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HIGH SENSITIVITY IONIZATION GAUGE

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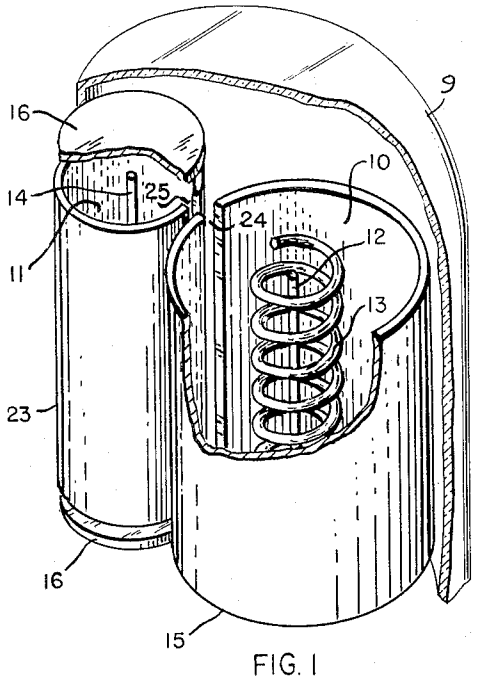

FIG. 1

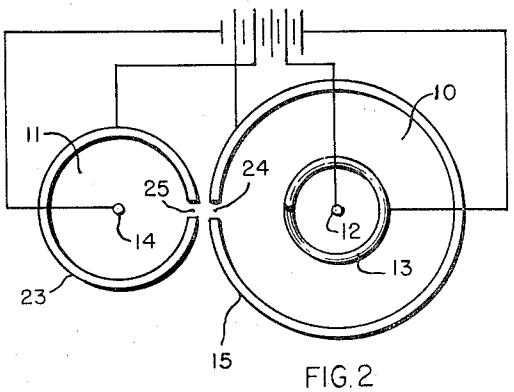

FIG. 2

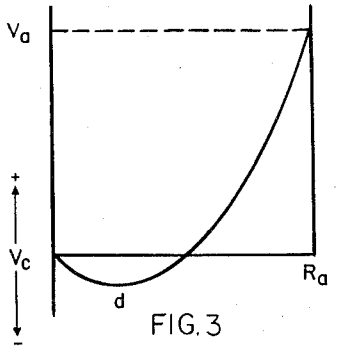

FIG. 3

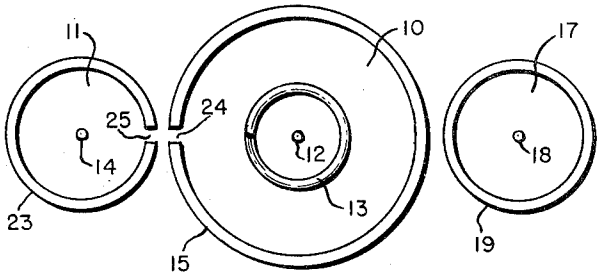

FIG. 4

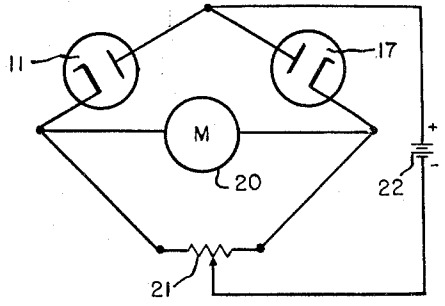

FIG. 5

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HIGH SENSITIVITY IONIZATION GAUGE

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11 Claims. (Cl. 324—33)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment of any royalty thereon.

This invention relates to an electron discharge device for measuring low pressures in vacuum systems by the measurement of ionization of the residual gas molecules by electrons emitted from the cathode of the device.

The usual ionization type of vacuum gauge is constructed as a normal triode, with a plate and grid and a hot cathode within said plate and grid. In operation, the grid is charged positively, and the anode is charged negatively with respect to the cathode. The envelope is connected to the system in which the pressure is to be measured, and the cathode is heated to emit electrons. The electrons are accelerated toward the grid, and collide with the residual gas molecules thus ionizing them. The positively charged ions are then attracted to the negative anode, where they are neutralized. The ion current to the anode is thus a measure of the number of residual gas molecules and thus of the pressure in the system. This type of vacuum gauge will measure down to about 10^{-8} mm. of mercury. This lower limit is due to the fact that at these low pressures the electrons accelerated by the positive grid strike the grid with sufficient energy to generate soft X-rays, which in turn strike the anode, because the anode almost completely surrounds the grid, and these X-rays cause emission of photoelectrons from the anode which are collected by the grid. This electron current from the anode becomes of sufficient magnitude to mask the ion current to the anode at about 10^{-8} mm. of mercury.

