April 5, 1966 R. G. HERB ETAL 3,244,990

ELECTRON VACUUM TUBE EMPLOYING ORBITING ELECTRONS

Filed Feb. 26, 1963 3 Sheets-Sheet 1

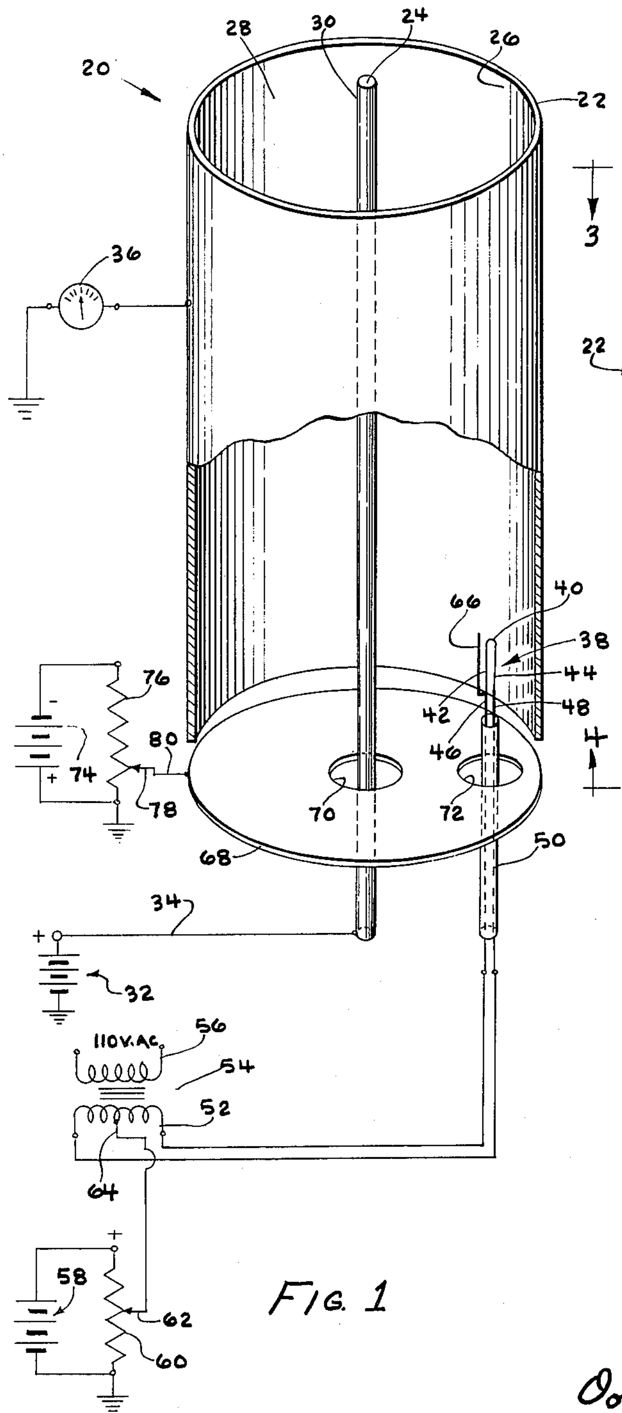

FIG. 1

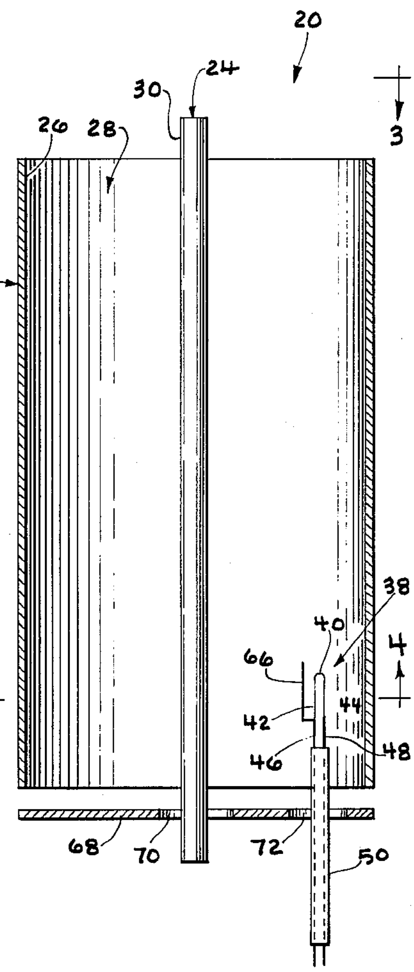

FIG. 2

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ELECTRON VACUUM TUBE EMPLOYING ORBITING ELECTRONS

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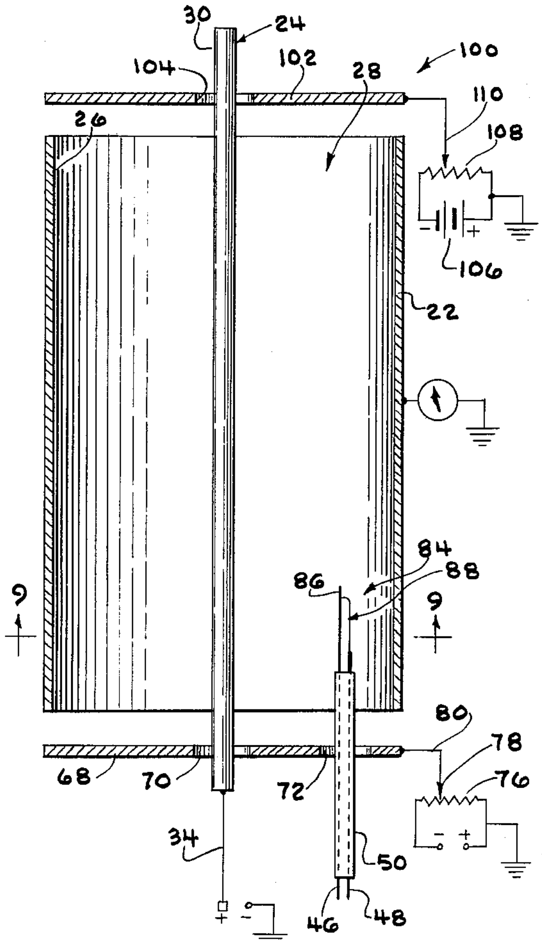


