Oct. 18, 1966 J. R. YOUNG 3,280,365

PENNING-TYPE DISCHARGE IONIZATION GAUGE WITH DISCHARGE INITIATION ELECTRON SOURCE

Filed April 15, 1963

Fig. 1.

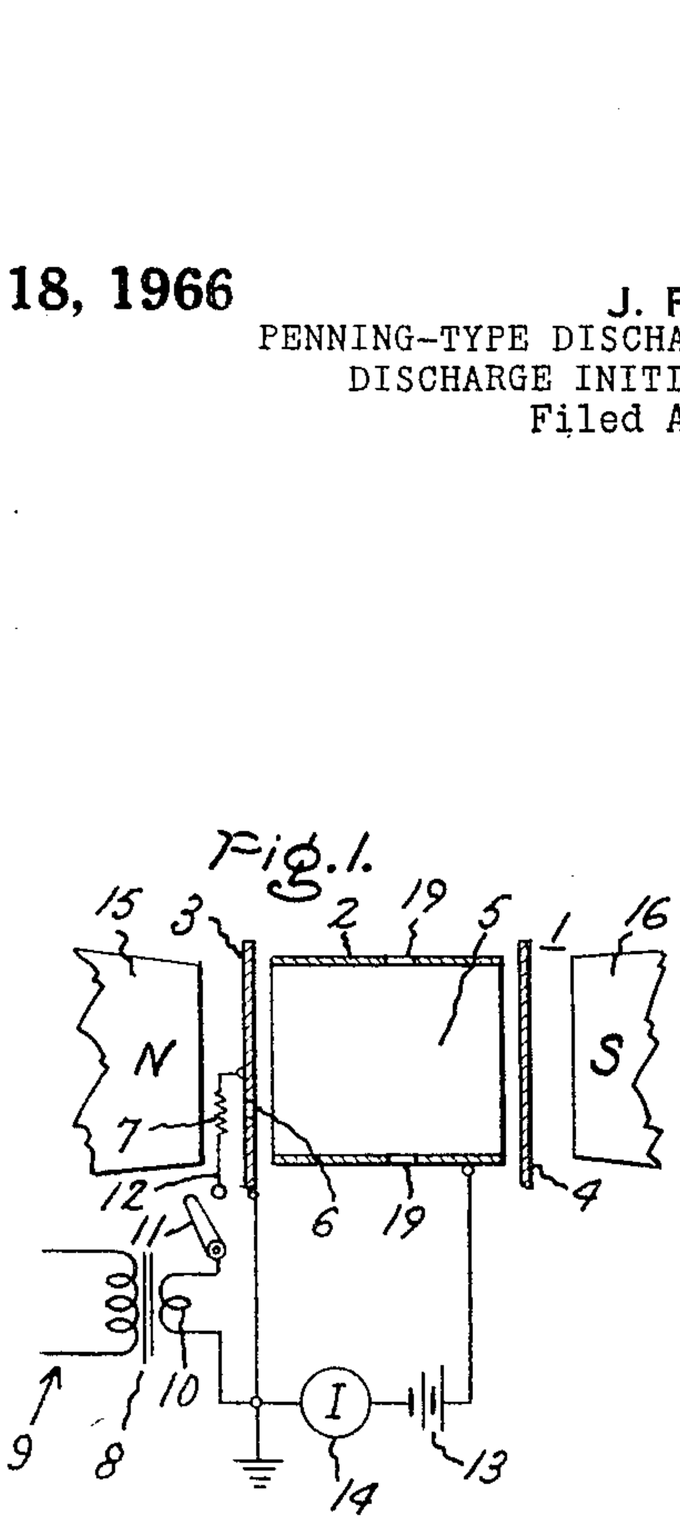



Fig. 2.

