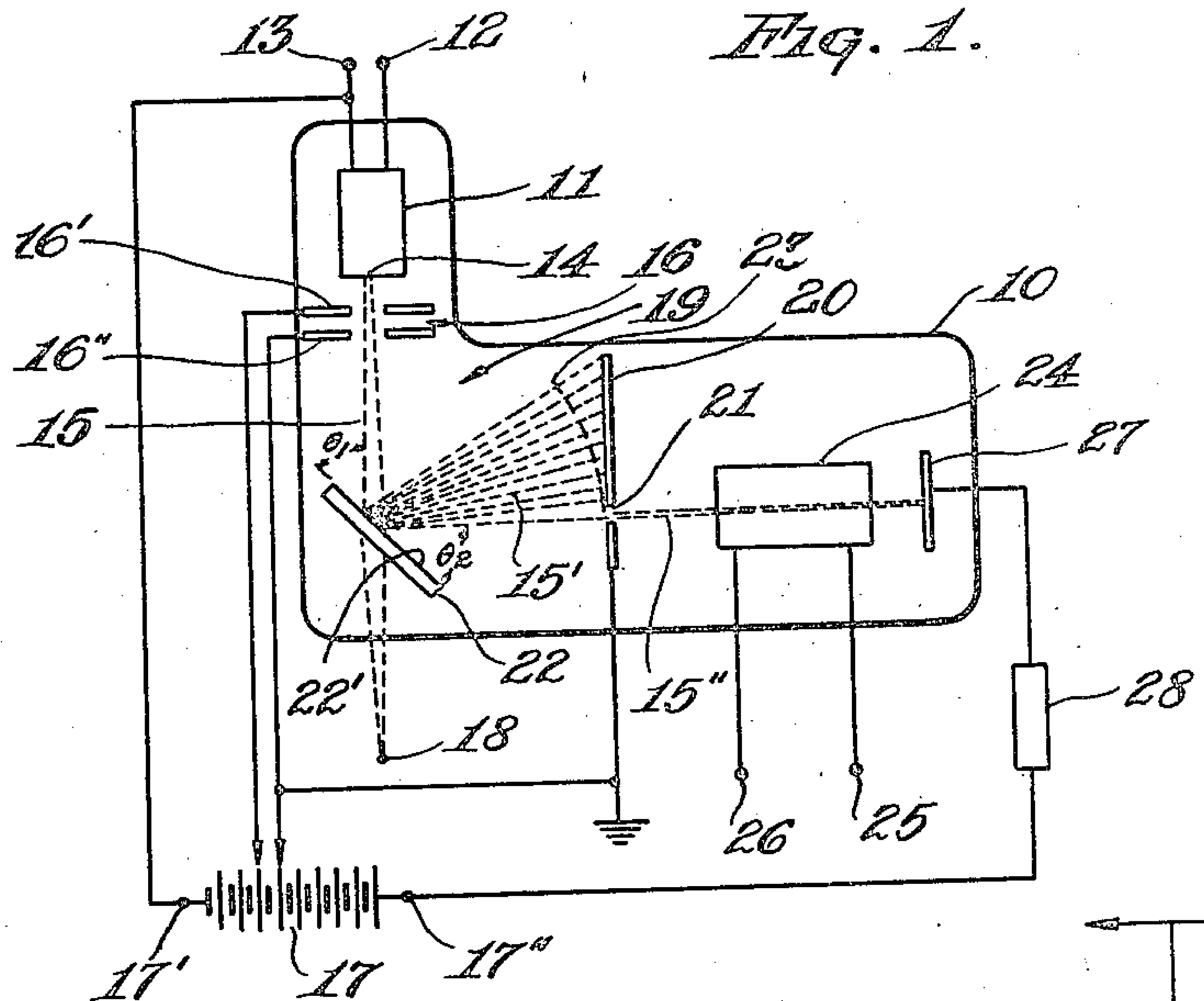


Fig. 3.