FIG. 7

FIG. 3

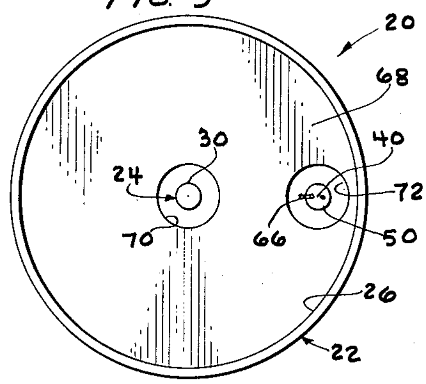
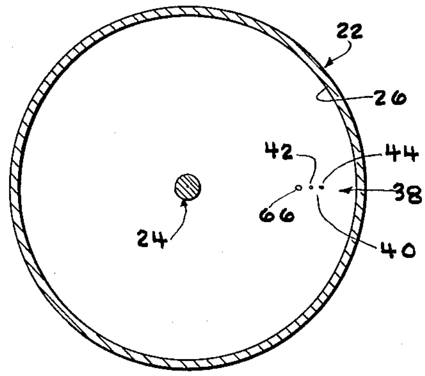


FIG. 4



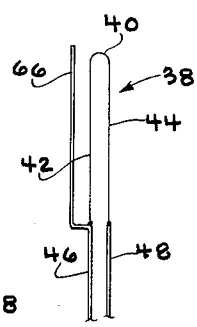


FIG. 5

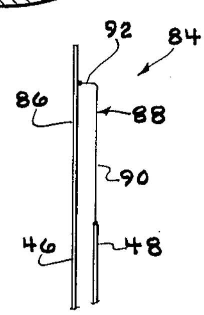


FIG. 6

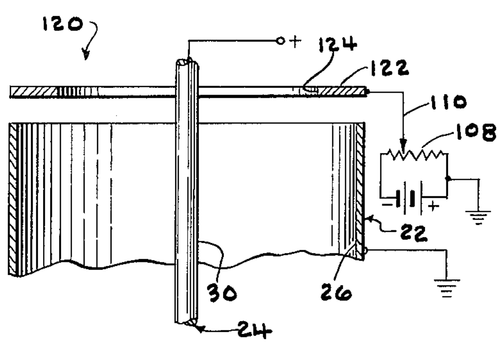


FIG. 8

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ELECTRON VACUUM TUBE EMPLOYING ORBITING ELECTRONS

Filed Feb. 26, 1963 3 Sheets-Sheet 3

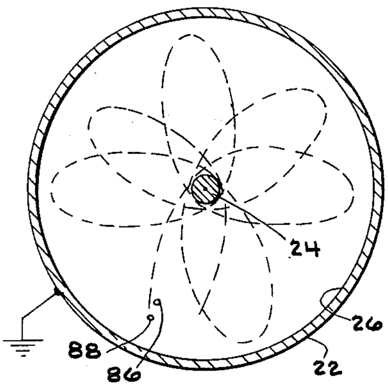

FIG. 9

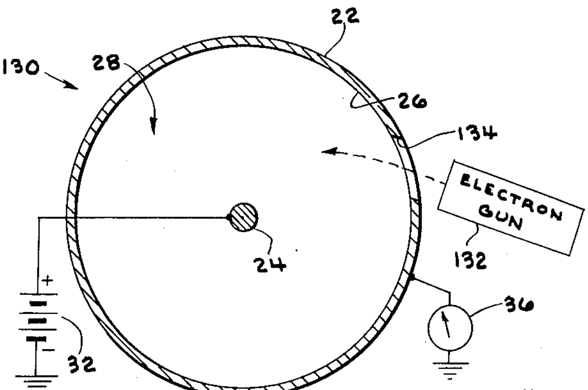

FIG. 10

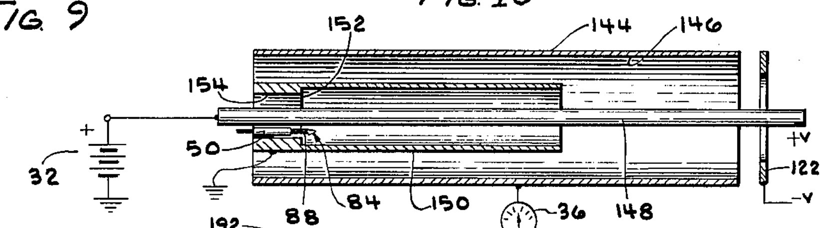

FIG. 11

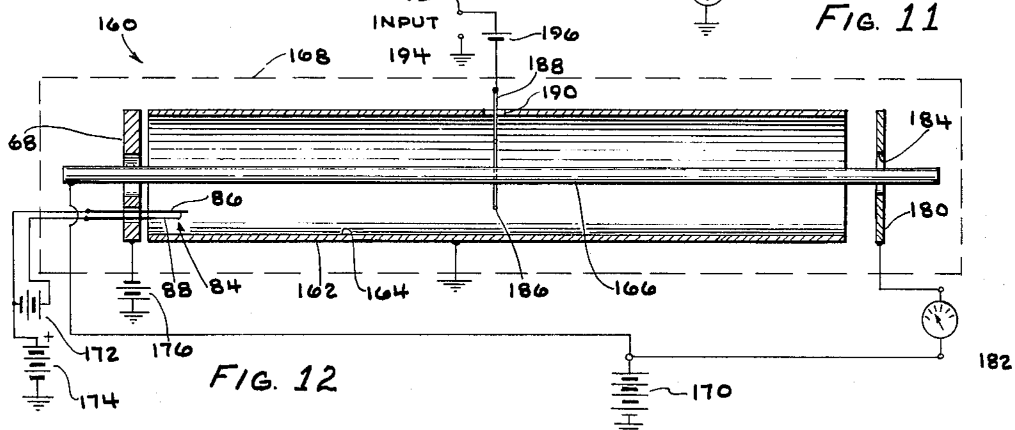

FIG. 12

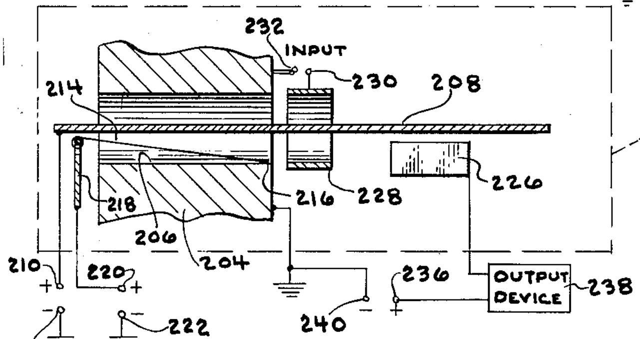

FIG. 13

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ELECTRON VACUUM TUBE EMPLOYING ORBITING ELECTRONS

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Filed Feb. 26, 1963, Ser. No. 261,104
19 Claims. (Cl. 328—252)