A modification of this standard type of vacuum gauge, the Bayard-Alpert Gauge, uses a fine wire anode, a cylindrical grid surrounding the anode, and a cathode outside of the grid. The operation is the same, but by making the anode small, a much smaller fraction of the X-rays strike the anode, so the photocurrent is much less. This simple modification enables measurements down to about 10^{-10} mm. of mercury.

The triode ionization type gauge can be used with the "flash filament" technique to extend the lower limit of measurement. The filament is cleaned of adsorbed gas, then allowed to remain cold on the vacuum to be measured. Residual gas is adsorbed on the filament over a period of time, after which the filament is quickly heated to incandescence, or "flashed." The high temperature drives off the adsorbed gases, giving a "puff" of gas which is measured ballistically by the ionization gauge in the usual manner. The greater the degree of vacuum, the longer it takes to adsorb a measurable quantity of gas.

The limitation of the standard ionization vacuum gauge and its modifications is the photocurrent from the anode caused by the soft X-rays generated by the electrons striking the grid at high velocity, and, in the case of the flash filament technique, the time required for the cold filament to adsorb a measurable quantity of gas becomes prohibitively long for very low pressures.

Therefore, it is an object of this invention to provide an

ionization type vacuum gauge in which the soft X-rays generated have substantially no effect on the gauge reading.

A further object is to provide an ionization type vacuum gauge which is capable of measuring pressures much lower than other vacuum gauges.

Another object is to provide a vacuum gauge capable of measuring routinely down to 10^{-14} mm. of mercury, and perhaps lower under ideal conditions.

Another object is to provide a vacuum gauge capable of operating as a conventional, Bayard-Alpert, or improved ionization vacuum gauge, depending on the pressure range, and on the connections and potentials applied.

Another object is to provide a vacuum gauge capable of operation with the "flash filament" technique with materially shortened adsorption time.

These and further objects of this invention will become apparent from the following specification taken in connection with the claims and drawings.

Fig. 1 is a perspective view partly cut away of a preferred embodiment of the invention.

Fig. 2 is a top view of Fig. 1 and includes a schematic representation of the applied potentials.

Fig. 3 is the voltage distance relationship in the diode when the gauge is operated in the improved manner.

Fig. 4 is a top view of a modification of Fig. 1.

Fig. 5 is a circuit used with the modification of Fig. 4.

Referring now to the accompanying drawings, there is shown in Fig. 1 a preferred embodiment of the improved ionization gauge comprising an envelope **9** in which **10** is a triode section in which **12** is a cathode, which is heated (heater source not shown) to emit electrons, consisting preferably of a strand of pure tungsten wire, and said cathode **12** is charged positively with respect to the triode anode **15** and said cathode **12** is charged negatively with respect to the triode grid **13**. Diode **11** also has its cathode **14** heated (heater source not shown) to emit electrons, and also consists preferably of a strand of pure tungsten wire, and said cathode **14** is charged negatively with respect to the diode anode **23** so the diode **11** operates under what is known as space charge limited conditions, where the voltage on the anode **23** is not sufficiently positive to attract all the electrons emitted by the cathode **14**, and there is a considerable relatively stationary space charge surrounding the cathode. The triode anode **15**, having a slot **24** therein is made negative with respect to the diode anode **23**, having a slot **25** therein. Triode anode **15** and diode anode **23** are placed in close proximity, and slot **24** and slot **25** are placed so that substantially all of the ions leaving triode **10** through slot **24** can enter diode **11** through slot **25**. Slots **24** and **25** each have an area which is relatively small compared to the total area of the anodes **15** and **23** respectively.

The envelope of the device is mechanically connected to the system in which the pressure is to be measured, and some of the residual gas molecules will be in the volume of the triode when the pressures in the system and in the gauge become equalized. The electrons emitted by the triode cathode are accelerated towards the positive grid, and some of the electrons will collide with gas molecules, thus ionizing them. These positively charged ions are then attracted to the triode anode, and most of them are neutralized by the negative charge thereon. However, a fraction of the ions approximately equal to the ratio of slot area to triode anode area will be traveling in a path that will cause them to go through the slot **24** in the triode anode **15**, and enter the volume of the diode **11** through the slot **25** in the diode anode **23**.

The voltage applied between the triode anode **15** and the diode anode **23** is of the proper amplitude and polarity to slow down the ions but not great enough to prevent the ions from entering the volume of the diode.

In the diode, the anode voltage and the cathode heating current are so proportioned to cause the diode to operate in the space-charged limited manner. In this mode of operation, the anode voltage is not high enough to attract all of the electrons which are emitted by the cathode, so an electron cloud forms as a sheath around the cathode. Because of the density of the electron cloud, the voltage in the densest portion will be more negative than the cathode. This potential vs. radius distribution is shown in Fig. 3, where V_a is the anode voltage in the diode, V_c is the cathode voltage in the diode, R_a is the anode radius, and the cathode is considered to be at the origin. Thus, in Fig. 3, point *d* is at the potential minimum, and this minimum is below the cathode potential.