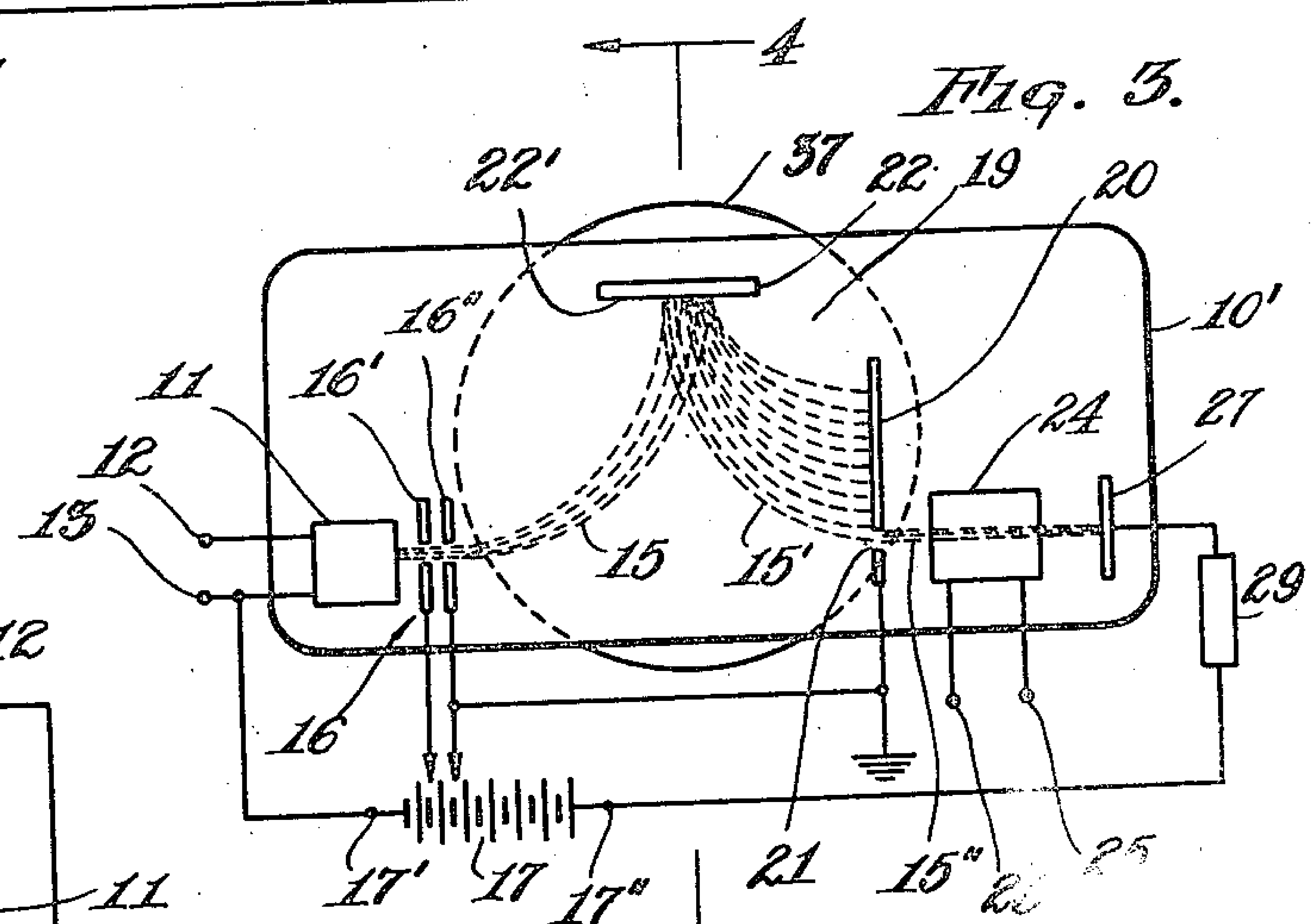
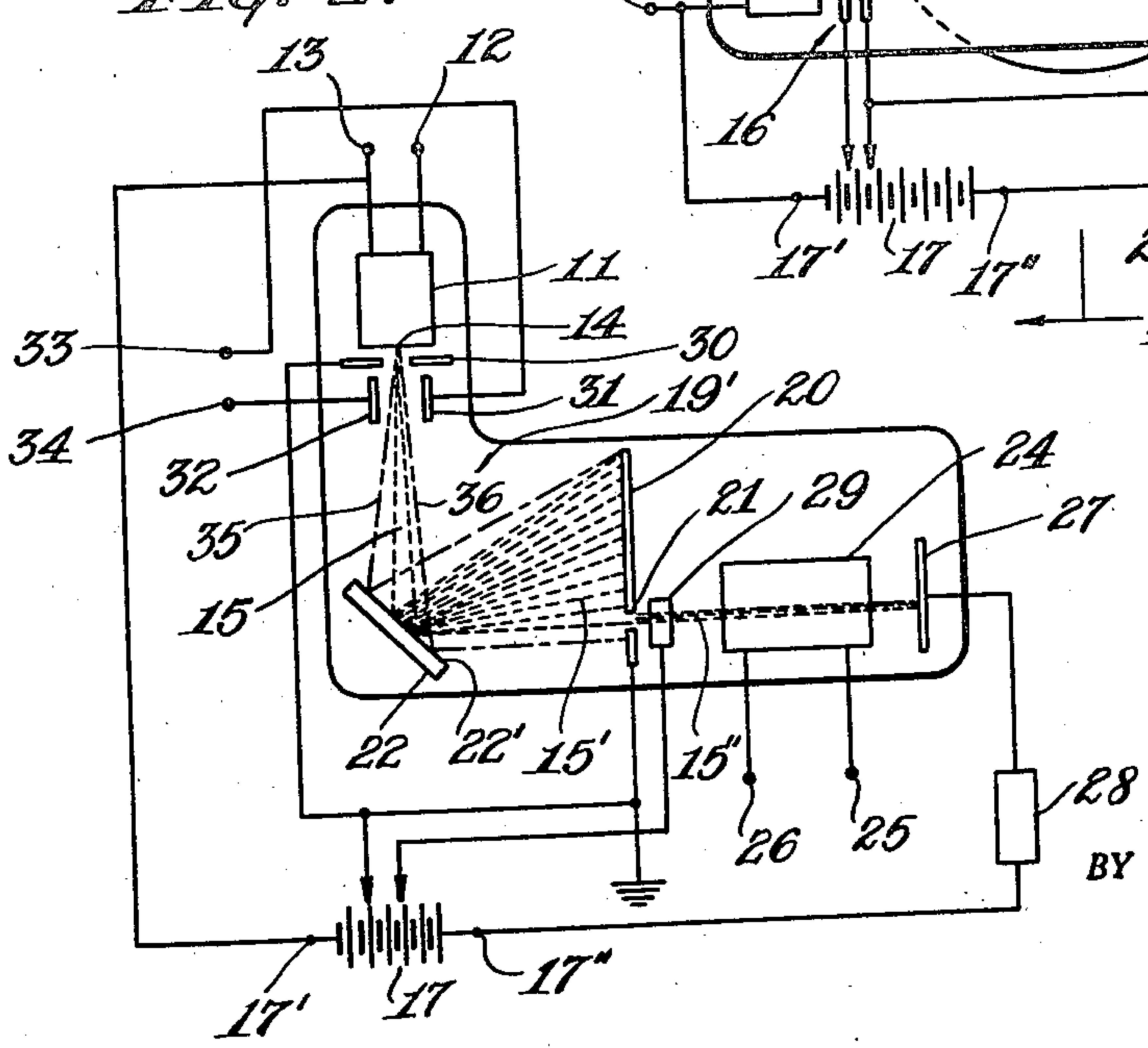


Fig. 2.



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Oct. 5, 1948. A. LEVIALDI 2,450,602

THERMIONIC DISCHARGE TUBE WITH ELECTRONIC VELOCITY FILTER

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Fig. 4.