Certain aspects of the subject matter disclosed in this application are disclosed and claimed in our copending application, Serial No. 332,190, filed December 20, 1963, which is a continuation-in-part of the present application.

This invention relates to electron orbiting devices and pertains particularly to devices which have important applications to ion gauges, electrometer tubes, amplifying devices and ion-getter vacuum pumps.

One object of the present invention is to provide a new and improved electronic device which is so arranged that the mean free path of the electrons may be much longer than the over-all size of the device, so that the probability that any electron will ionize a gas molecule in the device is greatly increased, the device thereby being adapted to serve as a highly efficient ion gauge, or as an ionizing device for an ion-getter vacuum pump.

A further object is to provide a new and improved electronic device of the foregoing character in which the mean free path of the electrons is increased by causing the electrons to travel in spiral paths or orbits, around one of the electrodes of the device, without utilizing any magnetic field.

A still further object is to provide a new and improved electron orbiting device of the foregoing character in which electrons are caused to move in spiral orbits in an electric field between an outer cylindrical electrode and an axial electrode in the form of a wire or cylinder received within the outer electrode.

Another object is to provide such a new and improved electron orbiting device in which electrons are injected or introduced into the space between the inner and outer electrodes with a substantial angular momentum so that electrons will travel in spiral orbits around the inner electrode.

A further object is to provide such a new and improved electron orbiting device in which the electrons may be injected by a heated filament disposed between the inner and outer electrodes and generally parallel to the inner electrode.

Another object is to provide such a new and improved electron orbiting device in which the proportion of electrons injected with high angular momentum is increased by providing an auxiliary electrode or shield to cooperate with the filament.

Another object is to provide a new and improved electron orbiting device of the foregoing character which may include one or more reflector electrodes at or near either or both ends of the outer electrode for reflecting the spiraling electrons.

A further object is to provide a new and improved electron orbiting device of the foregoing character having a light shield between the filament and the outer electrode to avoid photoelectric emission of electrons from the outer electrode due to the light produced by the filament.

Another object is to provide a new and improved electron orbiting device of the foregoing character and having a collector electrode and a control electrode disposed between the filament and the collector electrode so that the discharge device may serve as an electrometer tube or an amplifying device.

A further object is to provide electron orbiting devices

of the foregoing character which consume very little power and are extremely efficient.

Another object is to provide a new and improved electron orbiting device which will serve as an extremely sensitive ion gauge which generates a minimum of heat and generally causes very little disturbance in the vacuum system in which the ion gauge is employed.

A further object is to provide a new and improved electron orbiting device which will serve as an electrometer tube or amplifying device having unusually high gain.

Various other objects and advantages of the present invention will appear from the following description, taken with the accompanying drawings, in which:

FIG. 1 is a diagrammatic view, partly in perspective and partly in section, showing an electron orbiting device to be described as an illustrative embodiment of the present invention, such device being arranged to serve as an ion gauge or as an ionizing device for an ion-getter vacuum pump.

FIG. 2 is a central longitudinal sectional view taken through the device of FIG. 1.

FIG. 3 is an end view taken generally as indicated by the line 3—3 in FIG. 2.

FIG. 4 is a cross-sectional view, taken generally along the line 4—4 in FIG. 3.

FIG. 5 is a fragmentary enlarged elevational view illustrating the electron emitting filament and the associated shield wire as employed in the device of FIG. 1.

FIG. 6 is a view similar to FIG. 5, but illustrating a modified arrangement of the filament and shield wire.

FIG. 7 is a view similar to FIG. 2 but showing a modified construction having an additional reflector electrode and also the modified filament of FIG. 6.

FIG. 8 is a fragmentary view corresponding to the upper portion of FIG. 7 but illustrating a modified reflector electrode.

FIG. 9 is a diagrammatic cross-sectional view taken generally along the line 9—9 in FIG. 7, and showing possible orbits which may be traversed by some of the electrons.

FIG. 10 is a cross-sectional view, similar to FIG. 4, but illustrating a modified construction in which an electron gun provides the source of the electrons injected into the orbiting device.

FIG. 11 is a longitudinal sectional view showing a modified electron discharge device similar to that of FIG. 7, but including a light shield around the filament.

FIG. 12 is a longitudinal sectional view of a modified electron orbiting device provided with a collector electrode and a control electrode so as to serve as an electrometer tube or amplifying device.

FIG. 13 is a longitudinal sectional view showing a modified amplifying device adapted to be used at higher signal frequencies than the device of FIG. 12.

As already indicated, FIG. 1 illustrates an electron orbiting device **20** which is well adapted for use as an ion gauge in a vacuum chamber or system. Various ion gauges are already known for the purpose of giving an indication of the number of gas molecules in a vacuum system. In such ion gauges, electrons are caused to travel between the electrodes in the evacuated space. Some of the electrons will collide with gas molecules so as to ionize such molecules. The ionized gas molecules are then attracted to an ion collector electrode. The ion current is a measure of the concentration of the gas molecules in the vacuum system.

The electron orbiting device **20** of FIG. 1 has the important advantage that the electrons are caused to traverse spiral paths or orbits, in moving between the cathode and anode electrodes, so that the mean free path of the electrons is greatly lengthened. In this way, there is a much greater probability that each electron will ionize a gas molecule before passing to the anode. Thus, the electrons are utilized with greatly increased efficiency.