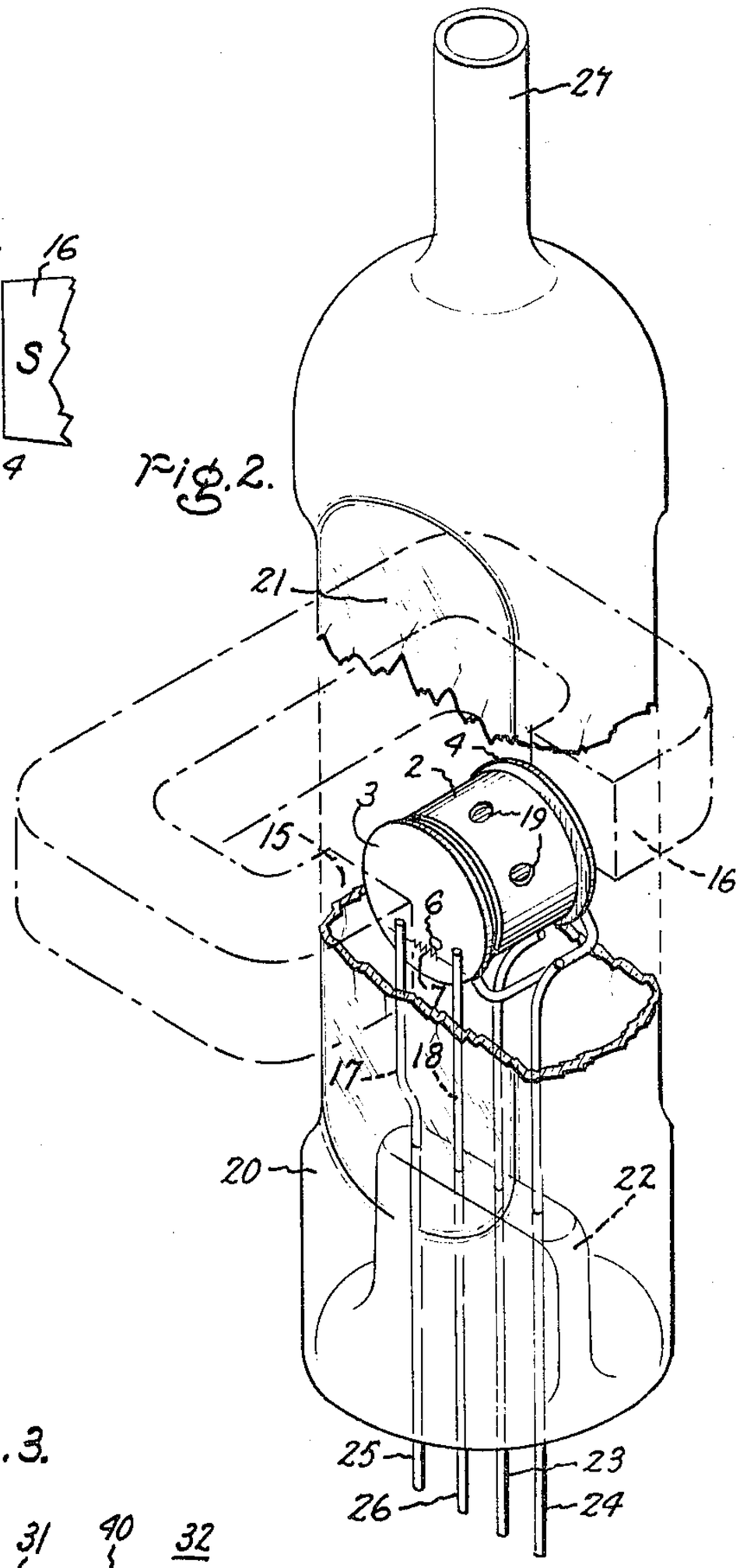
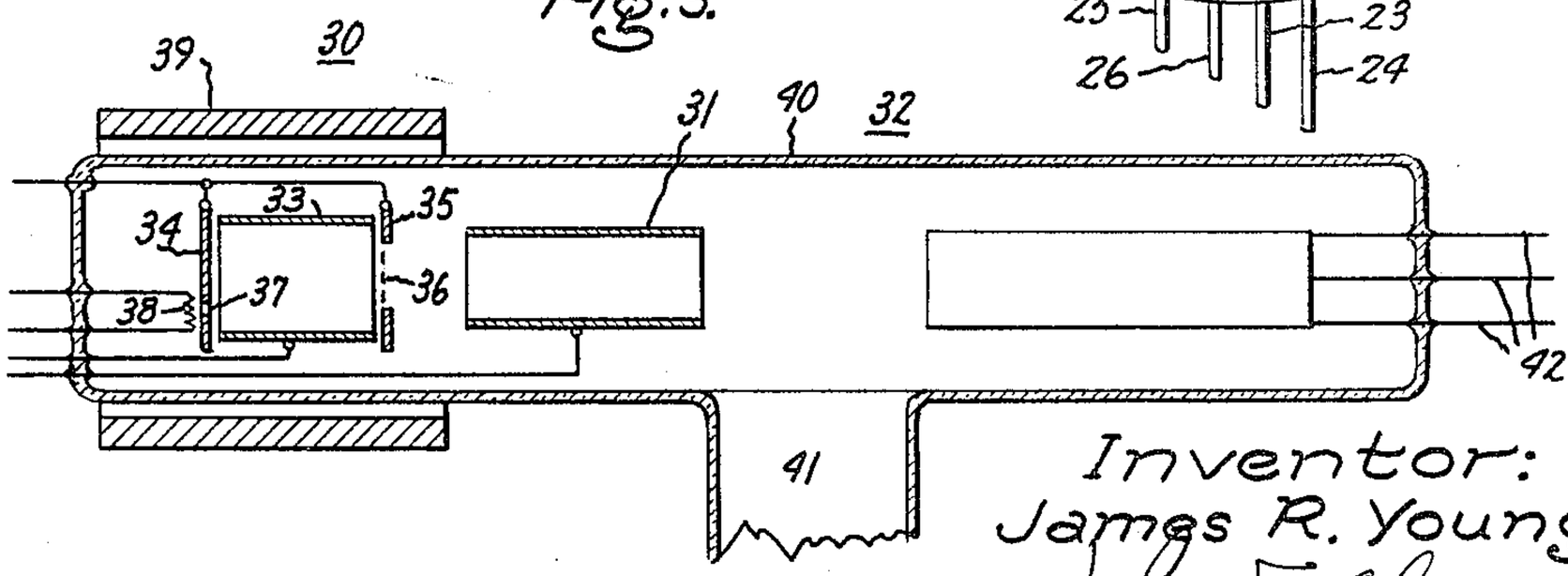