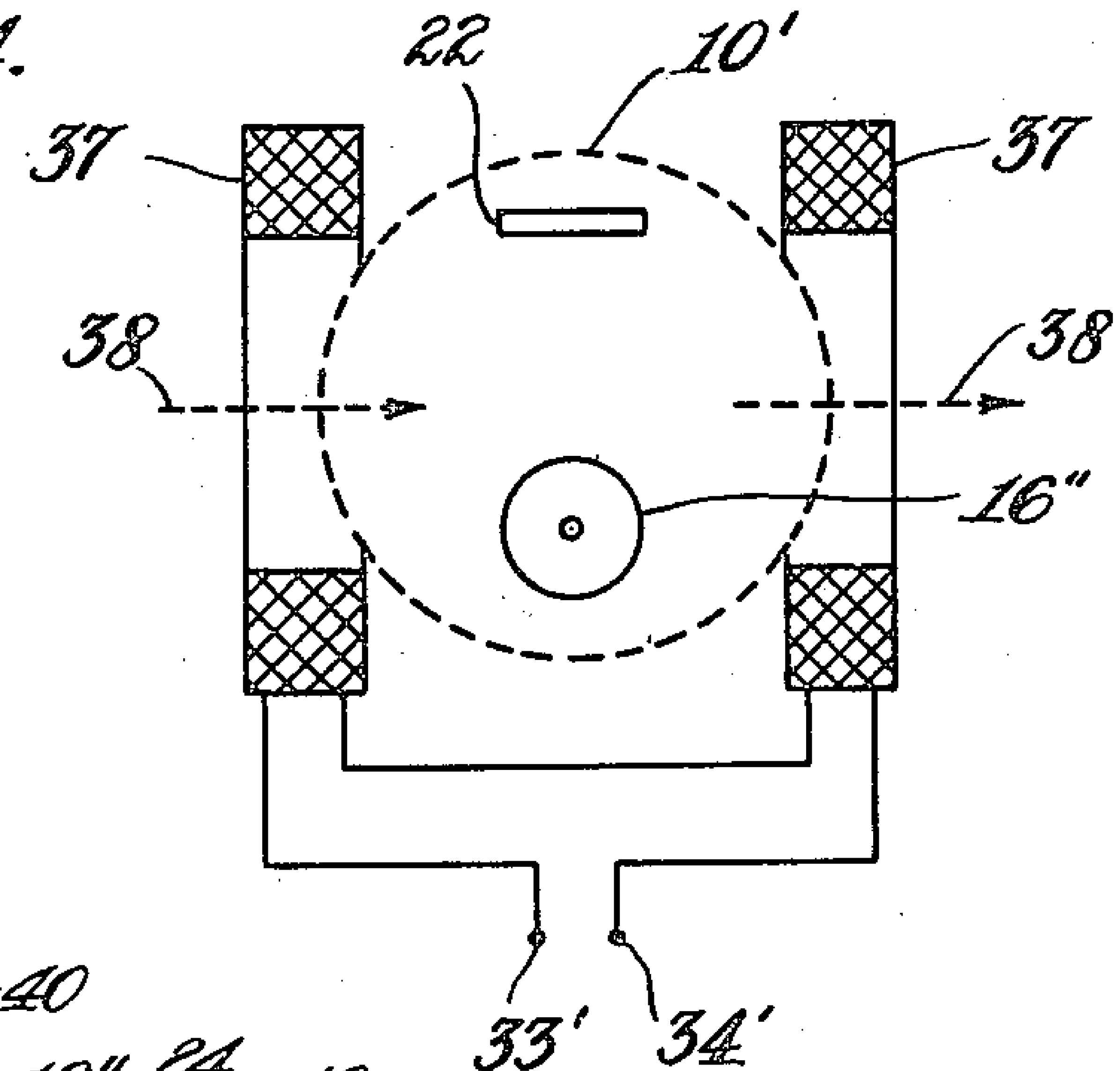


Fig. 5.