In the electron orbiting device 20 of FIG. 1, the electrons are caused to spiral in an electric field between an outer cylindrical electrode 22 and an inner or axial electrode 24. It will be seen that the outer electrode 22 has a cylindrical inner surface 26 which serves as the boundary of a cylindrical space 28 through which the electrons move. The illustrated outer electrode 22 is in the form of a thin-walled cylindrical metal tube, but it will be understood that the shape of the outside of the electrode 22 is of no particular concern and may be changed as may be desired or convenient.

The inner electrode 24 extends along the axis of the cylindrical surface 26 and is received within the outer electrode 22. The inner electrode 24 has a cylindrical outer surface 30. In this case, the inner electrode 24 is in the form of a cylindrical metal wire or rod, but it will be understood that the inner electrode may be hollow and tubular in form without affecting the operation of the electron orbiting device.

An electric field is produced in the space between the outer and inner electrodes 22 and 24 by impressing a voltage between such electrodes. Normally, the inner electrode 24 is positively charged so as to attract electrons. The outer electrode 22 is negatively charged so as to attract positively ionized gas molecules. The operating voltage may be derived from any suitable source of direct potential, such as a battery 32. It will be seen that a lead 34 is connected between the positive terminal of the battery 32 and the axial electrode 24. The negative terminal of the battery 32 may be grounded. In this case, a meter 36 for measuring the ion current is connected between the outer electrode 22 and ground. Thus, the negative terminal of the battery 32 is connected to the outer electrode 22 by way of the ground connections and the meter 36.

Electrons are injected into the space 28 between the outer and inner electrodes 22 and 24 in such a manner that some or all of the electrons will have sufficient angular momentum to travel in orbital paths around the positively charged central electrode 24. In this case, the electrons are enabled to traverse extremely long paths before finally being captured by the positively charged electrode or anode 24. Most of the orbiting electrons will travel in spiral paths which will not necessarily be circular.

Various electron injecting devices may be employed to introduce the electrons into the space between the concentric cylindrical electrodes 22 and 24. FIG. 1 illustrates a particularly simple yet effective electron injecting device 38 comprising a small narrow hairpin-shaped filament 40 disposed between the electrodes 22 and 24, near one end of the outer electrode 22. The illustrated filament 40 has parallel legs 42 and 44 which extend substantially parallel to the axial electrode 24. The axes of the legs 42 and 44 are in a single radial plane which also includes the axis of the central electrode 24. The filament 40 may be in the form of a fine wire made of tungsten or other suitable metal. An electric current may be passed through the filament 40 to heat the filament so that it will emit electrons. To supply the filament 40 with current, the ends of the filament are connected to heavier lead-in wires 46 and 48 which also serve as supports for the filament. The lead-in wires 46 and 48 may be brought into the space 28 through openings in an insulating rod or member 50 which may be made of ceramic material or the like.

Current for heating the filament 40 may be derived from any suitable source, such as a low voltage secondary winding 52 of a transformer 54. The primary winding 56 of the transformer 54 may be connected to an ordinary commercial source of alternating current at 110 volts and 60 cycles, or any other suitable voltage and frequency.

The filament 40 is preferably given a positive bias relative to the outer electrode 22. In this way, the electrons emitted from the filament 40 will be repelled from the outer electrode 22. Such biasing voltage may be derived from any suitable source, such as a battery 58. In this case, a variable potentiometer 60 is connected across the battery. The slider 62 of the potentiometer is connected to the center tap 64 of the secondary winding 52 so that the biasing voltage on the filament may be varied by adjusting the potentiometer 60.

Most of the electrons will be emitted from the filament 40 in directions other than a radially inward direction and thus will acquire substantial angular momentum, due to the electric field around the filament. Although the emitted electrons will be attracted by the positively charged axial electrode 24, many of the electrons will avoid immediate capture by the axial electrode by traveling in spiral paths or orbits around the axial electrode. The electrons may avoid capture for many revolutions so that the mean free path of the electrons may be many times the greatest over-all dimension of the electron orbiting device.

A shield electrode 66 may be provided between the electron injecting filament 40 and the central electrode 24 to prevent direct radial movement of electrons between the filament and the positively charged central electrode. As shown, the shield electrode 66 is in the form of a rod or wire which is parallel to the central rod 24 and the filament wires 42 and 44. The axis of the illustrated shield wire 66 is in the same radial plane as the axes of the legs 42 and 44 of the filament 40. The shield wire 66 may be mounted on and connected to the inner lead wire 46. Thus, the shield wire 66 is at substantially the same biasing voltage as the filament 40. The electric field around the filament 40 is modified by the shield wire 66 so that greater angular momentum may be imparted to the electrons emitted by the filament. It has been found, however, that the shield wire 66 is not strictly necessary and that electrons can be caused to orbit in spiral paths around the central electrode 24, even if the shield wire is omitted entirely.

In this case, the electron orbiting device 20 is also provided with a reflector plate or electrode 68 which is opposite one end of the cylindrical outer electrode 26. The reflector electrode 68 is circular in shape and corresponds generally in diameter to the cylindrical electrode 22. As shown, the reflector electrode 68 is in the form of a flat circular disk disposed perpendicular to the axis of the cylindrical electrode 22. The central electrode 24 passes through a central opening 70 in the reflector electrode 68. Another opening 72 is formed in the reflector electrode 68 to pass the lead-in wires 46 and 48 and the insulating support 50 for the filament 40.

The reflector electrode 68 is preferably given a negative bias, relative to the outer electrode 26 so as to repel the electrons and cause them to spiral around the central electrode 24. Such bias may be derived from any suitable source, such as a battery 74. A potentiometer 76 may be connected across the battery 74. The slider 78 of the potentiometer is connected to the reflector electrode 68 by a lead 80. The positive terminal of the battery 74 is grounded. By adjusting the potentiometer 76, the bias voltage on the reflector electrode 68 may be varied.