Fig. 3.

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# PENNING-TYPE DISCHARGE IONIZATION GAUGE WITH DISCHARGE INITIATION ELECTRON SOURCE

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13 Claims. (Cl. 315—111)

The present invention relates to ionization gauges and ionic pumps and more particularly to such devices as use a "Penning-type" discharge to cause ionization of gas molecules so that their presence may be measured and pressure of the gas determined and, in the pump use, that the ions be removed from an enclosure. More specifically, this invention relates to improved Penning type discharge initiating means for the mentioned devices.

One parameter which serves as a limiting factor in ionization gauges and ionic pumps is the low limit of measurable or operating pressure. In some such devices this pressure is set by the X-ray photo emission within the device causing a background of X-ray originated electron current. Another limitation is caused by the difficulty of starting ionization gauges and ionic pumps at very low pressures due to the small number of ionizable particles present at very low pressures.

Because of these and other limitations, present day ionization gauges are not generally available which will accurately measure gas pressures of less than $10^{-11}$ mm. of mercury. Even gauges which will measure this low are very complicated and require electronic focusing, etc. Additionally, it is often difficult to start any cold cathode discharge gauge or ionic pump at pressures of less than $10^{-7}$ mm. of mercury and still retain the long life associated with gauges and pumps which utilize the Penning-type discharge.

Accordingly, it is one object of the present invention to provide ionization gauges utilizing a Penning-type discharge which will readily and accurately measure gas pressures as low as $10^{-14}$ mm. of mercury.

It is another object of the invention to provide such gauges and ionic pumps which may be readily started at gas pressures as low as $10^{-14}$ mm. of mercury.

It is yet another object of the inventian to provide very low pressure operable ionization gauges and ionic pumps which utilize a Penning-type discharge and are constructed of an absolute minimum of parts, making their manufacture and installatoin a simple inexpensive operation.