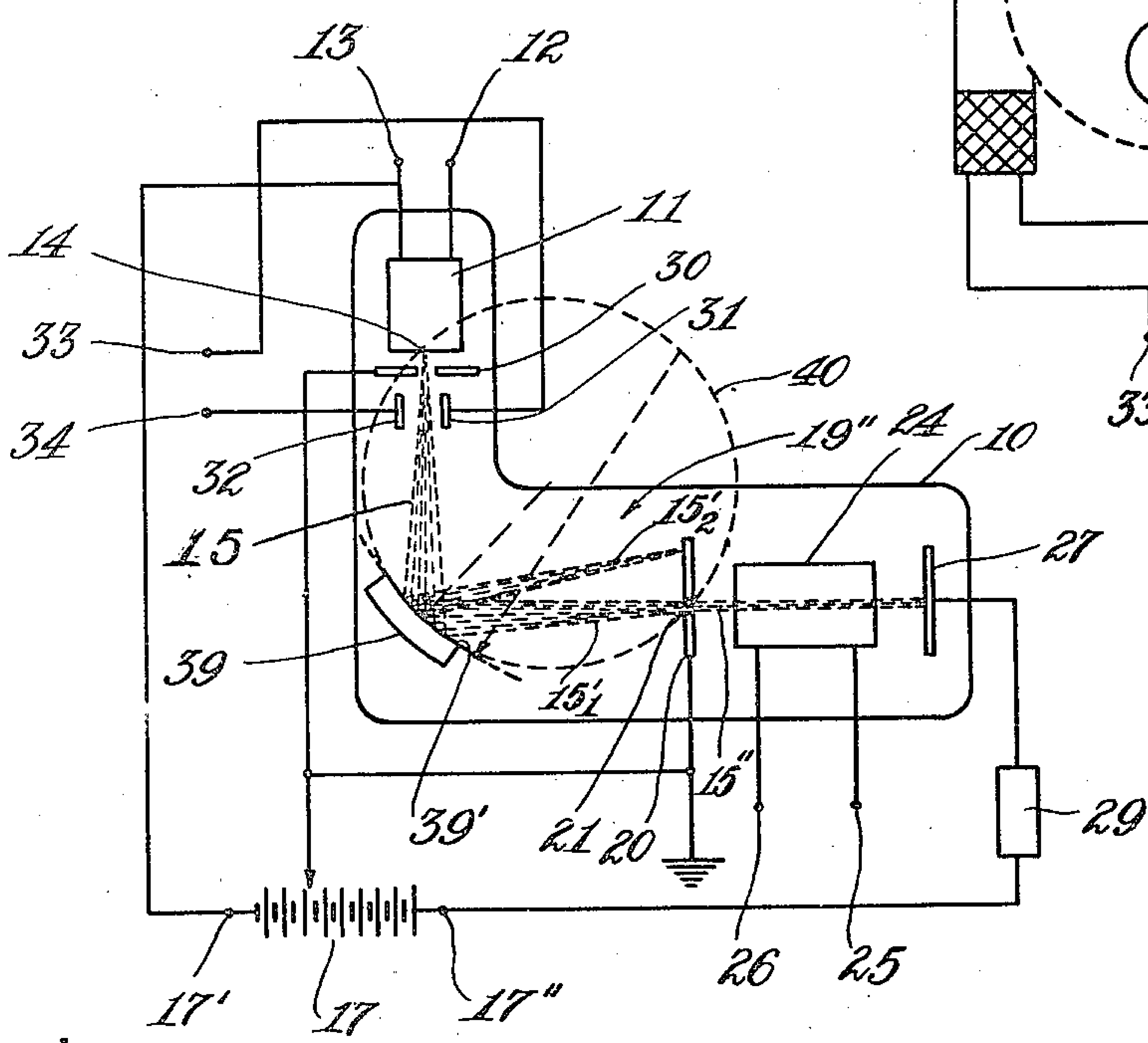
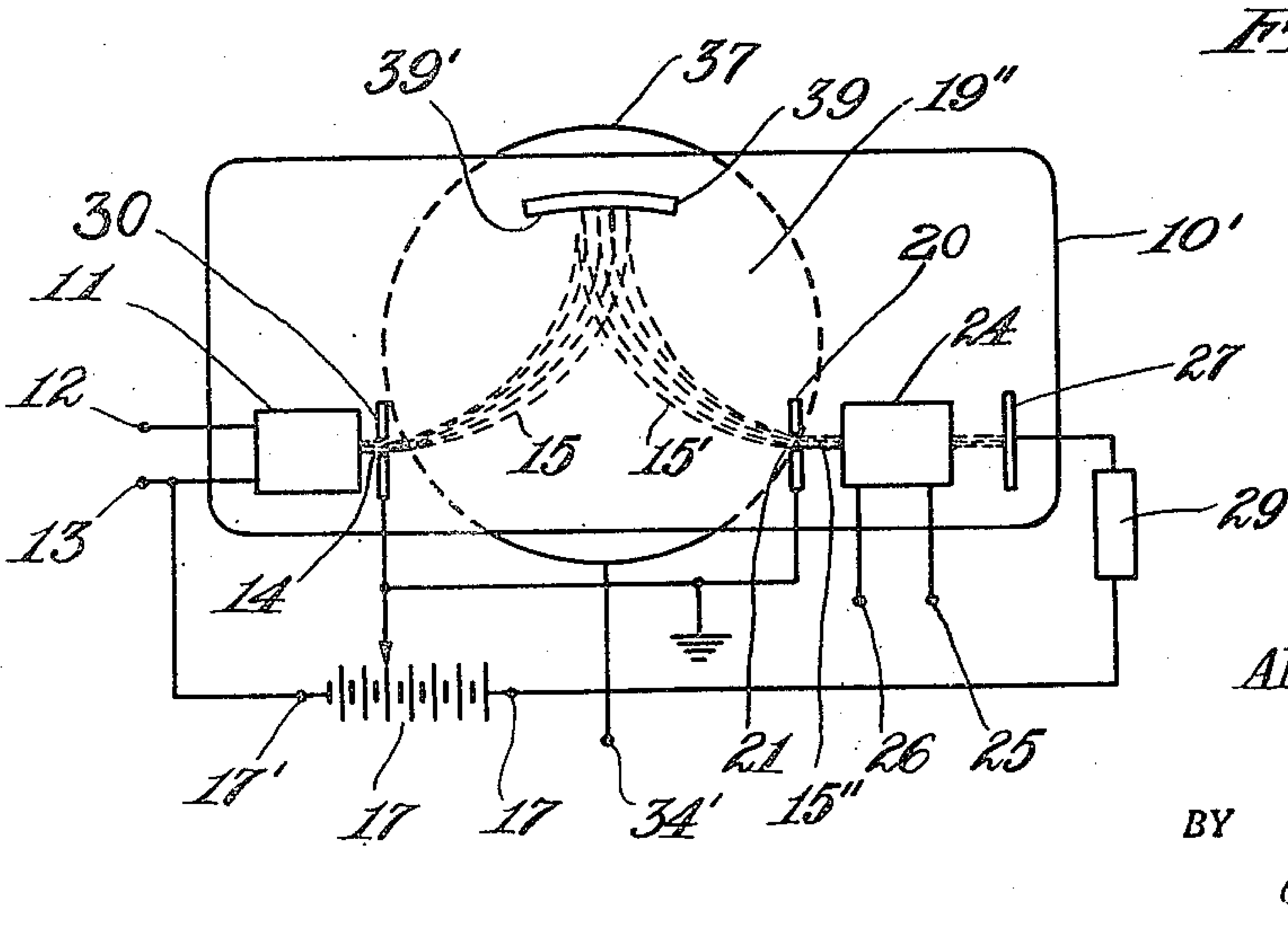


Fig. 6.



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UNITED STATES PATENT OFFICE

2,450,602

THERMIONIC DISCHARGE TUBE WITH ELECTRONIC VELOCITY FILTER

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Application August 17, 1944, Serial No. 549,889

11 Claims. (Cl. 315—19)

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This invention relates to velocity filters for electron beams and more particularly to thermionic discharge tubes utilizing monokinetic beams of low-velocity electrons.

