

Feb. 25, 1947.

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2,416,303

SECONDARY EMISSIVE SHELL RESONATOR TUBE

Filed Feb. 5, 1941

4 Sheets-Sheet 1

FIG. 1

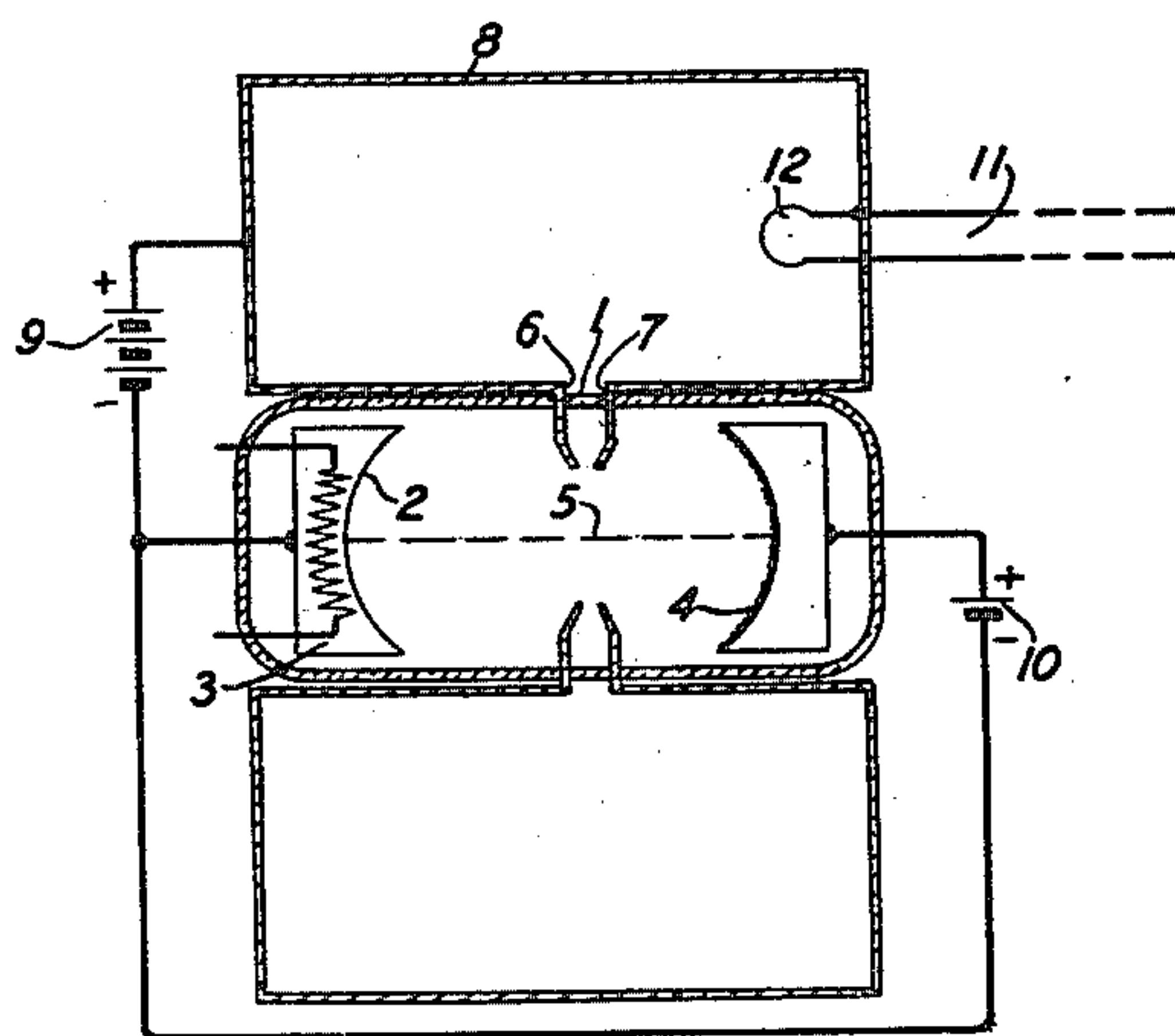


FIG. 2

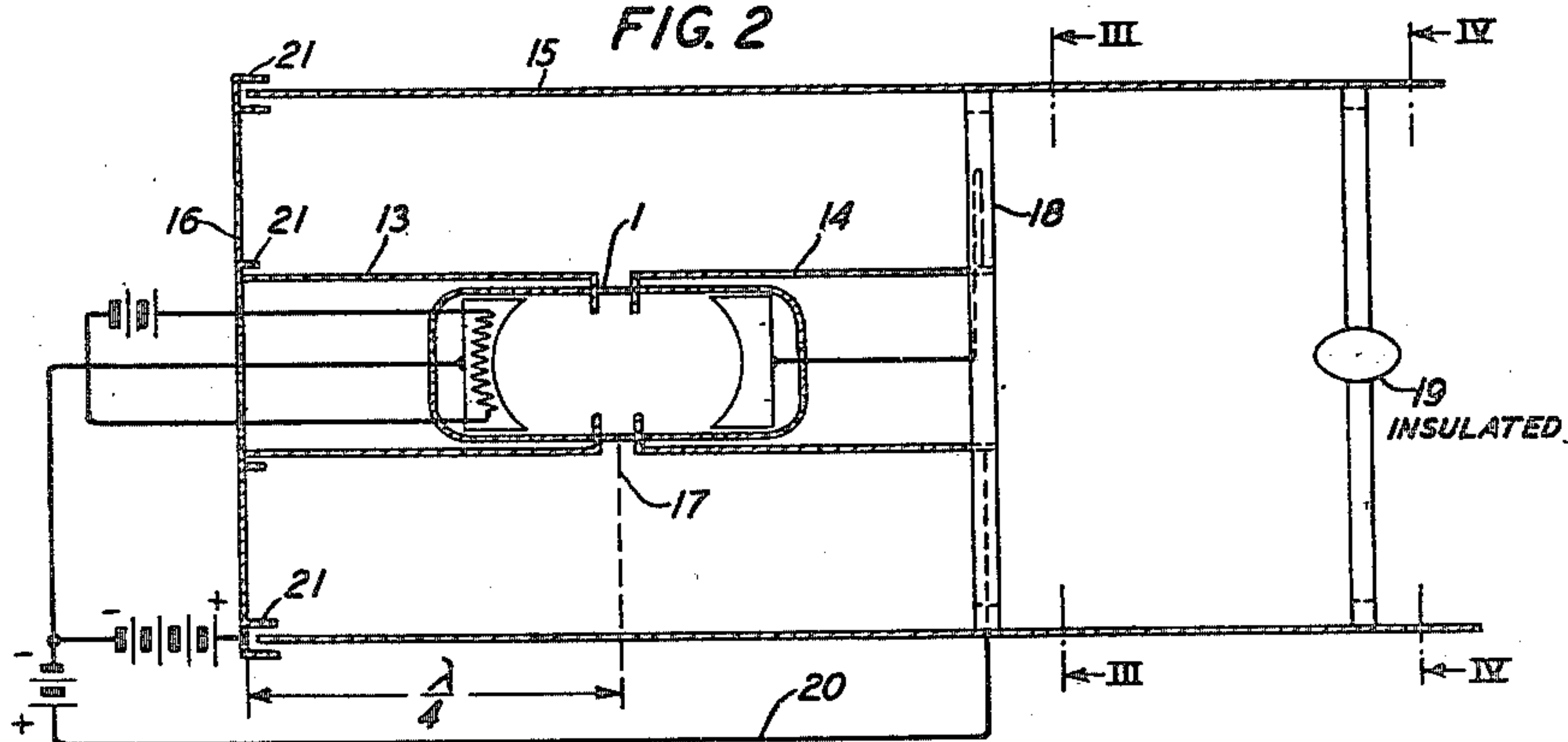


FIG. 3

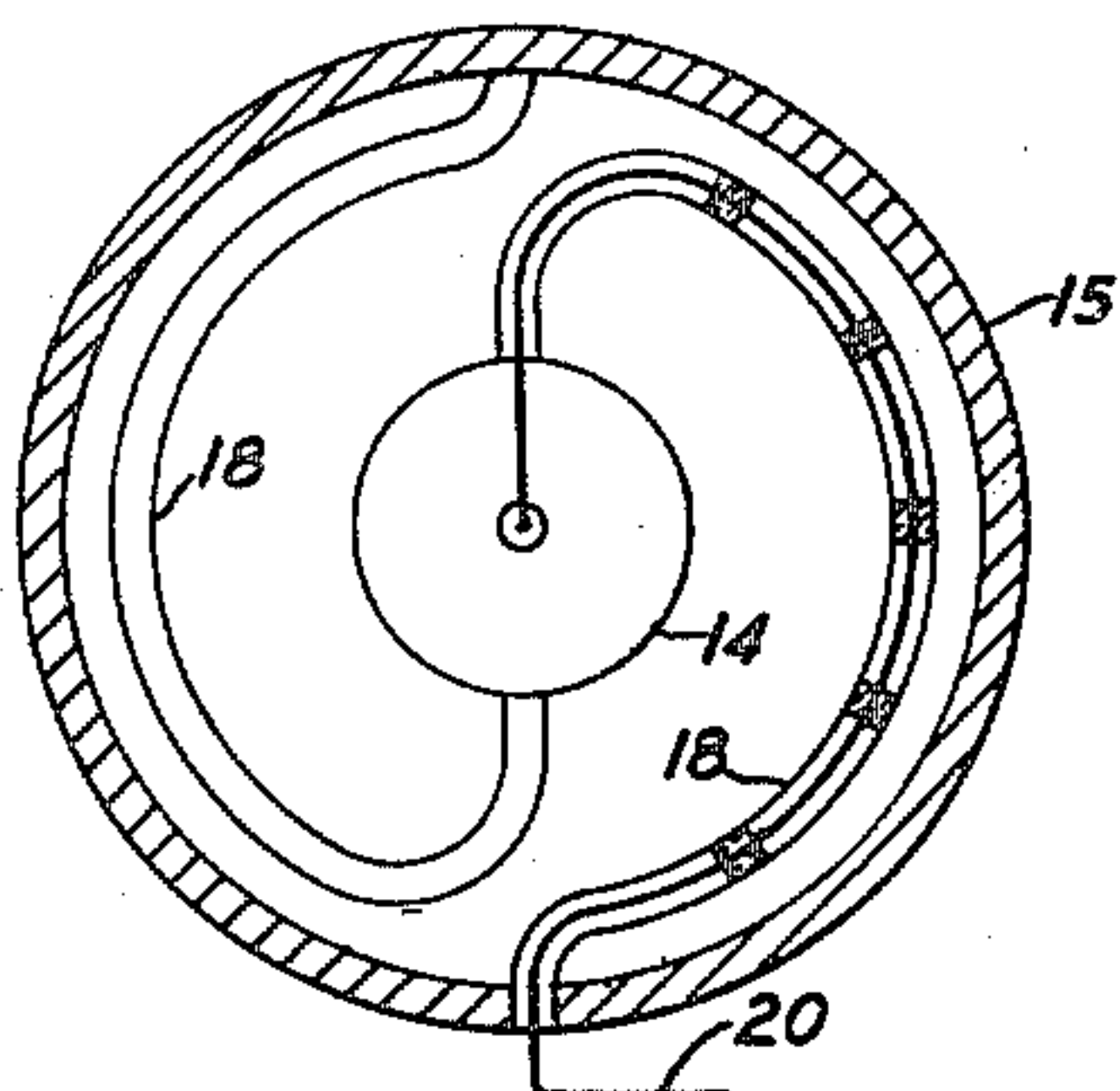
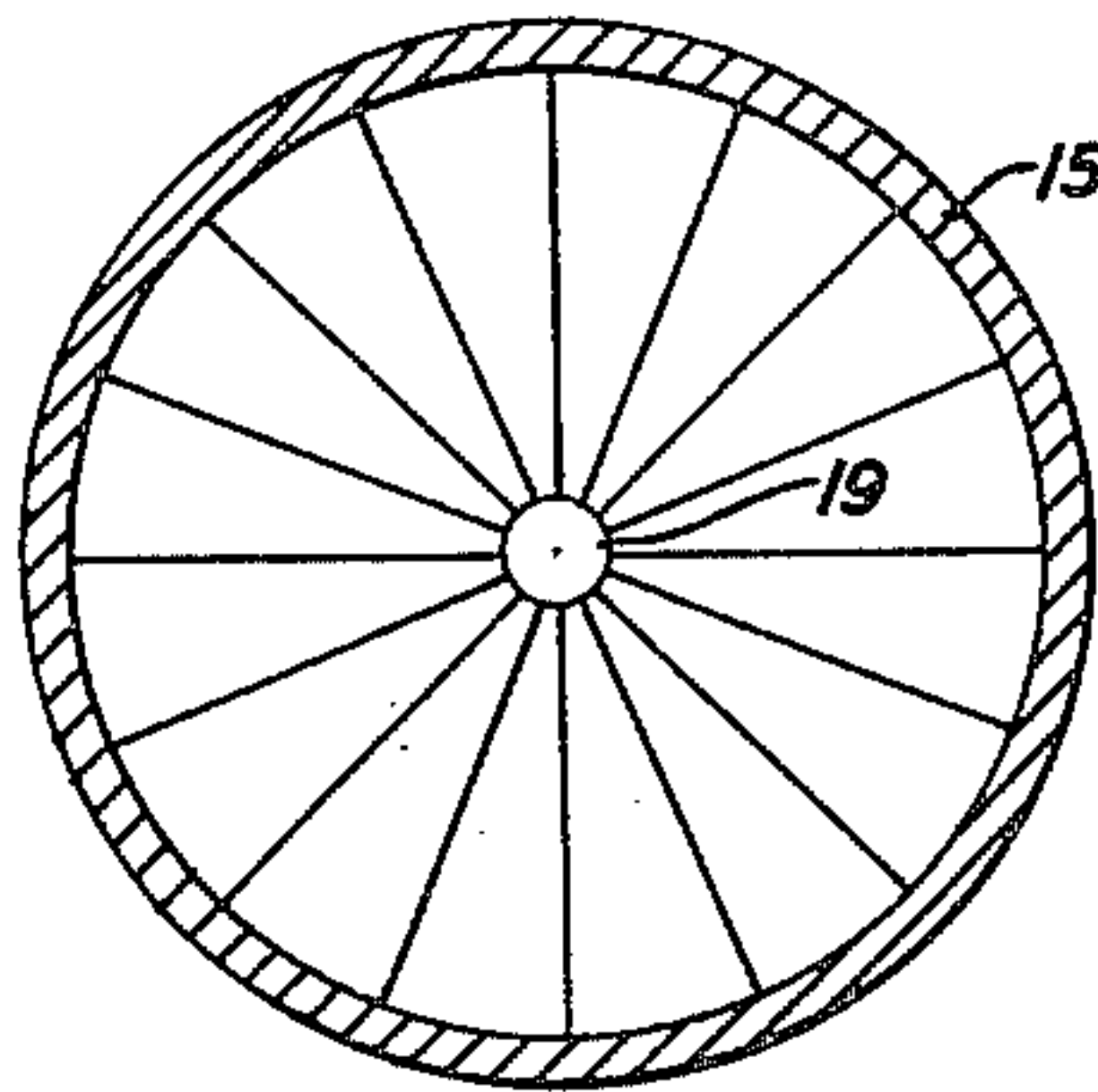