Briefly stated in accord with one preferred form of my invention I provide an ionic gage device utilizing a Penning type electric discharge and including an apertured anode member having a planar cathode member coaxially positioned transversely at either longitudinal end thereof. One cathode is provided with a de-centered, i.e., off center, aperture therein behind which I provide a thermionic cathode member which is adapted to be momentarily energized to thermionic emission. Emitted electrons are drawn through the apertured cathode into the interaction space between the anode and cathodes to ionize gas particles therein to cause the establishment of an electric discharge of the Penning-type. The filament is then de-energized while the discharge continues. De-centering the aperture and filament prevents excessive deterioration by positive ion bombardment. Its location outside the interaction or discharge space minimizes positive ion bombardment during starting and prevents the filament being coated with contaminating particles. Additionally, since the filament is cold and inactivated during all times other than starting, it does not deteriorate to any appreciable extent.

The novel features believed characteristic of the present invention are set forth in the appended claims. This invention itself, however, both as to organization and operation together with further objects and advantages thereof, may best be understood by reference to the following detailed description thereof, taken in connection with the accompanying drawing in which:



FIGURE 1 is a schematic sketch of an ionization gauge constructed in accord with one embodiment of the present invention together with circuit means for operation thereof.

FIGURE 2 is a perspective view, with parts broken away, of another embodiment of the invention, and

FIGURE 3 is a vertical cross-sectional view of an ionization gauge representing still another embodiment of the invention.

In FIGURE 1 of the drawing, an ionization gauge represented generally as 1 includes a hollow cylindrical anode member 2 and a pair of transverse planar cathode members 3 and 4 adjacent the open ends of cylinder 2. Anode 2 and cathodes 3 and 4 define an or ionization space 5 within which ionization of gaseous particles takes place. This ionization is accomplished by use of a Penning-type discharge. A Penning-type discharge is an oscillating electron discharge in which an electron is repelled from one cathode, attracted by the positive potential of the anode, and accelerated toward the other cathode until it is repelled by the negative potential thereon, whereby it reciprocates back and forth between the two cathodes, making innumerable of reciprocating passes before it is finally laterally attracted to the anode. A longitudinal magnetic field, parallel with the anode axis, is utilized to impart a helical motion to the electrons.

Means for providing a starting burst of electrons to cause the ionization gauge to become operative at extremely low pressures, as for example, below about $10^{-8}$ mm. of mercury, are provided by a de-centered aperture 6 in cathode 3, and electron emissive means such as thermionic filament 7 located immediately behind aperture 3. Conveniently, filament 7 may be activated by transformer 8, comprising a primary coil 9 and a secondary coil 10, which causes alternating voltage to be impressed across filament 7, upon the closing of switch 11 which connects conductor 12 through filament 7 and cathode 3 across the secondary 10 of transformer 8. Alternatively, filament 7 may be connected to a separate supply of undirectional voltage through switch 11. Other operating potentials for the ionization gauge of FIGURE 1 are provided by a unidirectional voltage source represented generally by battery 13 through a current measuring device represented generally by ammeter 14. In order that a Penning-type electron discharge takes place within interaction space 5 a magnetic field having a flux density of, for example, 750 to 2000 gauss may be provided by a permanent magnet represented schematically by magnetic poles 15 and 16.

The device of FIGURE 2 is illustrative of actual ionization gauges which have been constructed in accord with the present invention. As in FIGURE 1, the ionization gauge of FIGURE 2 includes a cylindrical apertured anode 2 and a pair of disc-shaped cathode members 3 and 4 concentric thereto which define an interaction space therebetween. Cathode 3 includes an "off center" hole 6 behind which there is located thermionic filament 7. Hole or aperture 6 is minute in size, being sufficiently large to admit a burst of electrons to interaction space 5, but yet not being excessively large to expose filament 7 to substantial positive ion bombardment from the interaction space. With a cathode disc size of 1.25 cm. holes ranging in size from 0.5 to 1.5 mm. have proved satisfactory for successful operation and long life. Thermionic filament 7 is connected between two terminal members 17