It is already known to filter high-velocity electron beams in which high-intensity electromagnetic fields may be easily utilized for separating the electrons into substantially monokinetic beams.

However, in electronic devices or thermionic discharge tubes which utilize accelerating potentials approximately equal to the mean initial velocity of the generated electrons, i. e. in devices operating with accelerating potentials of the order of a few volts, filtering of the electrons constitutes a rather difficult problem for which, so far as I am aware, no satisfactory solution has been found as yet.

One of the main difficulties encountered in filtering low velocity electrons consists in that the intensity of the electromagnetic fields which could be used for filtering purposes decreases to values falling within the range of the intensity of the terrestrial field during magnetic storms, so that even with special shielding materials and devices it is almost impossible to maintain the path-controlling magnetic field within the predetermined values.

However, I have now found that low-velocity electrons possess some inherent characteristics which may be used advantageously for filtering purposes. In fact, low-velocity electrons have relatively large associated wave lengths varying from 5.5 Å. for accelerating potentials of the order of 5 volts to 17.3 Å. for accelerating potentials of the order of 0.5 volts in accordance with the Broglie wave length formula.

Hence, even for electrons moving with nearly like velocities the associated wave lengths differ by considerable values, so that by directing the electron beam toward an adequate diffracting lattice structure, the electrons of the diffracted beam will be distributed according to the velocities thereof, thus making it possible to select a bundle of electrons having like velocities by means of an apertured diaphragm located in the path of the diffracted electron beam. Consequently, the electrons passing through the diaphragm aperture can be regarded as a monokinetic electron beam containing electrons of substantially like velocities determined by the glancing angle of the incident electron beam, the "grating distance" of the diffracting lattice structure, and the position of the diaphragm aperture within the area of the diffracted electrons, the velocity

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range of the monokinetic electron beam being further determined by the dimensions of the aperture.

It is therefore one of the main objects of the present invention to provide, in thermionic discharge tubes, a simple and effective means for obtaining a monokinetic beam of low-velocity electrons.

A further object of the present invention is to provide, in thermionic discharge tubes, a velocity filter for low-velocity electrons, the filtering characteristics of which can be varied over a continuous range of electron velocities.

These and other objects and advantages of the invention will be apparent from a consideration of the following detailed specification taken in connection with the drawings which form part of the specification, and wherein:

Fig. 1 is a schematic longitudinal section of a thermionic discharge tube incorporating an electron-velocity filter according to my invention;

Fig. 2 illustrates a modification of the electron-velocity filter shown in Fig. 1;

Fig. 3 shows another modification of the electron-velocity filter allowing of a coaxial mounting of the discharge tube elements;

Fig. 4 is a cross section of the thermionic discharge tube taken at arrows 4—4 of Fig. 3;

Fig. 5 shows another modification of the electron-velocity filter illustrated in Fig. 2; and

Fig. 6 illustrates a thermionic discharge tube similar to that shown in Fig. 4 but utilizing the electron-velocity filter of Fig. 5.

The same reference characters or numbers indicate like or corresponding parts or elements throughout the drawings.

Referring to Fig. 1, there is shown a thermionic discharge tube comprising an evacuated L-shaped tubular envelope **10** the shorter leg of which includes an electron gun **11** connected by means of terminals **12** and **13** to an adequate power supply source not shown in the drawings. The electron beam, emerging from an electron gun **11** at the orifice **14**, is accelerated and shaped into a convergent beam **15** by means of an electrostatic lens system **16** constituted by a first and second anode **16'** and **16''**, respectively, each connected to an intermediate potential of a direct current supply **17**, the negative pole **17'** of which is connected to terminal **13** of electron gun **11**, while anode **16''** is also connected to ground. The low-velocity electron beam **15** is focussed on a point **18** and penetrates into a diffraction zone **19** limited by the second anode **16''** of electron lens system **16** and a diaphragm **20** also connected to ground and provided with an aperture 21 so that substantially all points of diffraction zone 19 are at the same potential.

The convergent electron beam 15 is directed toward a diffraction element 22 of regular lattice structure located midway between orifice 14 and focus 18 and having a substantially plane diffracting surface 22′ placed at an angle of 45° with respect to the direction of the incident electron beam 15, so that a glancing angle θ_1 of 45° is formed between diffraction surface 22′ and the incident electrons. The diffraction element 22′ can be formed by a nickel or quartz plate, the choice of the material depending upon the lattice structure desired. Preferably, the reflecting surface of the plate is cut with certain crystallographic orientation angles with respect to the crystallographic axes of the material.

It has been shown by de Broglie that electrons moving at a velocity much below that of light with kinetic energy equal to V electron-volts, have associated a wave length which is given in angstroms by the formula

$$\lambda=\frac{12.24}{\sqrt{V}}$$

Now, since diffraction element 22, which may be formed of a crystal or metal having an adequate lattice structure, may be regarded as a plane grating of grating space d equal to the distance between the atom rows of the lattice structure, the incident electron beam 15 will be diffracted in accordance with de Bragg's formula $n.\lambda=d \sin \theta_1$ where λ is the wave length, θ_1 the glancing angle of the incident electron beam 15, d the grating space of the lattice structure and n any positive integer. With a fixed angle of incidence, the electrons of the diffracted beam 15′ will be dispersed over a relatively wide area covering a definite range of angles θ_2, formed between the diffracted electrons of beam 15′ and the plane diffracting surface 22′. For each angle θ_2 the diffracted electrons will have an associated wave length in accordance with de Bragg's formula. Hence, in the diffracted beam 15′ the electrons will be distributed in accordance with their velocity, electrons of lower velocity corresponding to larger angles θ_2 and vice versa. The distribution of the electrons within the dispersed diffracted electron beam 15′ will depend naturally upon the distribution of the mean electron velocities present in the incident beam 15, so that the maximum and minimum values of θ_2 are determined by the minimum and maximum velocity of the electrons emerging from orifice 14 of gun 11.