FIG. 4



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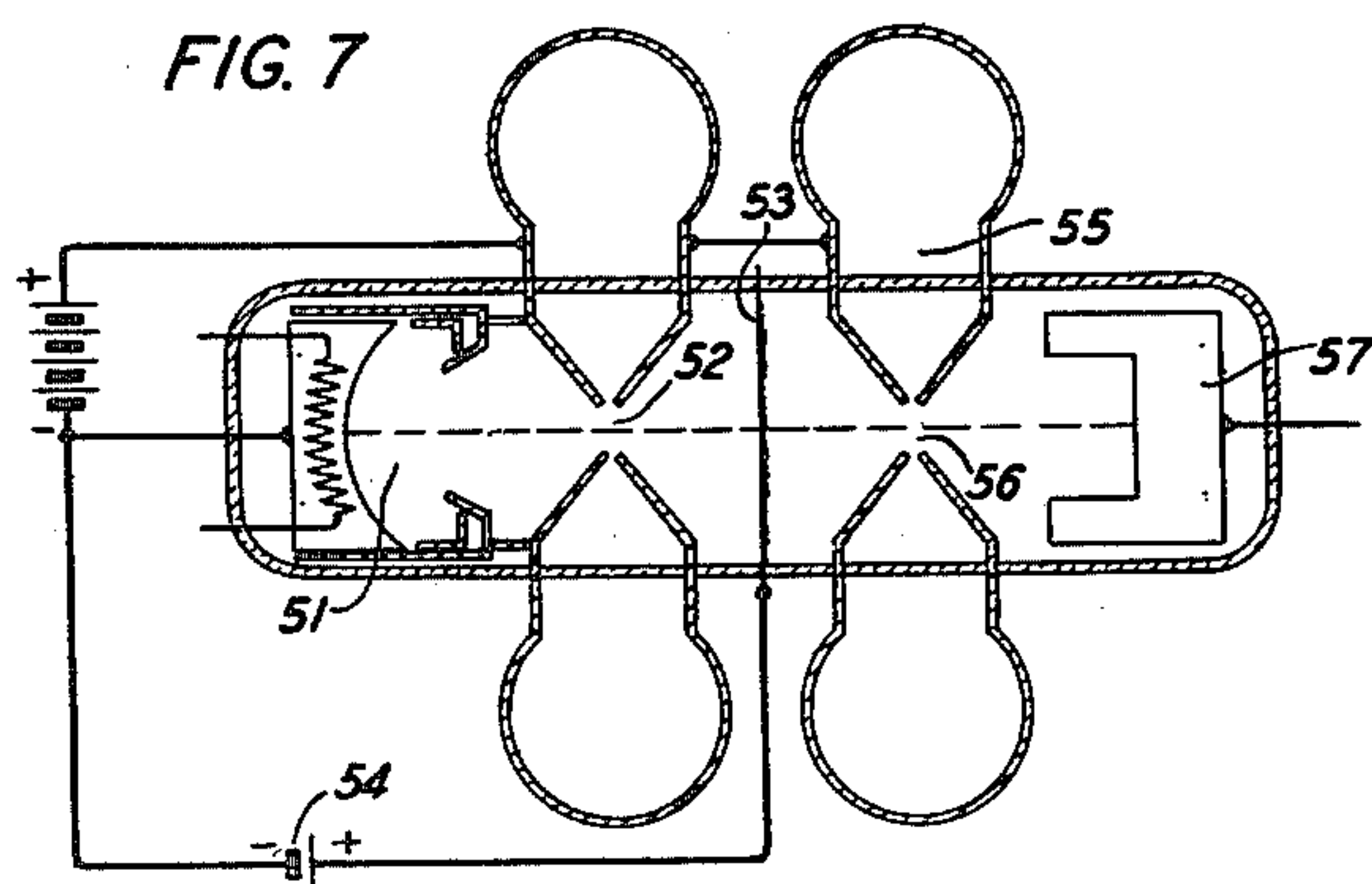
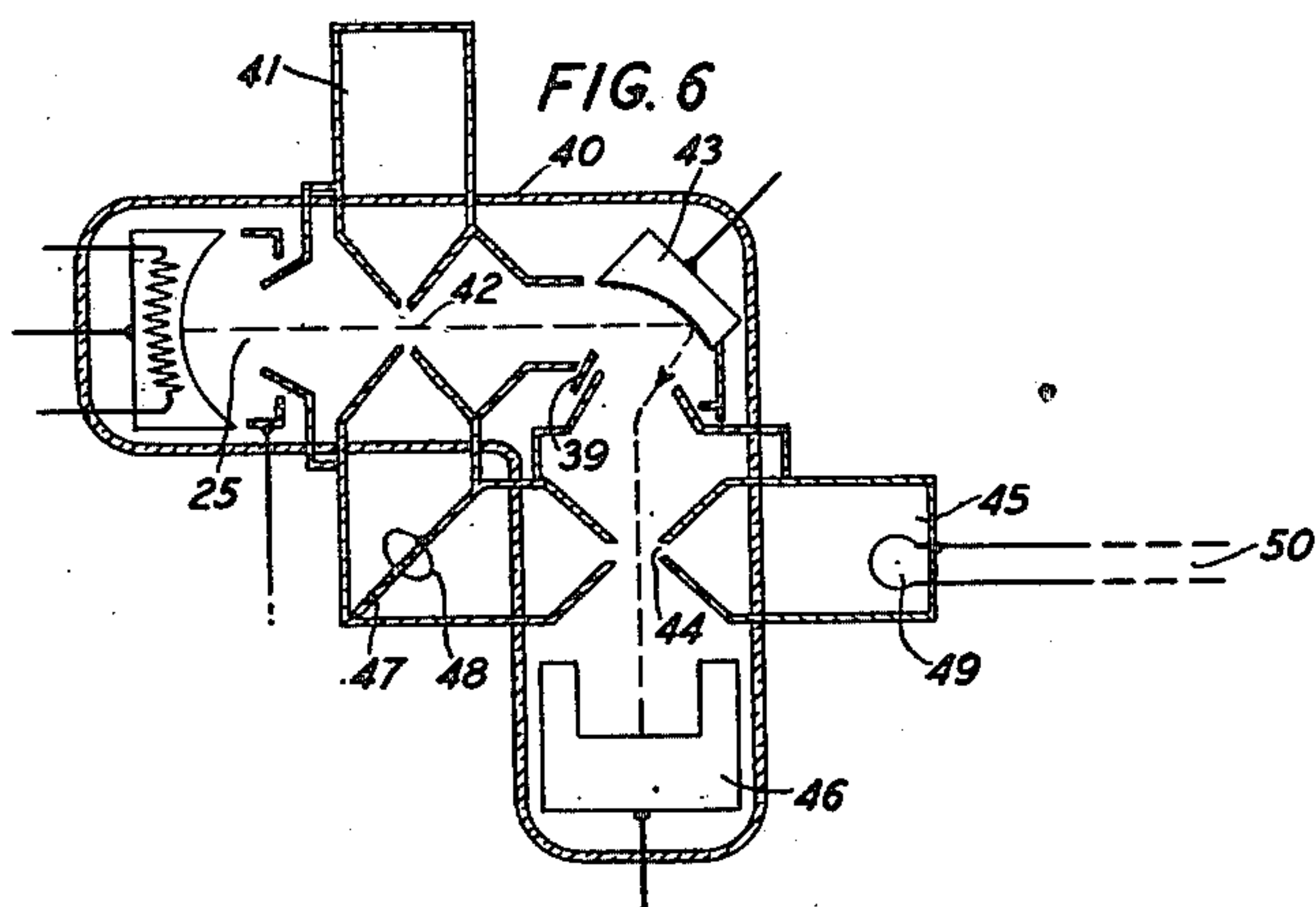
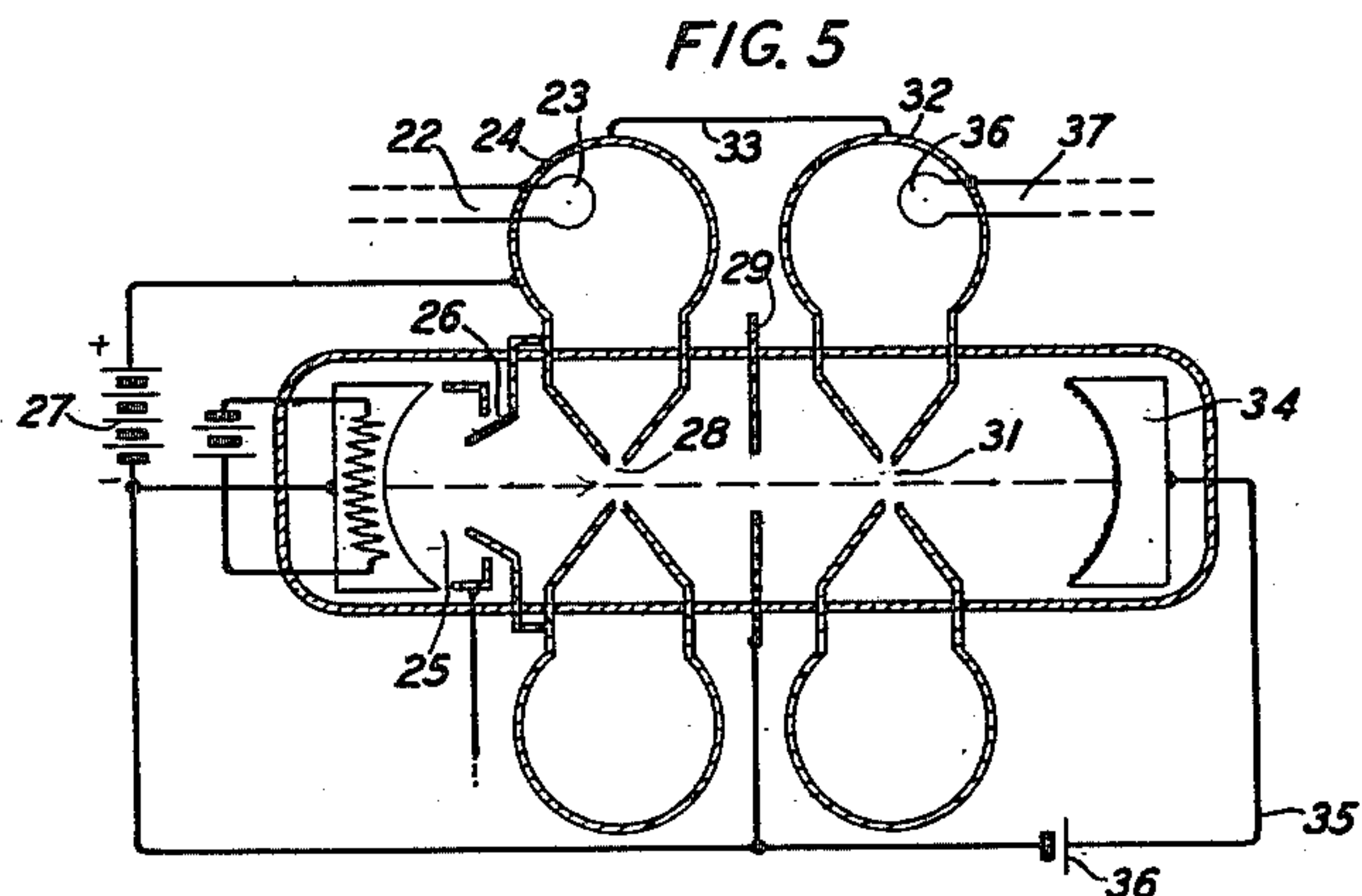
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SECONDARY EMISSIVE SHELL RESONATOR TUBE