and **18** rather than being connected at one end thereof to cathode **3**. This connection arrangement provides greater flexibility in arranging power supplies for the filament and for the ionization gauge anode and cathode. Thermionic filament **7** may conveniently be made of 0.003" tungsten wire or may be the same wire wound into a loose helix. Alternatively, thoria coated irridium wire may be used. During energization the filaments operate at approximate temperatures of from 1000° C. to 3000° C. and are extremely efficient thermionic emitters. A magnetic field sufficient to cause the establishment of a Penning-type electric discharge within interaction space **6** is provided by magnetic poles **15** and **16** which are juxtaposed longitudinally along the line normal to cathodes **3** and **4**.

Although not essential, it has been found desirable in some instances to provide transverse apertures **19** in anode **2** to increase the proximity between external gas molecules and interaction space **5**. These apertures may be in many shapes, sizes and forms and the anode may even constitute a partial foraminate article or mesh. It is required, however, that the apertures be such as not to allow material sputtered within interaction chamber **5** from cathodes **3** and **4** to deposit upon the electrode leads or upon the insulating envelope wall so as to electrically short circuit the electrodes. In the embodiment of FIGURE 2, three ⅛" diameter apertures, all located in the upper arc of horizontal cylinder **2** are quite satisfactory. The entire ionization gauge (with, of course, the exception of the magnetic means) is enclosed within an evacuable envelope **19** which preferably has at least a central region **21** wherein the external configuration of envelope **20**, which may be a non-conducting, non-magnetic, vitreous or refractory materials as for example, hard glass or quartz, is shaped with a pair of planar surfaces. These planar surfaces are substantially parallel with the plane of the cathode discs to facilitate bringing the poles **15** and **16** of the magnetic means as close thereto as is possible.

Operating potentials are supplied to the ionization gauge by bringing leads through a conventional "pinch" **22** or equivalent means to lead pins **23** and **24** which connect the anode and cathodes respectively to high voltage, and leads **25** and **26** which connect filament terminals **17** and **18** to an appropriate source.

Envelope **20** containing the ionization gauge is also provided with tubulation means **27** for connecting the gauge to a suitable enclosure, the pressure of which is to be measured thereby.

Operating parameters are not critical. In instances wherein an anode cylinder of approximately 1.25 centimeters in diameter and 1.25 centimeters in length were used with the cathode plates mounted about 0.5 mm. from the anode end cylinder, voltages between 1 kv. and 3 kv. have been applied between the anode cylinder and the cathode plates and magnetic flux densities of 750 to 2000 gauss have been used. As is well known to those skilled in the art, the optimum magnetic field which should be used depends upon the applied voltage and the device is more sensitive at higher voltages. However, for each configuration, a balance must be made between increased sensitivity and, at high voltages, a tendency for the discharge to become unstable. At normal operating potentials and magnetic field strengths the device shows a sensitivity of approximately 1 ampere per millimeter of mercury pressure.

In order that an ionization gauge of the present invention be utilized, it must first be connected through tubulation **27** to a device, the pressure of which is to be measured. In general, since the ionization gauges of the present invention are so simple, inexpensive and easily manufactured, they are generally, but not necessarily, incorporated with a vacuum system upon the construction thereof. When it is desired to start the ionization gauge to cause a measurement of the pressure of the system to which it is connected, switch **11** is closed. For starting at pressures as low as $10^{-9}$ to $10^{-11}$ mm. of mercury a



stable Penning-type discharge is initiated with switch **11** closed for a period of approximately only 5 seconds. Other more conventional gauges without the starting means utilized in the present invention may, at these pressures require days before a random event causes the starting thereof, or may never start at all. In these instances it often becomes necessary to start the ionization gauge before a pressure of $10^{-7}$ mm. of mercury is reached and maintain the gauge in operation continuously until low pressures are reached, because, once the conventional gauge has been stopped, it often can not be effectively re-started.