When the ions enter the diode, they are drawn to the potential minimum. Because of the inertia of the ions, they will overshoot the potential minimum before they lose all of their kinetic energy.

The potential applied between the triode anode **15** and the diode anode **23** is of the proper polarity to slow down the ions and the proper amplitude to allow the ions to enter, but to keep as many as possible from overshooting the potential minimum sufficiently to strike the diode anode **23**. This potential would not be necessary if the ions do not have very large energy.

Then the ions will be accelerated back towards the potential minimum, and again inertia will make them overshoot. Thus, the ions will tend to oscillate about the potential minimum until they are neutralized by an electron in the electron cloud, or until they drift axially out of the electron cloud.

While an ion is in the vicinity of the potential minimum, it will neutralize some of the electron space charge. Because an ion has a much larger mass and a much lower velocity than an electron for the same energy, it will neutralize many electrons, as each electron would only be in the field of each ion for a very short time. As many as 70,000 extra electrons can flow to the plate as a result of the entry of a single positive ion.

The change in plate current, resulting from the neutralization of part of the space charge by the ions from the triode is a measure of the degree of vacuum in the system.

The end plates on the diode serve to make it more difficult for the ions to leave the diode section after entering. Thus they can be reionized again and again by the electrons in the diode, and contribute even more effectively to space charge neutralization. It has been found that leaving the end plates unconnected results in better operation.

This improved ionization gauge can be operated in several ways:

a. As a conventional ionization gauge, the triode alone would be used.

b. As a Bayard-Alpert gauge, the diode cathode would be used as the electron source, the grid would be used normally, and the cold triode cathode would be used as the anode. This would give greater sensitivity than *"a."*

c. The device may be operated in the improved manner, with the triode connected as an ordinary ion gauge, and the diode operated as a space charge limited diode.

The following adaptations of the "flash filament" techniques are possible:

a. The diode filament can be used for adsorption and flashing, and the triode can be used as an ordinary ionization gauge to measure the puff ballistically.

b. The triode can be used to "pump" gas ions into the diode so less time is required for the cold diode filament to adsorb a measurable quantity of gas, then the diode filament is flashed, and the triode is used to measure the resulting puff ballistically. This will give greater sensitivity than *"a."*

c. The triode filament can be used to adsorb the gas, and the puff released on flashing can be measured ballistically in the diode. This method would be more sensitive than *"a"* or *"b."*

The soft X-rays which limit the degree of vacuum which may be measured with conventional gauges do not affect this gauge for three reasons:

1. Only a small fraction of the X-rays generated at the triode grid pass through the slot into the diode.

2. The photo-electrons which are emitted from the diode anode because of the X-rays falling on it are recollected by the diode anode, and so do not affect the external diode current.

3. The photoelectrons which are emitted from the diode cathode because of the X-rays falling on it are merely added to the thermionically emitted electrons in the space charge and so cause negligible external effect.

Fig. 4 is a modification of the improved ionization gauge in which another diode **17** comprising cathode **18** and anode **19** has been added, said diode **17** being substantially electrically and mechanically similar to diode **11** except that anode **19** does not contain a slot corresponding to slot **25** in the anode **23** of diode **11**.

The advantages of the modifications of Fig. 4 can best be achieved by using a cricuit such as in Fig. 5, which has a meter **20**, variable resistor **21**, a suitable source of current **22**, such as a battery, and diodes **11** and **17** as previously referred to, which can be used for the measurement of the anode current change in diode **11**. Since diodes **11** and **17** are similar, the anode currents of each should be very nearly equal. Resistor **21** is adjusted so meter **20** reads zero when no ions are entering diode **11**. Thus, when the anode current of diode **11** increases, the meter reading on meter **20** can be calibrated in terms of vacuum of the system being measured.

The main advantage of using the bridge circuit of Fig. 5 for the measurement of the anode current of diode **11** is that most of the random variations in the anode current of diode **11** are balanced out by similar variations in the anode current of diode **17**. Such random variations as filament temperature and anode voltage thus will have little or no effect on the reading.

What is claimed is:

1. An ionization type vacuum gauge comprising an envelope containing a gas the pressure of which is to be measured, a first space discharge device within said envelope comprising a hollow anode member with an aperture in the wall thereof, and a cathode and control grid within said member, means coupled to said discharge device for maintaining said grid at a positive potential with respect to said cathode and said cathode at a positive potential with respect to said anode, a second space discharge device within said envelope adjacent said first discharge device comprising a hollow second anode member with an aperture in the wall thereof, and a cathode within said second member, said second member being spaced from said first member and being disposed with the aperture thereof facing the aperture of said first member, means coupled to said second space discharge device for applying a potential difference between the cathode and anode thereof to cause space-charge limited operation thereof and for maintaining said second anode member at a positive potential with respect to said first anode member, and means in circuit with said second space discharge device for measuring the current therethrough.