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SECONDARY EMISSIVE SHELL RESONATOR TUBE

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FIG. 8

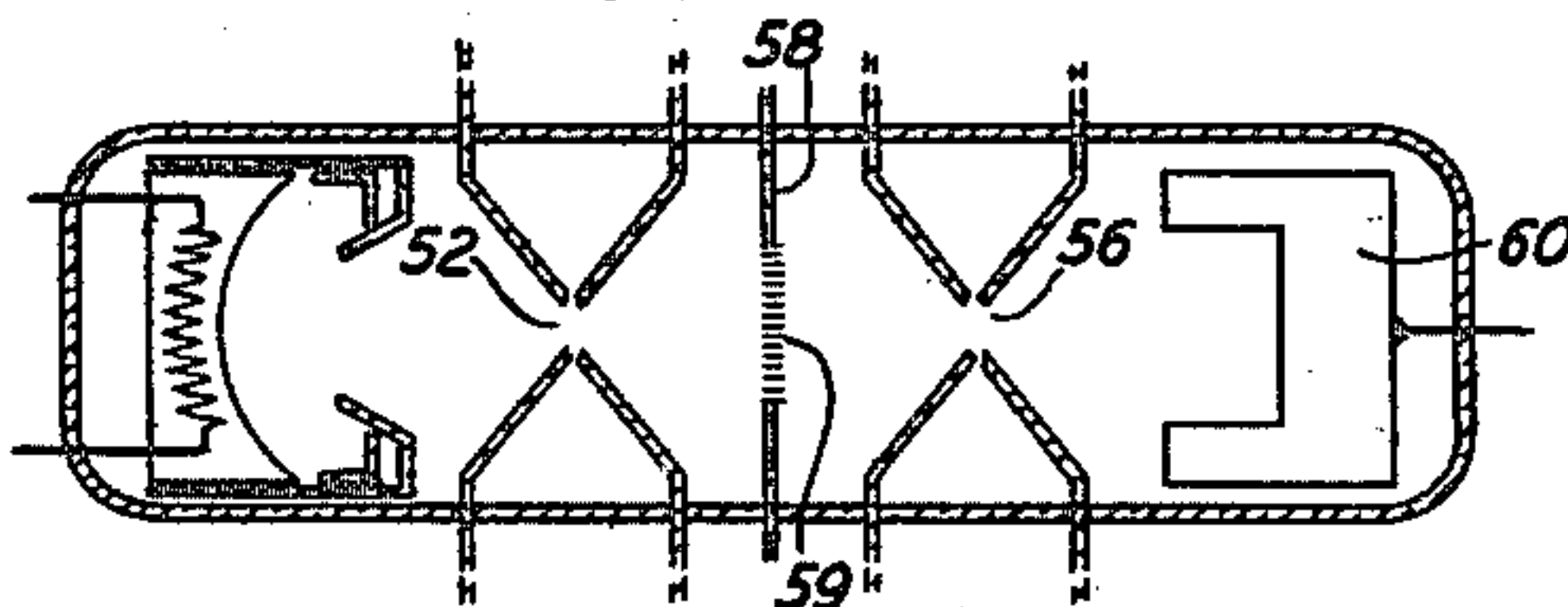


FIG. 9

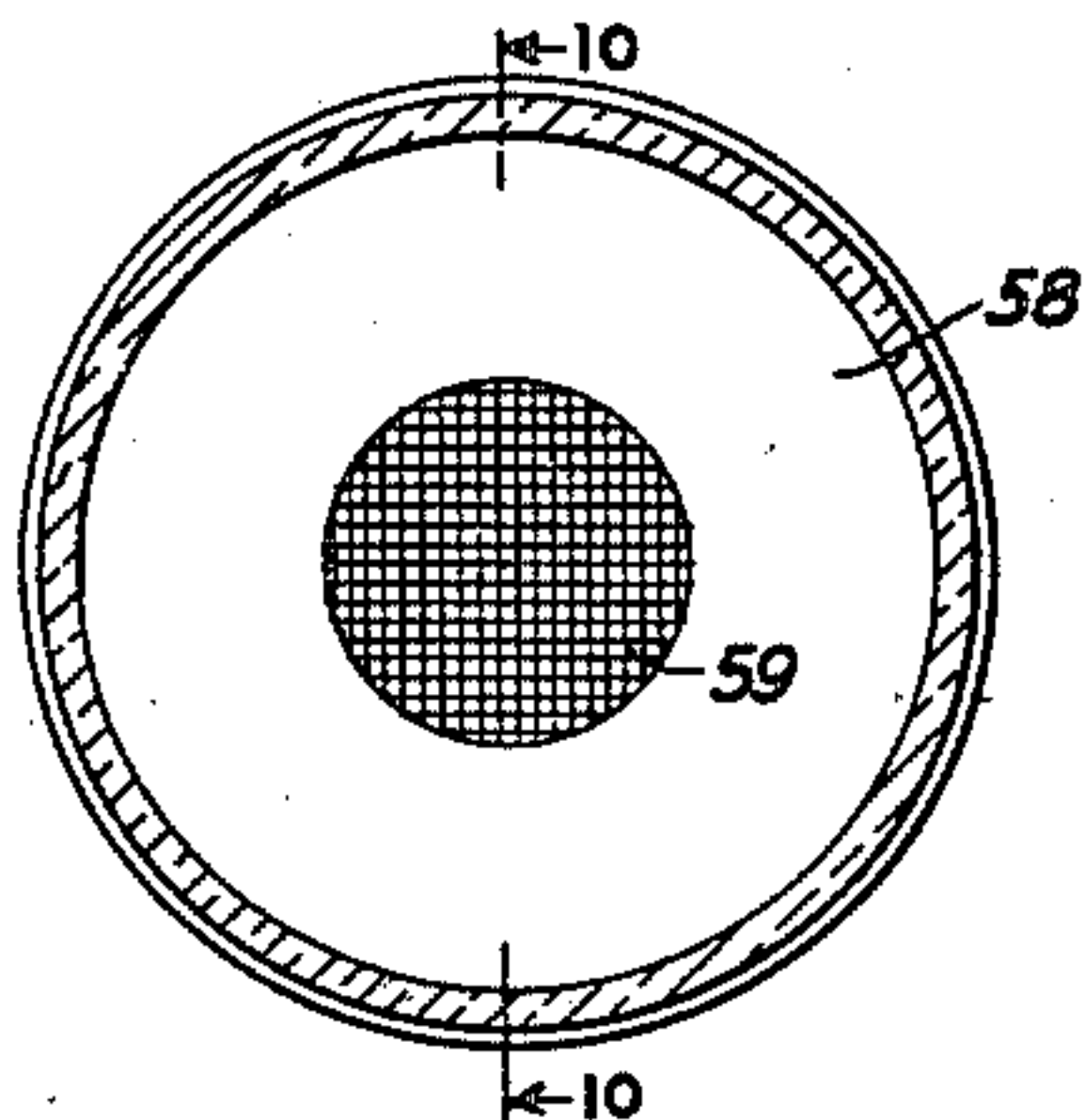


FIG. 10

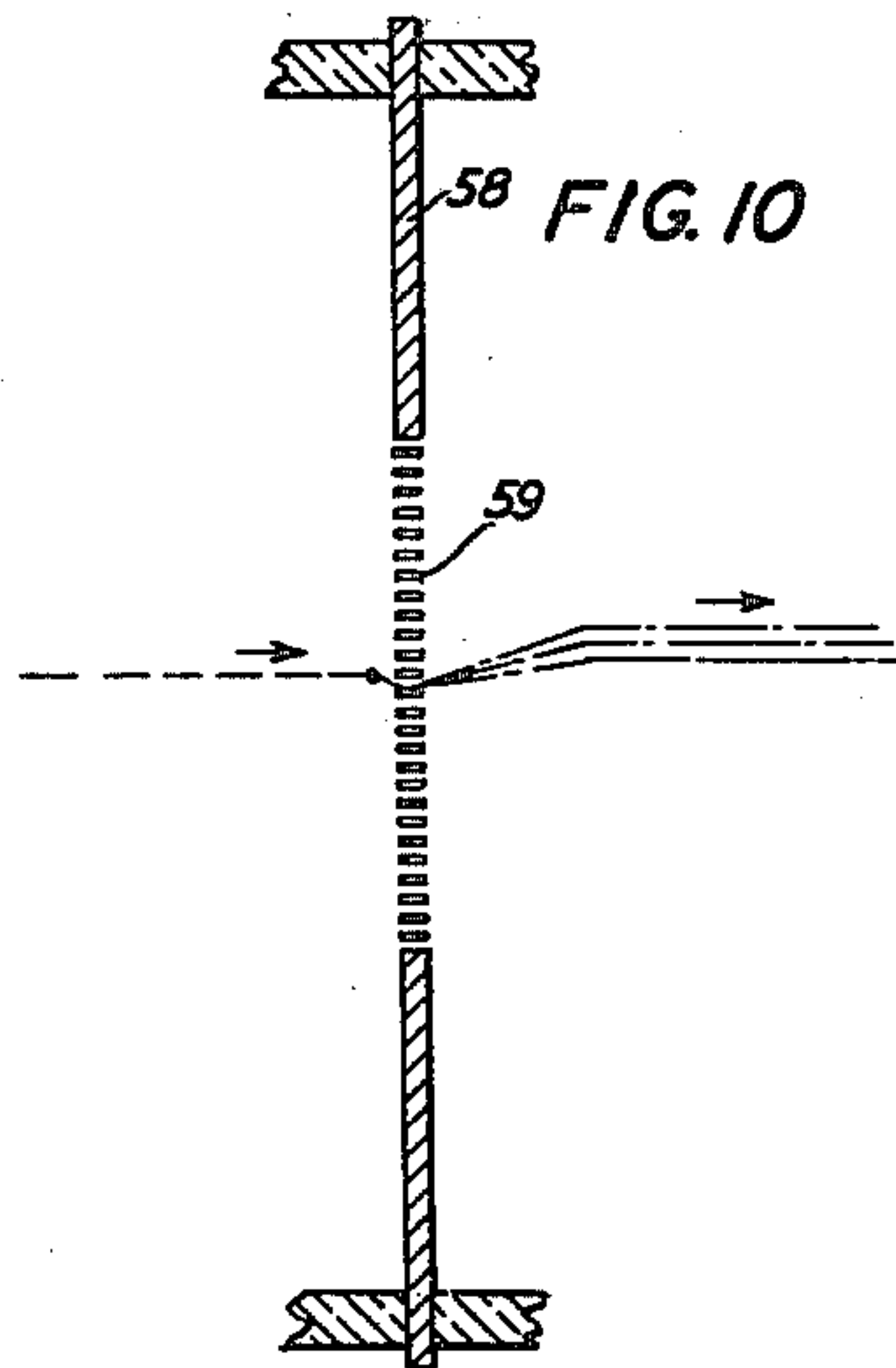
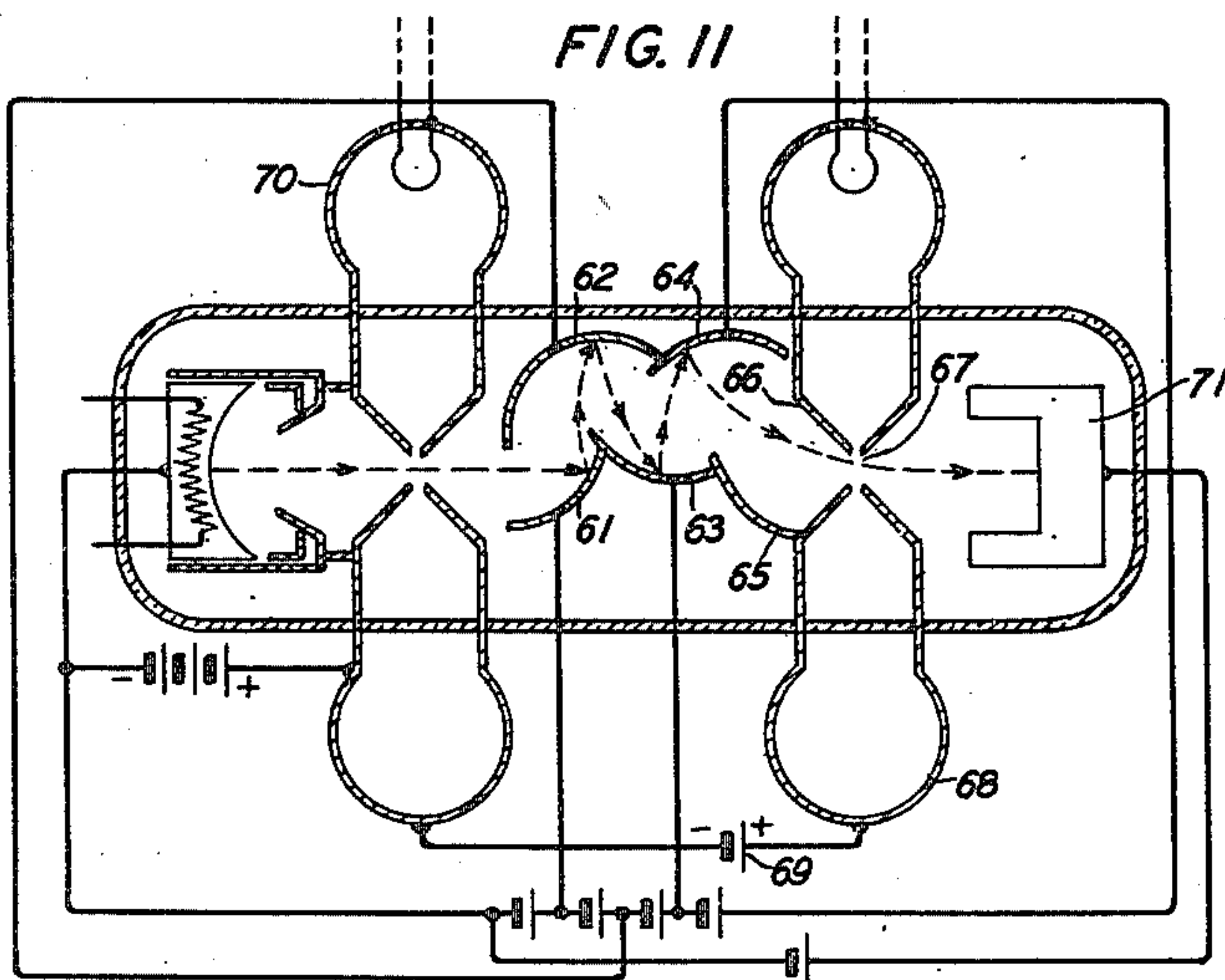