However, although scattered, the electrons of diffracted beam 15′ will be focussed on a line which, in first approximation, can be represented by a circle 23 drawn with the distance between plane diffracting surface 22′ and focus 18 as a radius, and aperture 21 of diaphragm 20 is located to coincide precisely with a point on the circumference of circle 23 which forms a minimum angle θ_2 with diffracting plane 22′, so that the electrons emerging from diaphragm aperture 21 will form a monochromatic and focussed electron beam 15″ containing electrons of very like velocities, since the diameter of aperture 21 can be made as small as desired.

It will be understood that, in the position shown of aperture 21, electron gun 11 together with diffraction element 22 and diaphragm 20, constitutes an electron velocity filter having a predetermined and fixed filtering characteristic, since the mean velocity of the electrons in monokinetic beam 15″ is solely determined by angle θ_2 between aperture 21 and diffracting surface 22′, and is not influenced by the distribution of electron velocities in incident electron beam 15. Hence, the electron velocity filter incorporated in the thermionic discharge tube shown in Fig. 1 operates as a "high-pass" electron-velocity filter, since aperture 21 of diaphragm 20 is located at a minimum angle θ_2 with respect to diffracting surface 22′.

The monokinetic and focussed electron beam 15″ emerging from diaphragm aperture 21 should be regarded as a tool prepared for further electronic work in devices requiring a practically perfect definition of electron velocity. In the thermionic discharge tube shown in Fig. 1 the monokinetic electron beam 15″ traverses modulation means indicated with the general reference numeral 24 in which the electron beam can be transformed or modulated in accordance with the particular performance characteristics of the thermionic discharge tube in response to a modulation potential applied to terminals 25 and 26 connected to modulation means 24. Collector electrode 27, connected to the positive pole 17″ of D.-C. supply 17 through a load impedance 28, may be formed of a fluorescent screen only, or may be constituted by an apertured target electrode, while load impedance 28 may be a pure resistance, a resonant circuit, or a mere conductor in the case of a thermionic discharge tube utilizing a fluorescent screen as indicating means.

In the thermionic discharge tube of Fig. 1, the incident electron beam 15 is focussed by means of an electrostatic lens system 16, the electron velocity of monokinetic beam 15″ being determined by the position of diaphragm aperture 21. The thermionic discharge tube shown in the drawing of Fig. 2 differs from that of Fig. 1 in that the incident and the diffracted electrons are travelling in divergent beams and that focussing of the electrons is applied to the monokinetic beam emerging from diaphragm aperture 21. For this purpose, a lens system, designated with general reference numeral 29 and connected to an intermediate potential of D.-C. supply 17, is located between diaphragm 20 and modulation means 24 of the tube, the diffraction zone 19′ of which is limited by an accelerating anode 30 and the diaphragm 20, both connected to ground potential. Furthermore, diffraction zone 19′ includes a pair of deflector plates 31 and 32 connected to control terminals 33 and 34, respectively, so that by applying an adequate potential to these terminals, the angle of incidence of electron beam 15 on diffracting surface 22′ may be varied within certain limits, as shown by the dotted lines 35 and 36. Consequently, the velocity of the electrons in the monokinetic electron beam 15″ will vary in accordance with the control potential applied to control terminals 33 and 34, so that a monokinetic electron beam of adjustable mean velocity can be obtained.

Although the electronic performance of thermionic discharge tubes shown in Figs. 1 and 2 is quite satisfactory, the L-shaped envelope 10 constitutes a constructive disadvantage which, under some circumstances, may restrict the utilization of the thermionic discharge tubes including the electron monochromator or velocity filter according to this invention.

Figs. 3 and 4 of the drawings show a longitudinal and cross section of a thermionic discharge tube, respectively, comprising a tubular envelope 10′, wherein the different construction elements of the tube can be connected to the contact pins of a standard base, if desired. As can be seen in the drawing, electron gun 11, electrostatic lens system 16, diaphragm 20, modulating means 24 and collector electrode or target 29 are coaxially mounted on a virtual axis parallel to that of tubular envelope 10' and coinciding with the axis of gun 11. Diffraction zone or chamber 19 is limited, similar to that of Fig. 1, by the second anode 16'' of electrostatic lens system 16 and diaphragm 20 and includes diffraction element 22 provided with a plane diffracting surface 22'. However, diffraction element 22 is not located in the direct path of the convergent electron beam 15 emerging from orifice 14 of electron gun 11, but is placed in a plane parallel to the axis of envelope 10', and convergent beam 15 is deflected toward diffracting surface 22' by means of a magnetic field perpendicular to the plane of the drawing and generated by a pair of coils connected in series to control terminals 33' and 34' to which an adequate D.-C. supply source (not shown in the drawing) is connected. The controlling magnetic field, formed as the sum of the individual magnetic fields schematically indicated with arrows 38 in the drawing of Fig. 4, also deflects the diffracted electrons towards diaphragm 20 and the diffracted electron beam 15' will be dispersed over a relatively wide area in a manner similar to that shown in Fig. 1. Hence, the electrons emerging from aperture 21 of diaphragm 20 form a monokinetic beam including electrons the mean velocity of which is determined by the position of the diaphragm aperture 21 within the area of the diffracted beam 15'. However, by varying the amplitude of the magnetizing D.-C. voltage applied to control terminals 33' and 34', i. e. by varying the intensity of the electromagnetic field generated by coils 37, the glancing angle θ_1 of the incident electron beam 15 may be varied within certain limits, so that an adjustable velocity monokinetic electron beam will be obtained.

The position of diaphragm 20 in the thermionic discharge tube shown in Figs. 3 and 4 is elected so that the sum of the mean trajectories of the incident and diffracted electron beams 15 and 15', respectively, is substantially equal to the focal distance of electrostatic lens system 16, so that monokinetic electron beam 15'' emerging from diaphragm aperture 21 is focussed to obtain a maximum concentration of the electrons.