It will be evident from FIG. 5 that the shield wire 66 is offset in a radially inward direction from the lead-in wire 46. FIG. 6 illustrates a modified electron injector 84 comprising a shield wire 86 which constitutes a linear extension of the lead-in wire 46. The construction of FIG. 6 employs a modified electron emitting filament 88 which is L-shaped. The filament 88 has an elongated leg 90 extending parallel to the shield wire 86. One end of the leg 90 is connected to the end of the lead-in wire 48. A shorter leg 92 extends between the other end of the leg **90** and the shield wire **86**. Here again, the filament **88** may be made of fine tungsten wire.

The electron orbiting device **20** provides a highly efficient ion gauge. With this gauge, electron mean free paths greater than 1,000 centimeters have been achieved, even though the maximum dimension of the gauge was only a few centimeters. Moreover, the gauge has yielded a positive ion current five times greater than an available ion gauge of the Bayard-Alpert type, even though the power consumption and electron emission of the present gauge was much less than that of the available gauge.

The electron orbiting device **20** may also serve as an efficient ionizing device for an ion-getter vacuum pump, in which the gas ions produced by the ionizing device are absorbed by a getter material. Normally, the getter is supplied by a getter sputtering device.

FIG. 7 illustrates a modified electron orbiting device **100** which for the most part is the same as the orbiting device **20** of FIG. 1. Corresponding components shown in FIG. 7 are given the same reference characters as in FIG. 1. Only the differences between electron orbiting devices **20** and **100** need be described in detail.

It will be seen that the orbiting device **100** employs the modified electron injector **84** of FIG. 6. The shield wire **86** is disposed between the filament **88** and the axial electrode **24**. The axis of the central electrode **24**, the shield wire **86** and the filament **88** are in substantially the same plane.

Moreover, the electron orbiting device **100** is provided with an additional reflector electrode **102** which is similar to the electrode **68** but is disposed opposite the other end of the outer cylindrical electrode **22**. The electrode **102** is in the form of a flat circular disk having an opening **104** therein through which the central electrode **24** extends. The reflector electrode is preferably given a small negative bias voltage relative to the outer electrode **22**. Such bias voltage may be derived from any suitable source, such as a battery **106** having its positive terminal grounded. A potentiometer **108** is connected across the battery **106**. The slider **110** of the potentiometer may be connected to the electrode **102**.

The electrode **102** has the effect of reflecting the spiraling electrons so that they tend to spiral in the opposite axial direction along the central electrode **24**. On the other hand, the end of the outer electrode **22** of FIG. 1 is left open. It will be understood that the extra reflector electrode **102** is not strictly necessary. Long mean free paths have been obtained with the open-ended construction of FIG. 1. Like the device **20** of FIG. 1, the electron discharge device **100** of FIG. 7 is well adapted for use as an ion gauge to measure the vacuum in a vacuum system or chamber.

FIG. 8 illustrates another modified electron orbiting device **120** which is the same as the device **100** of FIG. 7 except that the electrode **102** is replaced with a reflector electrode **122** having a much larger central opening **124** therein, so that the electrode **122** is in the form of a flat ring. It has been found that the electrode construction of FIG. 8 usually results in longer mean free paths than the construction of FIG. 7.

In the electron devices of FIGS. 1–8, the electrons travel in spiral orbits around the central electrode **24**. However, the orbits are not necessarily circular and in most cases will probably be noncircular. FIG. 9 indicates one type of noncircular orbit which may be traversed by some of the electrons. It will be seen that the electrons pass close to the central electrode **24** and then travel outwardly, close to the outer electrode **22** before again turning inwardly. Orbits of this type and other noncircular orbits are usually more advantageous than circular orbits because the electron may travel through several revolutions before coming close to the electron injecting filament. A few of the electrons may be recaptured by the filament. Such recapture shortens the mean free path of the electrons. Moreover, the electric field around the filament disturbs the orbits of the electrons. Some of the orbits may be improved, but other orbits will be modified so that the electrons will pass more quickly to the central electrode. Thus, the disturbing effect of the filament generally tends to shorten the mean free path of the electrons. As the electrons spiral away from the filament, the disturbing effect of the filament is diminished.

A mathematical analysis of the movement of electrons between the inner and outer cylindrical electrodes will provide guides as to the location of the filament and the bias to be applied to the filament. In view of the cylindrical configuration of the inner and outer electrodes, the potential at any radius ρ is given by the following equation:

$$\Phi=\frac{V\ln\left(\frac{R}{\rho}\right)}{\ln\left(\frac{R}{r}\right)} \qquad (1)$$

In this formula, Φ is the potential at the radius ρ; V is the voltage between the inner and outer cylinders; R is the radius of the outer cylinder; and r is the radius of the inner cylinder.

The electric field E between the cylinders is given by the following equation:

$$E=\frac{-d\Phi}{d\rho}=\frac{-V}{\ln\left(\frac{R}{r}\right)}\cdot\frac{1}{\rho} \qquad (2)$$

Although most of the electron orbits are probably noncircular, it will simplify the mathematical analysis to consider the case of circular orbits. The kinetic energy of an electron moving in a stable circular orbit of radius ρf is given by the following equation:

$$\tfrac{1}{2}mv^2=e[\Phi(\rho f)-bV] \qquad (3)$$

In this equation bV is the filament bias, and b is a number which is usually between zero and 0.1. For stability in a circular orbit, it is necessary to balance centrifugal force against the electric force, in accordance with the following equation:

$$\frac{mv^2}{\rho}=Ee=\frac{eV}{\ln\left(\frac{R}{r}\right)}\cdot\frac{1}{\rho} \qquad (4)$$

Equation 4 may be solved for the kinetic energy, giving the following equation:

$$\tfrac{1}{2}mv^2=\frac{eV}{2\ln\left(\frac{R}{r}\right)} \qquad (5)$$

This formula indicates that the kinetic energy for stability in a circular orbit is independent of the radius ρ. If an electron from the filament is to have a circular orbit of the radius ρf, the filament must be located at such radius. In view of this fact, Equations 3 and 5 may be combined to give the following equation:

$$\frac{eV}{2\ln\left(\frac{R}{r}\right)}=e\Phi(\rho f)-ebV \qquad (6)$$

The potential given by Equation 1 may be substituted in Equation 6 to give the following equation:

$$\frac{eV}{2\ln\left(\frac{R}{r}\right)}=\frac{eV\ln\left(\frac{R}{\rho f}\right)}{\ln\left(\frac{R}{r}\right)}-ebV \qquad (7)$$

This equation may advantageously be simplified by multiplying both side by

$$\frac{\ln\left(\frac{R}{r}\right)}{eV}$$

to obtain the following equation:

$$\ln\left(\frac{R}{\rho f}\right)=0.5+b\ln\left(\frac{R}{r}\right) \quad (8)$$

Equation 8 provides guides with regard to filament location and the biasing voltage on the filament to make a circular orbit possible.