It has been found in Penning-type discharge devices that positive ion bombardment of the cathodes causes an erosion thereof which is generally limited to a central circular portion thereof. This central circular portion is defined on the cathodes as portions concentric with the longitudinal axis of the Penning discharge, which in turn is radially and concentrically contained in the anode. Thus, for example, in devices of the present invention wherein the cathode disc has a diameter of approximately 1.25 centimeters, a region of deep erosion of the cathodes at the center thereof usually has a diameter of 0.6 to 1.0 mm. Since it is an object of the present invention to provide long life ionic devices, and since bombardment of the starting filament would cause its eventual destruction, even though in starting it is only energized for a very short period of time, it is therefore contemplated, in the practice of my invention that, irrespective of the dimension of the ionization gauge the aperture **6** and corresponding filament **7** be located outside the region of high erosion, which distance may readily be determined empirically by operating a Penning-type discharge in the device of any given dimension. For devices having a cathode diameter of 1.25 cm. a de-centering of 3 to 5 mm. has been found appropriate.

In construction of ionization gauges in accord with the present invention, it is desirable that ion pumping by trapping or removal of ions be maintained at a minimum. In this respect, therefore, I prefer to use as anode and cathode materials, inactive materials which do not actively pump, as for example, platinum, copper, tungsten and stainless steel.

While the present invention is directed primarily to the development of ionization gauges which may readily be started at extremely low pressures in a very short time, the problem of starting and of maintenance of a discharge at low pressures is present also in ionic pumps. Ionic pumps utilizing the Penning-type discharge are generally similar in structural configuration to ionization gauges utilizing the Penning-type discharge, with the more notable exception that, rather than using inactive metals as the cathodes, the cathodes are constructed of good gas gettering and sputtering active materials, as for example titanium, to cause sputtered material to fill getter the gas in the interaction space. In accord with one significant improvement in the development of ionic pumps utilizing Penning-type discharges, as disclosed by U.S. Patent 3,080,108—T. A. Vanderslice, and assigned to the same assignee as the present invention, collector electrodes are provided in the interaction space and preferably biased at a suitable potential to attract positive ions which are later covered by this sputtered material. When devices of this nature reach extremely low pressures, there is a problem of the maintenance of the discharge at low pressures. Some have sought to correct this by the inclusion of thermionic filaments, but such thermionic filaments, if maintained within the discharge space may readily be destroyed by positive ion bombardment, particularly if the filament is maintained in operation continuously.

It is therefore in the contemplation of my invention that ionic pumps and gases utilizing the Penning-type discharge may be improved so as to make it possible for such devices to be started initially at extremely low pres-

sures or to resume pumping at such pressures if for one reason or another pumping is discontinued. These ends are achieved in accord with my invention by the inclusion therein of an aperture within the body of one of the cathodes thereof which is de-centered from the longitudinal axis of the anode and particularly from the longitudinal axis of the Penning discharge between the cathodes so as to avoid the highly concentrate area of erosion on the cathode thereof. This aperture is backed by a thermionic filament which is suitable to provide, upon the instantaneous excitation thereof, thermionically emitted electrons which are drawn into the discharge and interaction space by the positive potential of the anode and are sufficient to cause sufficient ionization within the interaction space so that a Penning-type discharge may be initiated.