In the thermionic discharge tubes shown in Figs. 1 to 4, the focussing of either the incident or the monokinetic electron beam is obtained by means of suitable electron lens systems. The focussing of the electron beam can also be obtained by utilizing a concave diffraction element mounted in a manner similar to that used by Rowland for his spectroscope (A. C. Hardy and F. H. Perrin, The Principles of Optics, 1932, pg. 563). As can be seen in the drawings, the thermionic discharge tube shown in Fig. 5 is similar to that disclosed in Fig. 2, with the only difference that a diffraction element 39 having a concave diffracting surface 39' is utilized in the diffraction zone 19'' which is also provided with deflector plates 31 and 32 for varying the glancing angle of incident electron beam 15. The curvature of concave surface 39' corresponds to a circle 40 passing through orifice 14 of electron gun 11 and diaphragm aperture 21, while the lattice structure of the diffraction element 39 is curved with a radius equal to the diameter of circle 40. Due to this arrangement, the divergent electron beam 15 containing electrons of different velocities will be diffracted as a plurality of convergent monokinetic beams focussed on different points located on the circumference of circle 40, as indicated by beams $15'_1$ and $15'_2$ in the drawing of Fig. 5.

The aperture 21 of diaphragm 20, being located at the focus of electron beam $15'_1$ will thus constitute a source of a concentrated monokinetic electron beam 15'', containing electrons the velocity of which is determined by the position of diaphragm aperture 21 with respect to diffracting element 39 and orifice 14 of electron gun 11. By varying the glancing angle of incident electron beam 15, the velocity of the monokinetic electron beam 15'' can be also adjusted within certain limits, as already explained hereinbefore with reference to the electron velocity filter incorporated in the thermionic discharge tube shown in Fig. 2. In the thermionic discharge tube shown in Fig. 6 the concave diffracting element 39 is mounted in a way similar to that of plane diffraction element 22 in the tube disclosed in Fig. 3, so that the electron velocity filter including concave diffracting element 39 can also be used in a thermionic tube comprising a tubular envelope 10', the diffraction zone 19'' of the tube being limited by an accelerating anode 30 and the apertured diaphragm 20 both connected to ground. The deflection of the incident and diffracted electron beams 15 and 15', respectively, is obtained by means of an electromagnetic field generated by coils 37, as already explained hereinbefore with reference to Fig. 3.

While I have indicated and described several embodiments of thermionic discharge tubes incorporating electron velocity filters in accordance with my invention, it will be apparent to one skilled in the art that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

I claim:

1. A thermionic discharge tube comprising an evacuated envelope containing means for generating a beam of electrons, electrode means for accelerating and directing said electron beam to a diffraction element having a substantially regular lattice structure to produce a diffracted beam of electrons dispersed in accordance with the respective velocities thereof, a diaphragm provided with an aperture and located in the path of the diffracted electron beam to produce an emergent beam of substantially monokinetic electrons the velocity of which is determined by the glancing angles of the incident beam and said monokinetic electrons with respect to the diffracting surface of said diffraction element, said accelerating electrode and said apertured diaphragm being electrically interconnected to form a substantially equipotential space including said diffraction element, means to vary the initial velocity of said accelerated electron beam to vary the velocity of said emergent monokinetic electron beam, and a target electrode to collect the said monokinetic electron beam.

2. A thermionic discharge tube including an evacuated envelope containing means for producing, accelerating and focusing a beam of electrons to a diffraction element, said element having a lattice structure arranged so as to disperse the said electrons with respective velocities approximately as a function of the glancing angles of the incident beam, electron barrier means provided with an opening positioned in the path of the said diffracted beam so as to pass monokinetic electrons of approximate like velocity, said bar-

rier means and said accelerating means being electrically interconnected so as to include the said diffraction element in a substantially equipotential space, means to vary the initial velocity of the said beam thereby to vary the velocity of said passed electrons, means to modulate the said passed electrons in accordance with electric control energy, and a target electrode to collect the said modulated passed electrons.

3. A thermionic discharge tube comprising an evacuated envelope and within the envelope an electron diffraction element, means for producing, accelerating, and focusing a beam of electrons toward said diffraction element, said element having a lattice structure arranged to disperse the said electrons in divergent directions proportional to the respective velocities thereof, electron barrier means provided with an opening positioned in the path of the said dispersed electrons to pass a monokinetic beam of electrons of substantially like velocity, said barrier means and said accelerating means being electrically interconnected to provide a substantially equipotential space enclosed in said diffraction element, a target electrode to collect the said passed electron beam, and means intermediate said opening and said target electrode to modulate the said passed electron beam in accordance with electrical control energy.

4. A thermionic discharge tube comprising an evacuated envelope and within the envelope an electron diffraction element, means to generate a beam of electrons and to focus and direct said electron beam toward said diffraction element, said element having a lattice structure arranged to disperse the said electrons in divergent directions proportional to the velocities thereof, a diaphragm provided with an aperture positioned in the path of the said dispersed electrons to pass a monokinetic beam of electrons of substantially like velocity, said diaphragm and said focusing and directing means being electrically interconnected and enclosing the said diffraction element in a substantially equipotential space, a target electrode to collect the said passed electron beam, said generating, focusing, and directing means being adapted to vary the velocity of the electrons of the passed electron beam, and means intermediate said aperture and said target electrode to modulate said passed electron beam.

5. A thermionic discharge tube comprising an evacuated envelope and within the envelope an electron diffraction element, means for generating a beam of electrons, means to accelerate and direct said electron beam toward said diffraction element, said element having a substantially regular lattice structure arranged to disperse by diffraction the said electrons in divergent directions according to the respective velocities thereof, electron barrier means provided with an opening positioned in the path of the said dispersed electrons to pass a monokinetic beam of electrons of substantially like velocity, said barrier means and said accelerating and directing means being electrically interconnected and enclosing the said diffraction element in a substantially equipotential space, said accelerating and directing means including beam deflecting means to vary the angle of incidence of said generated electron beam on said diffraction element thereby to vary the velocity of the passed electrons, a target electrode to collect the said passed electron beam, and means intermediate said opening and said target electrode to modulate said passed electron beam.