The following table gives filament positions for various values of filament bias, for two different values of R/r. The values given in the table are such as to make a circular orbit possible. However, these values are not necessarily the best values.

$\frac{R}{r}=8 \quad \ln\left(\frac{R}{r}\right)=2.07$			$\frac{R}{r}=16 \quad \ln\left(\frac{R}{r}\right)=2.77$		
b	$\ln\left(\frac{R}{\rho f}\right)$	$\rho f/R$	b	$\ln\left(\frac{R}{\rho f}\right)$	$\rho f/R$
0.1	0.7	0.498	0.1	0.777	0.461
0.05	0.6	0.55	0.05	0.638	0.528
0.025	0.55	0.578	0.025	0.569	0.565
0.01	0.52	0.595	0.01	0.527	0.593
0.00	0.5	0.604	0.00	0.500	0.604

FIG. 10 comprises a diagrammatic illustration of another modified electron orbiting device **130** in which the electrons are injected into the space **28** between the outer and inner electrodes **22** and **24** by an electron gun **132** which gives the electrons sufficient angular momentum so that they spiral around the central electrode **24**. The electron gun **132** may be either inside or outside the vacuum chamber in which the electrodes **22** and **24** are situated. Electron guns are well known so that it will not be necessary to describe the construction of any particular electron gun. As shown in FIG. 10, the electron gun **132** propels the electrons into the space **28** through an opening **134** in the outer cylindrical electrode **22**. However, it will be understood that such an opening is not strictly necessary inasmuch as the electron gun may be aimed so as to propel the electrons into the space **28** through the open end of the cylindrical electrode **22**.

FIG. 11 illustrates another modified electron orbiting device **140** which employs the same electron injector **84** as illustrated in FIG. 6. The orbiting device **140** has an outer electrode **144** with an internal cylindrical surface **146**. An axial cylindrical rod or wire **148** forms the inner electrode. Thus, the electron orbiting device **140** is similar to the device **100** of FIG. 7. However, the obiting device **140** is provided with a light shield **150** which is disposed between the electron emitting filament **88** and the outer electrode **144** so as to minimize the photoelectric emission of electrons from the outer electrode **144** due to light from the filament **88**. The illustrated light shield **150** is in the form of a cylindrical tubular electrode having a diameter less than that of the internal cylinder **146** but substantially greater than that of the axial rod electrode **148**. The cylindrical shield **150** is received within the outer electrode **144** and around the central electrode **148**. The shield electrode **150** may be connected to ground, so that it will be at the same potential as the grounded outer electrode **144**. It will be understood, however, that a biasing voltage may be applied to the shield electrode **150**, if desired. At the end adjacent the filament **88**, the shield electrode **150** is stepped inwardly to form a shoulder **152** and a reduced internal cylindrical bore or surface **154**. The filament **88** projects into the electron discharge device through the reduced bore **154**. The ceramic tube **50**, as illustrated in FIGS. 1–7 may be employed to insulate the lead-in wires for the filament **88** and may be disposed within the bore **154**. It will be understood that the form of the insulator may be varied as desired. As in the case of the embodiments of FIGS. 1–9, the central electrode **148** may be supplied with a positive voltage, with respect to the outer electrode **144**. The voltage may be derived from any suitable source such as the battery **32**, corresponding to that of FIG. 1. The meter **36**, for measuring the ion current, may also be connected between the outer electrode **144** and ground, as in the arrangement of FIG. 1. The reflecting electrode **122** of FIG. 8 may be mounted opposite the end of the outer electrode **144**, remote from the filament **88**.

Some or most of the electrons from the filament **88** go into spiral orbits around the central electrode **148**. The electrons spiral along the inside of the shield electrode **150** and then pass out of the shield electrode into the space between the outer electrode **144** and the central electrode **148**. In this case, the shield electrode **150** is substantially shorter than the outer electrode **144** so that the shield electrode extends only part way along the outer electrode.

Inasmuch as the filament **88** is heated to an electron emitting temperature, the filament also gives off light. If the light is allowed to fall directly upon the outer electrode **144**, the light causes photoelectric emission of electrons from the outer electrode. Such emission produces a current through the meter **36**. Such current is combined with and tends to obscure the ion current produced by the movement of positively charged gas ions to the outer electrode **144**. However, in the embodiment of FIG. 11, the shield electrode **150** prevents the light from the filament **88** from falling directly upon the outer electrode **144**. The light from the filament **88** must be reflected several times within the light shield **150** before the light can reach the outer electrode **144**. Of course, these reflections greatly reduce the amount of light which reaches the outer electrode from the filament. Thus, the photoelectric emission of electrons by the outer electrode is greatly reduced so that it becomes a virtually negligible factor. The provision of the light shield **150** increases the sensitivity and accuracy of the electron discharge device **140**, particularly when employed as an ion gauge.

The electron orbiting devices illustrated thus far are particularly useful as ion gauges to measure the concentration of gas molecules in a vacuum chamber or system. The orbiting devices are also useful for ionizing gas materials in ion-getter vacuum pumps. With suitable modification, the electron orbiting devices of the present invention will have many other applications. Thus, FIG. 12 illustrates a modified electron orbiting device **160** which is arranged to provide an electrometer amplifying tube. The device may also be employed in connection with many other applications in which amplification is desired.

The electron orbiting device **160** is quite similar to the devices already described in that it comprises an outer electrode **162** having an internal cylindrical surface **164** within which a cylindrical inner electrode **166** is received. As before, the inner electrode **166** may be in the form of a cylindracl wire or rod extending along the axis of the internal cylinder **164**. The electrodes **162** and **166** are mounted within a housing or enclosure **168** in which a vacuum is maintained. As before, a positive voltage is applied between the inner electrode **166** and the outer electrode **162**. Such voltage may be derived from a battery **170** or any other suitable source. It has been found that a positive voltage of 200 volts is suitable, but the voltage may be varied over a wide range.