FIGURE 3 of the drawing illustrates a vertical cross-sectional view of another embodiment of the invention wherein an ionization gauge utilizing a Penning-type discharge and the inventive concept of this invention is further made more sensitive by the incorporation therein of an electron focusing means and an electron multiplier device which make possible the attainment of measurements at pressures at low as $10^{-21}$ mm. of mercury. The ionization gauge of FIGURE 3 includes an ion source means **30** for producing a measurable ion current, an ion focusing means **31** and an electron multiplier means **32**. The ion source means, represented generally by **30**, in FIGURE 3 includes a cylindrical anode member **33** with the ends thereof closed by disc-shaped cathode members **34** and **35**. Cathode member **35** is centrally apertured coaxial with anode **33** by the inclusion of a grid **36** in the central portion thereof so as to allow the free passage of electrons therefrom. Operating potentials and circuit connections for this device are similar to those used for the device of FIGURE 2 and illustrated in FIGURE 1. Cathode **34** is apertured off-center with respect to anode **33** to provide aperture **37** having thermionic filament **38** therebehind, as provided in the embodiments of FIGURES 1 and 2. A longitudinal magnetic field of such strength sufficient to sustain a Penning-type discharge, as disclosed hereinbefore, is conveniently established by cylindrical magnet **39**. An electron focusing cylinder is provided collinear with, and longitudinally spaced from, the grid opening **36** in cathode **35**. Electron multiplier, means represented generally by **32**, is also located longitudinally aligned with and spaced from electron focusing means **31**. Evacuable envelope **40** which is similar in nature to envelope **19** of FIGURE 2, may be connected to a system through tubulation **41**. In the operation of this embodiment of the invention the Penning-type discharge is initiated within the interaction space by pulsing of a voltage to filament **38** to cause a pulse of electrons to be drawn through aperture **37** into the interaction space by the attraction of the kilovolt potential upon anode **33** and a Penning-type discharge is initiated between cathodes **34** and **35**. A fraction of the positive ions contained within the discharge pass through grid **36** in cathode **35**, are focused by focusing cylinder **31** and impinge upon ion-electron charge multiplying means **32**. Electron multiplying means **32** may comprise a conventional electronic multiplier, as for example, that disclosed in Rev. Sci. Instr., vol. 18, p. 739 (1947). The electrical output of this gauge is taken from leads **42**. Since the ion-electron charge multiplying means is capable of providing a gain between $10^6$ and $10^7$ with a background as low as 1 pulse every 10 to 100 seconds, this embodiment of the invention should therefore be capable of measuring ion currents near one ion every 100 seconds or ion currents of $10^{-21}$ amperes. Since the gauge has a sensitivity of approximately 1 ampere per millimeter of mercury and since the characteristic of the gauge is substantially linear, this embodiment of the invention should be capable of measuring pressures as low as $10^{-21}$ mm. of mercury.



It may be seen that the basic ionic devices of the present invention are extremely simple, inexpensive and easy to manufacture. Ionization gauges constructed in accord with the invention are extremely sensitive, and may be readily started as very low pressures without including continuously operating hot filaments that are subject to destruction by positive ion bombardment. Additionally, the low pressure limit of these gauges is below the X-ray limit of most prior art gauges.

While the invention has been set forth hereinbefore with respect to particular embodiments thereof it is apparent that many modifications and changes will readily occur to those skilled in the art. Accordingly, I intend by the appended claims to cover all such modifications and changes as fall within the true spirit and scope of this invention.

I claim:

**1.** An ionization device for measuring and attaining low pressures and starting means therefor comprising in combination,

(a) a hollow anode member,

(b) a cathode member on each side of said hollow anode member to define an enclosed interaction ionization space therebetween and through said anode,

(c) means to cause a Penning type discharge between said cathodes and said anode in said interaction space,

(d) and a separate electron source and injection means external to said enclosed interaction space and separate from said anode and said cathodes to directly inject electrons into said interaction space to initiate said Penning discharge,

(e) said source and injection means being positioned and arranged to minimize the concentrated erosive effects of said Penning discharge.

**2.** The invention as recited in claim **1** wherein said electron injection means comprises electron emission means positioned adjacent one of said cathodes.

**3.** The invention as recited in claim **1** wherein said electron injection means comprises the combination of one of said cathodes defining an aperture therethrough and a thermionic emissive emitter adjacent said aperture to inject electrons therethrough into said interaction space.

**4.** The invention as recited in claim **3** wherein said aperture is located in said cathode at a point radially displaced from the longitudinal axis of said Penning discharge between said cathodes to avoid the maximum erosion area on said cathode caused by said Penning discharge.