FIG. 11



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FIG. 12

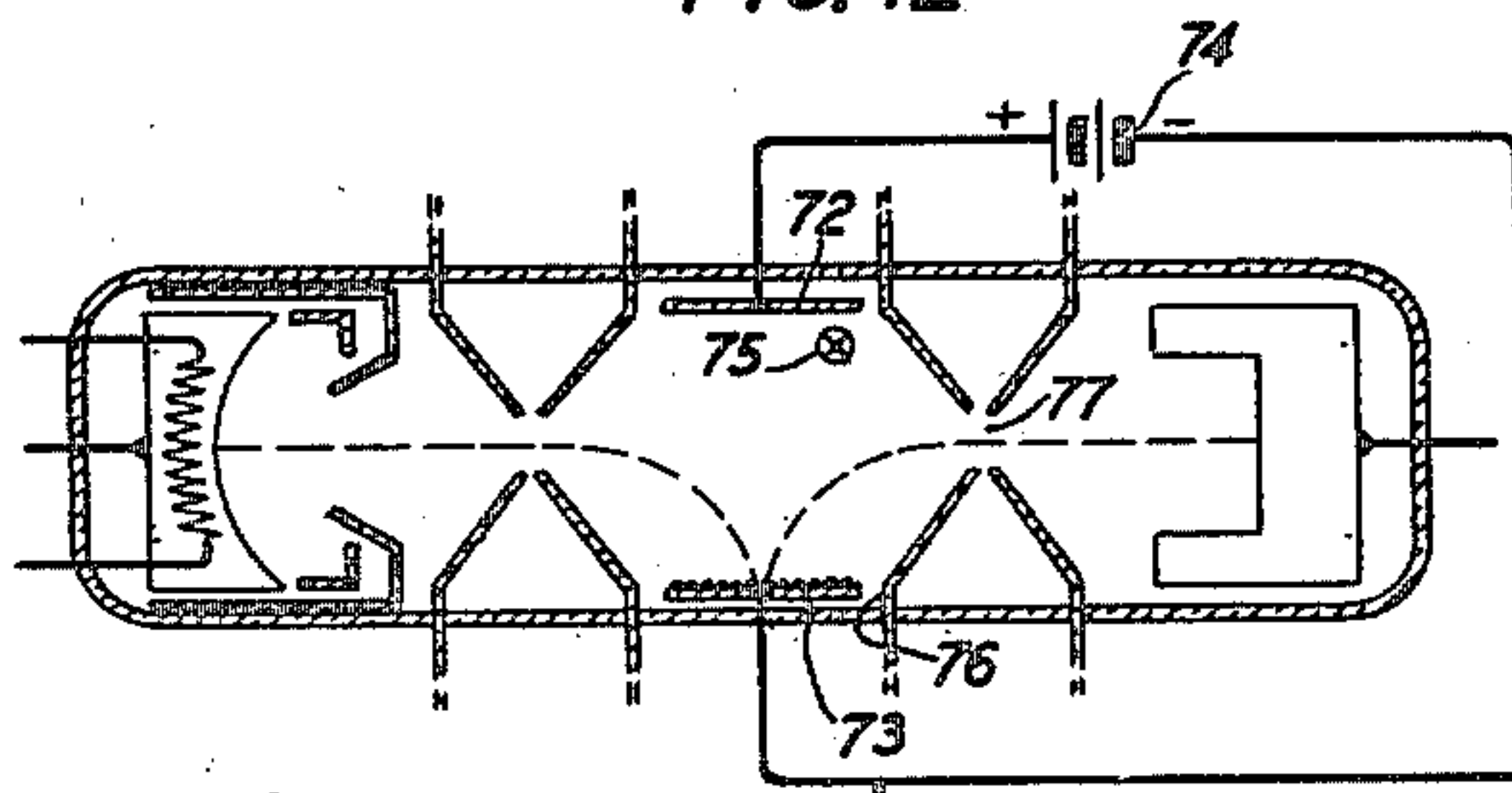
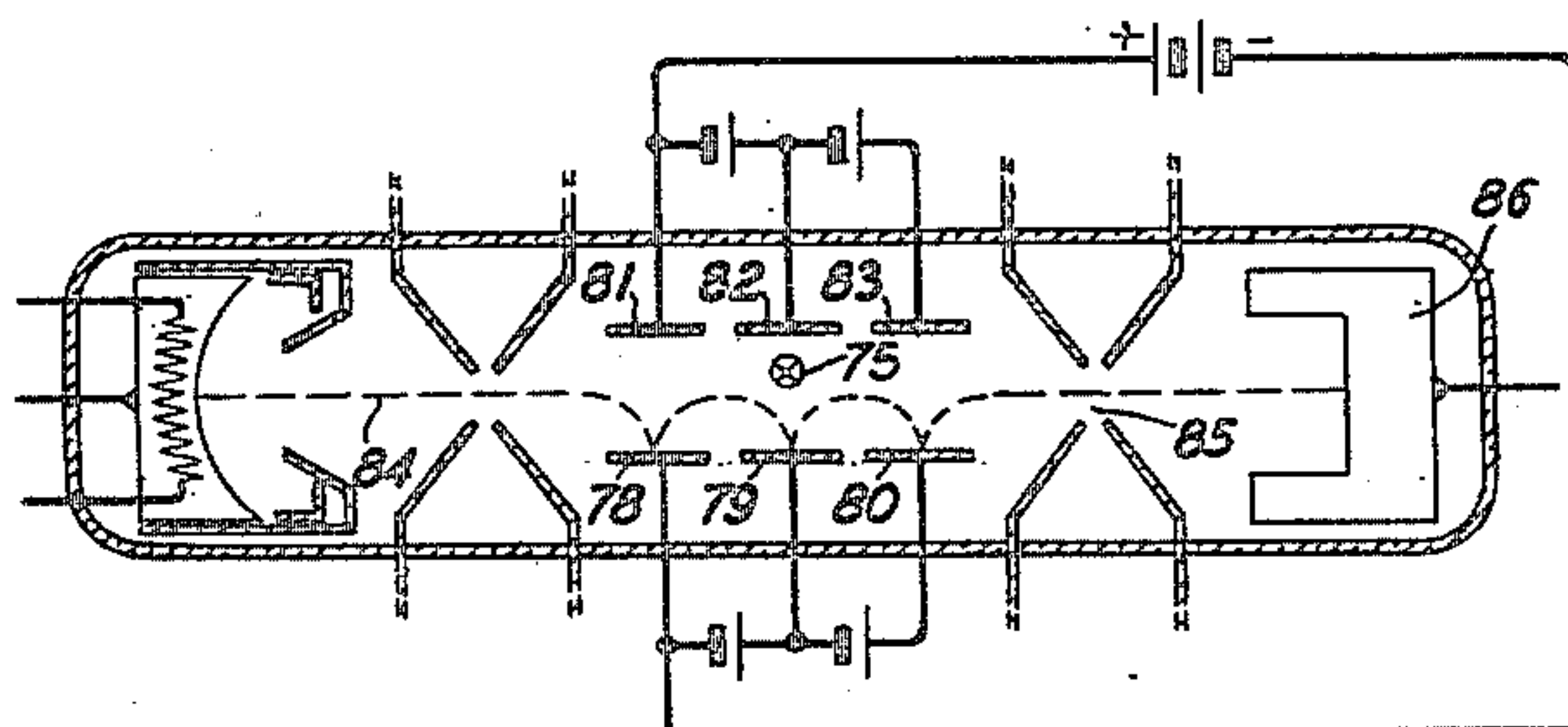


FIG. 13



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## UNITED STATES PATENT OFFICE

2,416,303

SECONDARY EMISSIVE SHELL RESONATOR  
TUBE

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Application February 5, 1941, Serial No. 377,442

9 Claims. (Cl. 315—12)

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This invention relates to electronic apparatus and more particularly to devices for conversion of electron velocity variation to electron density variation by means of secondary electron emission.

An object of the invention is to increase the transconductance of electronic apparatus such as amplifiers or oscillators.

Another object of the invention is to increase the input impedance of devices of the electron velocity variation type.

An additional object is to utilize secondary electron emission for conversion of the energy of a velocity-varied electron stream to energy of a density-varied beam.

This invention utilizes the principle that the number of secondary electrons emitted from a secondary emitter upon incidence of a primary electron depends upon the velocity of the incident electron. In accordance with the invention the electrons of a primary beam impinging upon a secondary electron emitting surface are subjected to a velocity variation so that the response of the secondary emitter will be variable, the number of secondary electrons emitted increasing and decreasing with increased and decreased velocity of the incident electrons. Thus, a velocity-varied stream gives rise at the secondary electron emitting surface to a density-varied beam of secondary electrons which is many times as large as the original primary electron stream. It is thus possible to utilize a very small primary stream with a short transit time through the input field and, accordingly, to attain high impedance at the input terminals of the device.

Various features and aspects of the invention will be apparent from a consideration of the following detailed specification and appended claims taken in connection with the accompanying drawing in which

Fig. 1 is a schematic diagram of an oscillator embodying the invention;

Fig. 2 is a similar diagram of an oscillator associated with a concentric conductor system or a wave guide;

Figs. 3 and 4 are end views of portions of the structure of Fig. 2, as observed from the right at the planes III—III and IV—IV respectively, of Fig. 2;

Fig. 5 is a schematic diagram of the circuit of an amplifier;

Fig. 6 shows a modified form of oscillator;

Fig. 7 shows an amplifier in which the secondary emitter responds to impinging electrons

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on one side to emit secondary electrons on the opposite side;

Fig. 8 shows a modification of the diagram of Fig. 7 in which the secondary emitter is in the form of a perforate grid or screen;

Fig. 9 is a face view of the secondary emitter of Fig. 8;

Fig. 10 is an enlarged section taken along the line 10—10 of Fig. 9;

Fig. 11 shows an amplifier involving a multiple-stage electron multiplier;

Fig. 12 is a modified form of amplifier in which crossed electric and magnetic fields are used for focussing electrons approaching and leaving the secondary emitting surface, and

Fig. 13 shows a modification of the amplifier utilizing a multistage electron multiplier.