The electron orbiting device **160** may employ the same electron injector **84** as illustrated in FIG. 6. A current to heat the filament **88** may be derived from any suitable source such as a battery **172**. The filament **88** and the shield wire **86** may be given a positive bias derived from a battery **174** or any other suitable source. The reflector electrode **68** of FIG. 1 may also be employed and may be given a biasing voltage derived from a battery **176** or some other suitable source. In some cases, the voltage on the reflector **68** may be the same as the voltage on the outer electrode **162**, in which case the reflector **68** is merely grounded.

As before, electrons from the filament **88** go into spiral orbits around the central electrode **166**. The spiraling electrons travel along the space between the electrodes **162** and **164** and eventually pass out of the outer electrode **162** at the end thereof remote from the filament **88**. In this case, a collector electrode **180** is disposed adjacent the remote end of the outer electrode **162**. Such electrode is adapted to collect the spiraling electrons which pass out of the outer electrode **162**. A positive voltage may be applied to the collector electrode so that the electrons will be attracted to such electrode. The positive voltage may be derived from the battery **170** or any other suitable source. A meter **182** or any other suitable output device may be connected in circuit with the collector electrode **180**. The meter **182** is adapted to measure the current to the collector electrode **180**.

As illustrated, the collector electrode **180** is in the form of a flat circular disk disposed opposite the end of the outer electrode **162** and generally perpendicular to the axis of the inner electrode **166**. The inner electrode **166** may pass through a central opening **184** in the collector electrode **180**.

At a point disposed between the electron emitting filament **88** and the collector electrode **180**, the electron discharge device **160** is provided with a control electrode **186** which regulates the passage of the electrons to the collector electrode. As shown, the control electrode **186** comprises a wire formed into an annular shape and mounted coaxially around the inner electrode **186** and within the outer electrode **162**. A lead-in wire **188** extends to the control electrode **186** through an opening **190** in the outer electrode **162**. The voltage or signal to be measured or amplified is applied across input terminals **192** and **194**. The input terminal **192** is connected to the control electrode **186** while the terminal **194** is grounded.

It has been found that the electron orbiting device **160** of FIG. 12 provides a sensitive amplifying device. Thus, any change in the voltage on the control electrode **186** changes the current to the collector electrode **180**. Moreover, it has been found that the input impedance between the control electrode **186** and ground is extremely high, inasmuch as the control electrode draws substantially no current, particularly when the control electrode is maintained at a negative potential relative to the filament **88**. By means of a suitable battery **196**, the control electrode **186** may be biased negatively relative to the grounded outer electrode **162** but it is normally sufficient to return the input circuit to ground so that the control electrode **186** is maintained at the same bias potential as the outer electrode **162**. It has been found that the input impedance of the electron orbiting device **160** is at least as high as that of other available electrometer tubes. Moreover, the electron discharge device **160** of the present invention gives a considerably higher gain than other available electrometer tubes. The higher gain is a distinct advantage, whether the tube is employed as an electrometer tube or for other amplifying purposes.

FIG. 13 illustrates another modified amplifying tube **200** intended particularly for amplifying signals at ultrahigh frequencies. Here again, the device is mounted within a housing or envelope **202** in which a vacuum is maintained. In this case, the device **200** comprises an outer electrode **204** which may be in the form of a metal block or body through which a cylindrical bore **206** has been formed. The device **200** comprises an inner electrode **208** in the form of a cylindrical wire or rod extending axially within the bore **206**. To provide for efficient use at ultrahigh frequencies, the bore **206** may be of small size, such as 1/16 of an inch. The outer electrode **204** may be grounded. A positive voltage of 200 volts, or some other suitable voltage, may be applied between the axial electrode **208** and ground. Thus, the central electrode

208 is connected to a positive terminal **210** to which the power supply is connected. The negative power supply terminal **212** is grounded.

In this case, electrons are injected into the space between the outer and inner electrodes **204** and **208** by means of an electron emitting filament **214** disposed in such space. As shown, the filament **214** comprises a fine wire, made of tungsten or some other suitable material. One end of the filament wire **214** may be welded or otherwise secured to the outer electrode **204**, the weld being indicated at **216**. The filament **214** extends generally in the same direction as the inner electrode **208** but the filament angles inwardly toward the inner electrode from the weld point **216** at which the filament is secured to the outer electrode **204**. The other end of the filament **214** is connected to a support in the form of a heavier lead-in wire **218**. The filament **214** may be heated to an electron emitting temperature by passing current through the filament. Thus, the lead-in wire **218** may be connected to a power supply terminal **220**, the other power supply terminal **222** being grounded.

As before, some of the electrons emitted by the filament **214** go into spiral orbits around the central electrode **208**. It will be seen that the central electrode **208** extends out of the cylindrical bore **206** beyond the right-hand end of the outer electrode **204**, as shown in FIG. 13. Some of the spiraling electrons pass out of the bore **206** and continue to spiral around the central electrode **208**. A collector electrode **226** is disposed to the right of the outer electrode **204** and adjacent the central electrode **208**. Thus, the collector electrode is spaced from the filament **214**. At a point closer to the end of the outer electrode **204**, the discharge device **200** is provided with a control electrode **228** which is illustrated as a ring disposed around the central electrode **208** and spaced from the outer electrode **204**. The illustrated control electrode **228** is cylindrical in form and has an inner diameter corresponding to that of the bore **206** in the outer electrode **204**. The current to the collector electrode **226** may be varied by changing the voltage on the control electrode **228**. Thus, the signal to be amplified is applied between the control electrode **228** and the grounded outer electrode **204**. Accordingly, FIG. 13 illustrates input terminals **230** and **232** connected to the control electrode **228** and to the outer electrode **204**, respectively.

A positive voltage is applied to the collector electrode **226** so that it will attract electrons. Thus, the collector electrode **226** is connected to a positive power supply terminal **236** through an output device **238**. The negative power supply terminal **240** is grounded.