2. An ionization gauge comprising a tube envelope containing a gas the pressure of which is to be measured; a first space discharge device within said envelope comprising a hollow first anode element having a restricted opening in a wall thereof, a cathode disposed within said element, and a control electrode disposed within said element; a second space discharge device within said envelope adjacent said first discharge device comprising a hollow second anode element having a restricted opening in a wall thereof, and a cathode disposed within said second element; said second element being disposed with its

restricted opening adjacent the restricted opening in said first member.

3. An ionization gauge as set forth in claim 2, further including a third space discharge device within said envelope adjacent said first space discharge device comprising a hollow third anode element having continuous walls and a cathode disposed within said third element.

4. An ionization gauge as set forth in claim 3, including means for applying a potential difference between the cathode and anode of each of said second and third space discharge devices, respectively, to cause space-charge limited operation of said devices, a bridge circuit, said second and third discharge devices being connected in series with opposite arms of said circuit, means for equalizing the current flow through said second and third discharge devices thereby balancing said bridge circuit, means connected across said bridge circuit for indicating a condition of unbalance thereof, means for heating the cathode of said first discharge device, and means for maintaining the control electrode of said first discharge device at a positive potential with respect to its cathode, the cathode of said first discharge device at a positive potential with respect to its anode element, and said last named anode element at a negative potential with respect to said second anode element.

5. An ionization gauge comprising an envelope containing a gas the pressure of which is to be measured, a first space discharge device within said envelope comprising a hollow, substantially cylindrical first anode element having a longitudinal slot therein, a first filament within said element disposed on the longitudinal axis thereof, and a grid within said element concentric with said filament; and a second space discharge device within said envelope adjacent said first discharge device comprising a hollow, substantially cylindrical second anode element having a longitudinal slot therein and a second filament within said second element disposed on the longitudinal axis of said second element, said second element being disposed with the slot therein adjacent and substantially parallel to the slot in said first element.

6. An ionization gauge as set forth in claim 5, further including a conductive member covering and spaced from each end of said second element.

7. An ionization gauge as set forth in claim 5, including means for heating said first and second filaments, means coupled to said first discharge device for maintaining its grid at a positive potential with respect to its filament and its filament at a positive potential with respect to its anode element, means coupled to said second discharge device for applying a potential difference between the filament and anode element thereof to cause space-charge limited operating thereof, and for maintaining said second member at a positive potential with respect to said first member, and means in circuit with said second discharge device for measuring the current therethrough.

8. An ionization gauge as set forth in claim 5, including means for heating said second filament, said first filament being maintained cold, means for maintaining said grid at a positive potential with respect to said second filament and said second filament at a positive potential with respect to said first filament, and means in circuit with said first and second filaments for measuring the space current therebetween.

9. An ionization gauge as set forth in claim 5, including means for heating said first filament, means for maintaining said grid at a positive potential with respect to said first filament and said first filament at a positive potential with respect to said first element, means for flashing said second filament comprising means for quickly heating said second filament from cold condition to incandescence, and means in circuit with said first discharge device for measuring the change in current therethrough due to said flashing of said second filament.

10. An ionization gauge comprising an envelope containing a gas the pressure of which is to be measured; a first space discharge device within said envelope comprising a hollow, substantially cylindrical first anode element having a longitudinal slot therein, a first cathode within said element disposed on the longitudinal axis thereof and a grid within said element concentric with said cathode; a second space discharge device within said envelope adjacent said first device comprising a hollow, substantially cylindrical second anode element having a longitudinal slot therein and a second cathode within said second element disposed on the longitudinal axis thereof, said second element being disposed with the slot therein adjacent and substantially parallel to the slot in said first element; and a third space discharge device within said envelope adjacent said first device comprising an unslotted, hollow, substantially cylindrical third anode element, and a third cathode within said third element disposed on the longitudinal axis thereof, said third element being disposed with its longitudinal axis substantially parallel to that of said first element.

11. An ionization gauge as set forth in claim 10, further including a bridge circuit having four arms, said second and third devices being in series with the first and fourth arms of said bridge, respectively, means in at least a third arm of said bridge for varying the impedance thereof, a source of potential to cause space-current limited operation of said second and third devices connected across said bridge from the junction of the first and fourth arms thereof to the junction of the second and third arms thereof, a meter for indicating unbalance of said bridge connected between the junction of the first and second arms thereof and the junction of the third and fourth arms thereof, means for heating the cathode of said first device, and means for maintaining the grid at a positive potential with respect to said first cathode, said first cathode at a positive potential with respect to said first element, and said first element at a negative potential with respect to said second element.

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