Referring to Fig. 1, the evacuated chamber 1 of suitable dielectric material, encloses a primary cathode 2 with its heating element 3 and a secondary electron emitting anode 4. The cathode 2 has an electron emitting surface preferably arcuate or spherical in form and there may be associated with the cathode any suitable focussing device for causing the electron beam to proceed as a concentrated pencil of electrons with its central axis along the broken line 5. The cathode 2 cooperates with the annular flanges 6 and 7 of conducting material which serve as a high potential anode or accelerator to constitute an electron gun. Flanges 6 and 7 extending inwardly through the wall of the dielectric receptacle 1 into which they are sealed are flat centrally apertured discs welded or soldered at their peripheries outside the tube to an external annular shell to constitute integral portions of an annular resonance chamber 8, the natural frequency of which corresponds to the frequency of the oscillations to be produced. A high potential source 9 with its positive terminal connected to the resonance chamber 8 and its negative terminal connected to the cathode 2 furnishes polarizing potential for accelerating the electrons. The electron stream is impelled against the surface of the element 4 which is preferably coated with a substance such as caesium, or caesium oxide, or a layer of caesium oxide with an under layer of silver, to facilitate emission of secondary electrons. When oscillations are in any manner set up within the resonance chamber 8, the resulting electromagnetic field tends to produce an equipotential surface across the space surrounded by the flange 6 and a second equipotential surface across the space surrounded by the annular flange 7. Electrons of the high



velocity beam in their transit through the electromagnetic field bounded by these equipotential surfaces experience a velocity variation which is a positive acceleration when the field aids motion of the electrons and is a deceleration when the field opposes it. The spacing in the longitudinal direction of the tube between the flanges 6 and 7, together with the dimension of the openings, determines the transit distance of the electrons within the field. This spacing is preferably so predesigned in conjunction with the predetermined velocity of electrons arriving at that zone as to enable most efficient velocity variation to occur. The transit time of the electrons through the electromagnetic field should preferably be less than one-quarter period. The high velocity electrons, velocity varied in accordance with the field through which they have passed, proceed toward the element 4, the potential of which is determined by the source 10 connected between cathode 2 and the element 4 to render the element 4 slightly positive. As the electrons approach element 4 they are decelerated by an amount depending upon the difference in potential of the chamber 8 and the element 4. Consequently, they arrive at the surface of the element 4 at velocities within the velocity region for which the surface 4 is most efficient in emission of secondary electrons.

Zworykin, Morton and Malter at page 355 of the Proceedings of the Institute of Radio Engineers for March 1936, vol. 24, No. 3, have shown that the ratio of secondary emission current to primary current for certain types of secondary electron emission surfaces rises rapidly with velocity up to a few hundred volts and that the rate of rise or the slope of the characteristic is greatest in the very low voltage region. It is, accordingly, desirable in apparatus embodying the present invention to operate the device with the potential of element 4 just sufficient to insure that the lowest speed electrons of the velocity-varied beam reach the anode 4 and are collected. If the transit path between the velocity variation zone and the element 4 be made very short the stream of electrons impinging upon the element 4 will be substantially uniform in number or density but varying in velocity. Consequently, the secondary electrons emitted will be few when the impinging primary electron velocity is low and will be much larger when the velocity of impinging primary electrons is highest. The secondary beam emitted from element 4 will therefore be density varied. These secondary electrons will be impelled by the high accelerating potential of the flange 7 toward the velocity varying space or gap between the flanges 6 and 7. Arriving at that space at high velocity and at instants at which the field is so directed as to oppose their transit the clusters or groups of the density-varied secondary beam will serve to yield energy to the resonance chamber 8 and will suffer a deceleration in the process. They will then proceed on toward the cathode 2 but will not reach it for the reason that its potential is lower than that of their originating surface 4. After coming to a rest position they will again be accelerated in the reverse direction toward the emitter 4 losing energy to the chamber 8 as they again traverse its velocity varying gap. In this fashion the secondary electrons deliver energy to the chamber 8 in their excursions through its field and are finally withdrawn from the zone and collected at the flanges 6 and 7.

In order to insure correct phasing of the clus-

ters or groups of electrons of the density-varied secondary stream as they pass the energy extracting gap first in one direction and then in the other, it is desirable to insure that the transit times toward the gaps in the two directions are equal. Since the primary electrons proceeding from the source 2 experience a greater acceleration in reaching the equipotential surface of the flange 6 than do secondary electrons emitted from the higher potential element 4 in proceeding toward the equipotential surface of flange 7, the transit time from the respective sources to the center of the velocity varying gap will tend to be slightly different. A compensation for this may be made by positioning the secondary electron emitting anode 4 slightly closer to the center of the gap thus reducing the distance that its lower velocity electrons must travel to reach the center of the gap.

Oscillation energy may be supplied from the chamber 8 to an output circuit 11 by a coil 12 connected to the circuit 11 and introduced into the space within the chamber 8.

In Fig. 2, the details of the discharge device 1 are similar to those of the corresponding device of Fig. 1. However, the annular flanges 6 and 7 of the velocity variation gap are associated with sections 13 and 14 respectively, of the central conductor of a concentric conductor system. The outer conductor 15 of the concentric conductor system and the section 13 of the center conductor are short-circuited by a metallic cap 16 and the discharge device 1 is so positioned with respect to the cap 16 that the distance from the cap 16 to the central plane of the velocity varying gap indicated by broken line 17 corresponds to an odd number of quarter wave-lengths of the oscillations to be produced. The central conductor 14 may terminate at its opposite end in a fin 18 or extension designed as explained in connection with the disclosure of Figs. 32, 33 and 34 of U. S. Patent 2,129,714, issued September 13, 1938, to G. C. Southworth to excite the desired type of wave in the concentric system thus permitting the outer conductor 15 to continue on as a wave guide. The fin 18 corresponds in function and design to the members 52, 53 of the Southworth disclosure and there is preferably associated with it a sieve 19 of radial wires to block any superposed remnant of the symmetric electric waves and permit the passage to the right of only the purified resultant symmetric magnetic waves. Of course, other means of converting from one type of wave to another type as revealed in Patent 2,129,714 or elsewhere may be used to excite the desired type of wave in the wave guide. To prevent the lead 20 to the collector of the tube from itself forming a part of the radiating system, it should preferably be introduced through a hollow portion of one of the extensions 18 as shown in Fig. 3. In order to obtain a nice adjustment of the position of the gap, the cap 16 is provided with circular projecting sleeves 21 telescoping with the inner and outer conductors 13 and 15.

In the amplifier of Fig. 5, an input circuit 22 is connected by an internal loop 23 with the electromagnetic field inside the input resonant chamber 24 which is generally similar to the chamber 8 of Fig. 1 and is preferably tuned to the frequency of the incoming waves. An electron gun 25 indicated schematically may be of any well-known design but is preferably constructed in accordance with the disclosure of Parker-Samuel application, Serial No. 327,826, filed April 4, 1940. The primary electron stream from the electron



gun 25 is accelerated by the potential of the chamber 24 and of the annular anode 26 which are connected to the cathode by an external path including the high potential accelerating source 27. The high potential velocity-varied electron stream emerging from the velocity varying gap 28 is retarded by the field associated with an apertured retarding disc 29 which is held at the same potential as the cathode. Since the deceleration between the gap 28 and the disc 29 is substantially equal to the acceleration between the cathode of the electron gun 25 and the gap 28, electrons which were decreased in velocity in the velocity varying path will fail to pass through the aperture of the disc 29. Electrons accelerated in the velocity variation operation will succeed in passing through the disc 29 thus giving rise to a density-varied stream directed toward the gap 31 associated with a resonant output chamber 32 similar to chamber 24 and similarly tuned. Since the chamber 32 is connected by a conductor 33 to the chamber 24 it is at high potential and the electrons of the density-varied stream will be accelerated and will pass through the gap 31 at relatively high velocity permitting energy to be extracted by the opposing electromagnetic field which they encounter in the gap. After emerging from the gap 31 the density-varied stream impinges upon the element 34 which is connected to the cathode of the electron gun 25 by an external path 35 including a source of potential 36 of just sufficient magnitude to insure that all electrons of the density-varied stream are collected. The element 34 is provided with a concave or spherical surface in the same manner as element 4 of Fig. 1 and is, likewise, coated with a material to facilitate emission of secondary electrons. Accordingly, each group of electrons of the density-varied stream impinging upon the element 34 gives rise to a larger group of secondary electrons. The secondary electrons are accelerated by the high potential of the chamber 32 and pass through the gap 31 yielding energy to the electromagnetic field of the chamber 32. Retarded and turned back by the field associated with the zero potential disc 29 they are again accelerated toward the gap 31 to deliver energy thereto a second time. It will be apparent that in this system energy is delivered to the resonant chamber 32 both by the density-varied primary electrons which succeed in passing through the aperture of disc 29 and by the secondary electrons which they release at the surface of element 34. The correct phasing to enable the electromagnetic field of the chamber 32 to extract the maximum energy from the groups of electrons may be attained by proper positioning of the gap 31 with respect to the virtual cathode at 29 and the secondary electron emitting cathode at 34 in the manner already described in connection with the description of Fig. 1. Amplified oscillations corresponding in wave shape and frequency to those supplied by the input circuit 22 but greatly augmented in their energy content may be supplied to the output circuit 37 by the loop 38 introduced within the chamber 32.