6. A thermionic discharge tube comprising an evacuated envelope and within the envelope a diffraction element, means for generating a beam of electrons, means to accelerate and direct said electron beam toward said diffraction element, said element having a substantially regular lattice structure arranged to disperse by diffraction the said electrons in divergent directions proportional to the respective velocities thereof, electron barrier means provided with an opening positioned in the path of the said dispersed electrons to pass a monokinetic beam of electrons of substantially like velocity, said barrier means and said generating means being electrically interconnected and enclosing the said diffraction element in a substantially equipotential space, said accelerating and directing means including electrostatic beam deflecting means to vary the angle of incidence of said generated electron beam on said diffracting surface in accordance with electrical control energy, a target electrode to collect the said passed electron beam, and means intermediate said opening and said target electrode to modulate said passed electron beam.

7. A thermionic discharge tube comprising an evacuated envelope and within said envelope an electron diffraction element, means for generating a beam of electrons, means to accelerate and direct said electron beam toward said diffraction element, said element having a substantially regular lattice structure arranged to disperse by diffraction the said electrons in divergent directions proportional to the respective velocities thereof, electron barrier means provided with an opening positioned in the path of the said dispersed electrons to pass a monokinetic beam of electrons of substantially like velocity, said barrier means and said generating means being electrically interconnected and enclosing the said diffraction element in a substantially equipotential space, said accelerating and directing means including magnetic field beam deflecting means to vary the angle of incidence of said generated electron beam on said diffracting surface in accordance with electrical control energy, a target electrode to collect the said passed electrons, and means intermediate said opening and said target electrode to modulate said passed electron beam.

8. A thermionic discharge tube comprising an evacuated envelope, and within said envelope an electron diffraction element, an electron gun provided with an electron lens system to produce a beam of electrons directed toward said diffraction element, said element having a lattice structure arranged to disperse the said electrons in divergent directions proportional to the respective velocities thereof, electron barrier means provided with an opening positioned in the path of the said dispersed electrons to pass a monokinetic beam of electrons of substantially like velocity, said barrier means and said electron gun means being electrically interconnected and enclosing the said diffraction element in a substantially equipotential space, the sum of the mean paths of the incident electron beam and the diffracted electron beam to said opening being substantially equal to the focal distance of said electron lens system, a target electrode to collect the said passed electron beam, and means intermediate said opening and said target electrode to modulate said passed electron beam.

9. A thermionic discharge tube comprising an evacuated envelope, and within the envelope an electron diffraction element having a surface the cross-section of which is a concave substantially circular line, means for generating a beam of

electrons, an electron lens system for focusing said beam of electrons and directing said beam toward said surface, said element having a substantially regular lattice structure at said surface elastically curved in the plane of said cross-section with a radius of curvature substantially equal to the diameter of the circle of said diffracting line, said beam being diffracted by said element to disperse the said electrons with respective velocities approximately as a function of the glancing angles of the incident and diffracted beams, electron barrier means provided with an opening positioned in the path of the said diffracted electrons to pass a monokinetic beam of electrons of substantially like velocity, said barrier means and said lens system being electrically interconnected and enclosing the said diffraction element in a substantially equipotential space, the sum of the mean paths of said incident beam and the diffracted beam to said opening being substantially equal to the focal distance of the said electron lens system, the said circle passing substantially through the source of said incident beam and through said opening, means to vary the velocity of the electrons of said passed beam in accordance with electrical control energy, a target electrode to collect the said passed electron beam, and means intermediate said opening and said target electrode to modulate said passed electron beam.

10. A thermionic discharge tube comprising an evacuated envelope, and within the envelope an electron diffraction element having a surface the cross-section of which is a concave substantially circular line, means for generating a beam of electrons, an electron lens system for focusing said beam of electrons and directing said beam toward said surface, said element having a substantially regular lattice structure at said surface elastically curved in the plane of said cross-section with a radius of curvature substantially equal to the diameter of the circle of said diffracting line, said beam being diffracted by said element to disperse the said electrons approximately as a function of the respective velocities thereof, electron barrier means provided with an opening positioned in the path of the said diffracted electrons to pass a monokinetic beam of electrons of substantially like velocity, said barrier means and said electron gun means being electrically interconnected and enclosing the said diffraction element in a substantially equipotential space, the sum of the mean paths of said incident beam and the diffracted beam to said opening being substantially equal to the focal distance of the said electron lens system, the said circle passing substantially through the source of said generated beam and through said opening, said electron lens system being adapted to vary the velocity of the electrons of the passed beam in accordance with electrical control energy, a target electrode to collect the said passed electron beam, and means

intermediate said target electrode and said opening to modulate said passed electron beam.

11. A thermionic discharge tube comprising an evacuated envelope, and within the envelope an electron diffraction element having a surface the cross-section of which is a concave substantially circular line, means for generating a beam of electrons, an electron lens system for focusing said beam of electrons and directing said beam toward said surface, said element having a substantially regular lattice structure at said surface elastically curved in the plane of said cross-section with a radius of curvature substantially equal to the diameter of the circle of said diffracting line, said beam being diffracted by said element to disperse the said electrons with respective velocities approximately as a function of the glancing angles of the incident and diffracted beams, electron barrier means provided with an opening positioned in the path of the said diffracted electrons to pass a monokinetic beam of electrons of substantially like velocity, said barrier means and said electron gun means being electrically interconnected and enclosing the said diffraction element in a substantially equipotential space, the sum of the mean paths of said focused beam from said lens system to said element and the diffracted beam from said element to said opening being substantially equal to the focal distance of the said electron lens system, the said lens system being adapted to vary the angle of incidence of said focused beam on said element in accordance with an electrical control quantity, the said circle passing substantially through the source of said focused beam and through said opening, a target electrode to collect the said passed electron beam, and means intermediate said opening and said target electrode to modulate said passed electron beam.

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