Due to the small size of the electron orbiting device **200** of FIG. 13, the device functions efficiently as an amplifier at ultrahigh frequencies. The coaxial arrangement of the electron discharge device also contributes to the efficiency and utility of the device at ultrahigh frequencies.

It will be apparent that the electron orbiting devices of the present invention have many advantages and applications. Thus, for example, they find important applications as ion gauges, ionizing devices for ion-getter vacuum pumps, electrometer tubes and high frequency amplifying devices. An important factor in the operation of the electron orbiting devices is the manner in which the electrons are caused to move in spiral orbits between the cylindrical electrodes. Such orbital movement of the electrons is achieved without providing any magnetic field to deflect the electrons. The orbital movement of the electrons is caused by the character of the electric field between the electrodes and the manner in which the electrons are injected into the space between the electrodes.

Various modifications, alternative constructions and equivalents may be employed without departing from the true spirit and scope of the invention as exemplified in the foregoing description and defined in the following claims.

We claim:

1. An electronic device, comprising the combination of a hollow generally cylindrical boundary electrode, envelope means forming a vacuum space including the interior of said boundary electrode, a cylindrical anode extending axially within said boundary electrode, said boundary electrode being spaced outwardly from said anode, means for injecting electrons into the space between said anode and said boundary electrode at a predetermined injection point therebetween with substantial angular momentum about said anode so that the electrons will travel in spiral orbits around said anode, a collector anode spaced along said cylindrical anode from said injection point for collecting the spiralling electrons, and a control electrode disposed between said injection point and said collector anode for controlling the movement of the spiralling electrons to said collector anode.

2. A device according to claim 1, in which said control electrode comprises a ring-shaped member extending around said cylindrical anode and spaced outwardly therefrom.

3. A device according to claim 1, comprising means for producing a positive voltage on said collector anode relative to said boundary electrode so as to attract the spiralling electrons.

4. A device according to claim 1, in which said collector anode is in the form of an annular member extending around and spaced outwardly from said cylindrical anode.

5. A device according to claim 1, in which said cylindrical anode has an end portion which extends outwardly from said boundary electrode beyond the corresponding end thereof, and in which said collector anode is disposed along said outwardly extending end portion of said cylindrical anode.

6. A device according to claim 1, in which said cylindrical anode has an end portion which extends outwardly from said boundary electrode beyond the corresponding end thereof, and in which said collector anode and said control electrode are disposed along said outwardly extending end portion of said cylindrical anode.

7. A device according to claim 1, in which said means for injecting electrons comprises an electron emitting cathode disposed in the space between said cylindrical anode and said boundary electrode.

8. A device according to claim 1, in which said means for injecting electrons comprises an electron emitting thermionic cathode disposed in the space between said cylindrical anode and said boundary electrode.

9. An electronic device, comprising the combination of a hollow generally cylindrical boundary electrode, envelope means forming a vacuum space including the interior of said boundary electrode, a cylindrical anode extending axially within said boundary electrode, said boundary electrode being spaced outwardly from said anode, means for injecting electrons into the space between said anode and said boundary electrode at a predetermined injection point therebetween with substantial angular momentum about said anode so that the electrons will travel in spiral orbits around said anode, a collector anode spaced along said cylindrical anode from said injection point for collecting the spiralling electrons, and a control electrode disposed between said injection point and said collector anode for controlling the movement of the spiralling electrons to said collector anode, said means for injecting electrons comprising an elongated electron emitting cathode disposed in the space between said cylindrical anode and said boundary electrode and generally parallel to said cylindrical anode, and an elongated shield electrode positioned between said electron emitting cathode and said cylindrical anode for modifying the electric field therebetween whereby the electrons emitted by said cathode are given sufficient angular momentum to go into orbits around said cylindrical anode.

10. A device according to claim 9, in which said cathode comprises a thermionic filament.

11. A device according to claim 9, in which said cathode comprises a thermionic filament having one end connected to and supported by the corresponding end of said shield electrode.

12. A device according to claim 9, in which said cathode comprises a thermionic filament in the form of a flat loop of wire disposed generally in a radial plane which includes the axis of said cylindrical anode.

13. A device according to claim 9, comprising means for producing a positive voltage on said cylindrical anode relative to said boundary electrode.

14. A device according to claim 13, comprising means for producing a positive biasing voltage on said cathode and said shield electrode relative to said boundary electrode, said positive biasing voltage being substantially less than the positive voltage on said cylindrical anode.

15. An electronic device, comprising the combination of a hollow generally cylindrical boundary electrode, envelope means forming a vacuum space including the interior of said boundary electrode, a cylindrical anode extending axially within said boundary electrode, said boundary electrode being spaced outwardly from said anode, means for producing a positive voltage on said anode relative to said boundary electrode, an electron emitting cathode in the form of a thermionic filament disposed between said anode and said boundary electrode and substantially parallel to said anode, a shield wire adjacent said filament and substantially parallel thereto, said shield wire being positioned between said filament and said anode for preventing direct movement of electrons therebetween whereby the electrons emitted by said filament will be injected into spiral orbits around said anode, means for producing a positive biasing voltage on said filament and said shield electrode relative to said boundary electrode, said positive biasing voltage being substantially less than the positive voltage on said anode, a collector anode spaced along said cylindrical anode from said filament for collecting the spiralling electrons, means for producing a positive voltage on said collector anode relative to said boundary electrode for attracting the spiralling electrons, and a control electrode disposed between said filament and said collector anode for controlling the movement of the spiralling electrons to said collector anode.

16. A device according to claim 15, in which said collector anode comprises an annular

member extending around and spaced outwardly from said cylindrical anode.

17. A device according to claim **15**, in which said control electrode comprises a ring member extending around and spaced outwardly from said cylindrical anode.

18. A device according to claim **15**, in which said cylindrical anode has an outwardly projecting end portion which extends outwardly from said boundary electrode beyond the corresponding end thereof, and in which said collector anode is disposed along said outwardly projecting end portion of said cylindrical anode.

19. A device according to claim **15**,

in which said cylindrical anode has an outwardly projecting end portion which extends outwardly from said boundary electrode beyond the corresponding end thereof, and in which said collector anode and said control electrode are disposed along said outwardly projecting end portion of said cylindrical anode.

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