In Fig. 6, the envelope 40 encloses an electron gun 25 similar to that of Fig. 5. The resonant input chamber 41 determines by its natural frequency the wave-length of the oscillations to be produced. The velocity-varied electron stream emerging from the velocity varying gap 42 is directed against a secondary electron emitting surface 43 similar in shape and character to the

element 4 of Fig. 1 but with its axis of symmetry at approximately 45 degrees with respect to the axis of the incident beam of electrons. Accordingly, secondary electrons from the surface of the emitter 43 instead of being returned toward the gap 42 are focussed and accelerated toward the gap 44 of a resonant output chamber 45 so as to deliver oscillation energy to its electromagnetic field. A collecting element 46 serves to withdraw the electrons after transit through the gap 44. If an input circuit and an output circuit be coupled to the input and output chambers, respectively, as in the disclosure of Fig. 5, the device may serve as an amplifier. As illustrated, however, with the resonant chambers 41 and 45 positioned at right angles to each other and having a common wall 47 the device lends itself readily to production of oscillations if a suitable feedback from the output chamber to the input chamber be provided. This may be effected by a small loop 48, a portion of which is introduced into each chamber. The system will, therefore, function to supply high frequency oscillations to the loop 49 within the chamber 45 and to the output circuit 50.

As in the structures of the preceding figures high speed primary electrons emitted by the gun 25 are focussed on the gap 42 and velocity varied by the electromagnetic field as they pass through the gap. These velocity-varied electrons are then decelerated because of the lower potential of the secondary emitter 43 which, with the decelerating element 39 of the same potential, serves to reduce the electron velocity to the magnitude most suitable for the secondary electron emitter.

Fig. 7 illustrates an alternative form of the apparatus of Fig. 6 and like that of Fig. 6 may be employed either as an amplifier or as an oscillator. In this embodiment of the invention, an electron gun 51 projects a stream of electrons through the velocity-varying gap 52 against a thin foil 53 which is maintained at a positive potential with respect to the cathode by means of the source 54. On the opposite side of the foil 53 there is a coating of secondary electron-emitting material. The foil is preferably so thin that under bombardment by the velocity-varied stream on the one side it emits from the opposite and coated side a stream of secondary electrons which is accelerated by the high polarizing potential of the resonant output system 55 to deliver oscillation energy to the electromagnetic wave field in the gap 56. A collector 57 withdraws the decelerated electrons from the field.

Fig. 8 is in all respects identical with the disclosure of Fig. 7 except that the thin foil 53 is replaced by a disc 58 having a central apertured grid-shaped portion 59 as indicated in greater detail in Fig. 9 and in the enlarged section along the line 10—10 of Fig. 9 presented in Fig. 10. As illustrated in the latter figure electrons arriving from the left and impinging upon one of the coated flat beams or rods of the grid 59 will give rise thereto an emission of a plurality of secondary electrons passing out from the grid in the opposite direction toward the collector 60.

It will, of course, be understood that although only the tube structure is shown in Figs. 8, 9 and 10, there will be associated with the velocity-varying and wave energy-extracting elements, resonant chamber systems exactly as in the case of Figs. 5 and 6, and external circuits of an amplifier as in Fig. 5, or of an oscillator as in Fig. 6.

The apparatus of Fig. 11 is similar to that of



Fig. 8 but in lieu of the single stage electron emitter 58, 59, there is provided a four-stage device 61, 62, 63, 64. The density-varied multiplied electron stream emerging from the final cathode 64 of the electron multiplier is directed by a focussing and accelerating system 65, 66 to the gap 67 associated with a resonant output chamber 68 to the electromagnetic field of which it delivers oscillation energy in transit through the gap 67. A source of potential 69 renders the chamber 68 slightly positive with respect to the chamber 70 in order to accelerate the electrons from the last stage of the multiplier to a velocity suitable for most efficient energy transfer. The electron collector 71 withdraws the spent electrons from the field.

The apparatus of Fig. 12 resembles that of Figs. 7 and 8 in that a single secondary electron-emitting stage is used between the velocity-varying input gap and the wave energy-extracting output gap. In this device, a pair of parallel deflecting plates 72 and 73 are provided, plate 73 being polarized negatively with respect to 72 by a source 74. The primary stream is directed upon the plate 73 by a cross magnetic field extending in a direction perpendicular to the plane of the paper represented diagrammatically by a cross within a circle 75. Under idealized conditions of field uniformity and zero initial velocities, the electron path is a cycloid. The upper surface of plate 73 is coated with a suitable material to facilitate electron emission and secondary electrons are accordingly emitted to be accelerated by the positive potential of the output system 76 and to deliver oscillation energy to the gap 77 of the output system in the same manner as in the apparatus of Fig. 11.

The apparatus of Fig. 13 is substantially identical with that of Fig. 12 with the exception that a multistage electron multiplier is used. The secondary electron-emitting cathodes 78, 79 and 80 which are at successively higher positive potentials comprise flat plates with which are respectively associated the parallel plates 81, 82 and 83 positively polarized with respect to their corresponding secondary electron emitters as in the case of the plate 72 of Fig. 12. The electron path will, therefore, follow the broken line 84 proceeding by a series of substantially cycloidal hops from each secondary electron emitter to the next and passing from emitter 80 through the energy-extracting gap 85 to the collector 86. This structure permits increased amplification to be attained.

What is claimed is:

1. An electron discharge device comprising an electrically resonant substantially closed chamber of conducting material having an energy-transfer gap therein, means for producing and impelling a beam of electrons past the gap and closely adjacent to it to interact with the electromagnetic field of the resonant system in the vicinity of the gap whereby energy is transferred from the field to the beam to effect a velocity variation of its electrons, a secondary electron emitter, means for impelling the electron beam against the secondary emitter, and means for directing the resulting secondary electrons past the energy-transfer gap and closely adjacent to it to impart energy to the electromagnetic field associated therewith.

2. An oscillator comprising a primary cathode, a pair of spaced conducting members constituting an electron velocity-varying gap, means for accelerating electrons from the cathode past the

gap, a source of secondary electrons in the path of the primary electrons and upon which the primary electrons impinge to release a larger number of secondary electrons, and means to impel the secondary electrons past the gap to enable it to extract energy therefrom.

3. An electron discharge device comprising a source of an electron beam, means for periodically varying the velocity of the electrons of the beam, means in the path of the beam for retarding the average velocity electrons to substantially zero velocity whereby the slowest electrons are turned back, a secondary electron-emitting surface upon which the highest velocity electrons impinge, and means for setting up a wave-energy extraction field through which both the highest velocity electrons and the resulting secondary electrons produced by their impact may pass to yield energy to the field.

4. An electron discharge device comprising a source of an electron beam, means for varying the velocities of electrons of the beam to successively accelerate and decelerate electrons as they pass a given zone, means for withdrawing all electrons whose velocity lies at one side of a given velocity to cause the beam to become density varied, means responsive to impinging electrons to emit secondary electrons, and means for causing the resultant density-varied beam to impinge upon the secondary electron-emitting means.

5. An amplifier comprising a source of an electron beam, means for velocity varying the electrons of the beam in accordance with signal variations, means for density varying the beam, and means in the path of and responsive to impact of the density-varied beam to yield secondary electrons in a correspondingly density-varied secondary beam, the magnitude of the electron groups of which varies in accordance with the velocities of the impinging electrons.

6. An electron discharge device comprising a source of an electron beam, a resonant input chamber, means whereby the velocities of the electrons of the beam are varied in accordance with the field intensity of electromagnetic waves within the chamber, means for density varying the beam, a source of secondary electrons in the path of the beam responsive to impact thereof to produce a density-varied beam of secondary electrons, a resonant output chamber and means whereby the secondary beam imparts electromagnetic wave energy to the output chamber.

7. An electron discharge device comprising two resonant electrically-conductive chambers, each apertured to permit transit therethrough of a beam of electrons, the transit paths of the chambers being at an angle to each other and the chambers having a common wall, means for producing an electron stream and impelling it through the first chamber, a secondary electron emitter between the chambers in the path of the stream, means for impelling the secondary electrons from the emitter through the second chamber, and means adjacent the common wall of the chambers for coupling them to feed back to the first chamber wave energy produced in the second.

8. An electron discharge device comprising a pair of chambers electrically resonant at the same frequency and having axially aligned apertures to permit passage of a beam of electrons therethrough, a source of an electron beam aligned with the apertures to project a beam through one chamber to cause the electrons of



the beam to be velocity-varied by the electromagnetic field within the chamber during their passage therethrough, retarding means between the chambers for reducing the velocities of the electrons sufficiently to turn back the lowest velocity electrons so that only the higher velocity electrons proceed through the apertures of the other chamber to deliver energy to the electromagnetic field within that chamber, and a secondary electron emitter upon which the electrons impinge upon emergence from said other chamber.

9. The combination in accordance with claim 8 characterized in this that means is provided to impel secondary electrons emitted by the secondary emitter to pass through the apertures of said other chamber to impart additional energy to its electromagnetic field.

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### **Disclaimer**

2,416,303.—*Carlyle V. Parker*, Sunnyside, N. Y. SECONDARY EMISSIVE SHELL RESONATOR TUBE. Patent dated Feb. 25, 1947. Disclaimer filed Apr. 11, 1950, by the assignee, *Bell Telephone Laboratories, Incorporated*.

Hereby enters this disclaimer to claims 3, 4, and 5 of said patent.  
[*Official Gazette May 9, 1950.*]