**5.** An ionization gage for use in measuring very low pressures and starting means therefor comprising in combination,

(a) a hollow open ended cylindrical anode member,

(b) an imperforate planar cathode member on each side of said anode member transversely and coaxially therewith to define a substantially enclosed interaction space between said cathodes and through said anode,

(c) magnetic means positioned adjacent said interaction space to define a magnetic field having lines of force running generally perpendicular to said cathodes and through said anode,

(d) means to cause a Penning type discharge between said cathodes in said interaction space,

(e) and Penning discharge initiating means for said interaction space,

(f) said initiating means comprising a thermionic emissive filament outside of said interaction space and adjacent one of said cathodes,

(g) the said one of said cathodes defining an aperture in its otherwise imperforate structure adjacent said filament,

(h) the said aperture being radially displaced from the longitudinal axis of said anode and between said

longitudinal axis and the periphery of said anode, and

(i) means to cause electron emission from said filament through said aperture generally parallel with the lines of force of said magnetic field to initiate said Penning discharge.

**6.** An ionization gage and starting means comprising in combination,

(a) an evacuable envelope adapted to be connected in gas flow relationship with a low pressure chamber,

(b) a substantially imperforate hollow open ended cylindrical anode positioned in said envelope,

(c) a pair of substantially parallel imperforate planar cathodes one at each end of said anode and positioned concentrically and transversely therewith and closely adjacent thereto,

(d) said anode and said cathode defining a substantially enclosed interaction space,

(e) means to connect said anode and said cathode to a source of potential to provide a Penning type discharge therebetween in said interaction space and generally coaxial with said anode,

(f) permanent magnet means adjacent said envelope to provide a magnetic field extending axially between said cathodes and in said anode,

(g) means defining an electron opening in one of said otherwise imperforate cathodes at a point removed radially from the longitudinal axis of said Penning discharge,

(h) said opening being further characterized in proportion, with an anode of about 1.25 cm. diameter, said cathode opening having a diameter of about .5 to 1.5 mm., and spaced radially from about 3 mm. to about 5 mm. from the longitudinal axis of said anode and Penning discharge,

(i) a thermionic emissive filament positioned out of said interaction space and adjacent said electron opening,

(j) means to energize said thermionic emissive filament to inject and direct electrons through said electron opening axially into said interaction space to initiate said Penning discharge.

**7.** An ionic device useful in attaining and measuring low vacua and comprising: an evacuable envelope having means for attaching the same to a vacuum system; an apertured anode member supported therein; a pair of oppositely disposed substantially parallel cathode members disposed adjacent opposite ends of said anode member and defining therewith an interaction space, one of said cathode members having therein a minute aperture decentered so as to avoid the central portion thereof which is subject to deep ion erosion; means for supplying a burst of electrons within said interaction space to initiate therein a Penning-type electric discharge at very low pressures and including a thermionic filament located adjacent the aperture in said one cathode and outside of said interaction space, means for supplying electric current to said filament, and means to temporarily energize said filament only until said discharge is initiated; means for impressing a magnetic field in said interaction space which is substantially normal to the planes of said cathodes, and means for applying a positive potential to said anode relative to said cathodes sufficient, in connection with said magnetic field, to sustain a Penning-type discharge within said interaction space upon entry therein of a pulse of electrons from said filament.

**8.** An ionization gauge comprising: an evacuable envelope having means for attaching the same to a system the pressure of which is to be measured; a hollow cylindrical anode member supported therein; a pair of oppositely disposed cathode members, one disposed adjacent each of the ends of said anode member to define therewith an interaction space, one of said cathode members having a minute aperture therein decentered sufficiently to avoid the central portion thereof which is subject



to deep erosion by positive ion bombardment during operation; means for supplying a burst of electrons within said interaction space to initiate therein a Penning-type electric discharge at very low pressures and including a thermionic filament located adjacent the aperture in said one cathode member and outside of said interaction space, means for supplying electric current to said filament, and means to temporarily energize said filament only until said discharge is initiated; means for impressing a magnetic field substantially parallel with the longitudinal axis of said anode, and means for applying a positive potential to said anode relative to said cathodes sufficient, in conjunction with said magnetic field, to sustain a Penning-type discharge within said interaction space upon entry therein of a pulse of electrons from said filament.

**9.** The ionization gauge of claim **8** wherein said anode member and said cathode members are composed of a relatively inert poorly sputtered material selected from the group consisting of stainless steel, tungsten, platinum, molybdenum and copper.

**10.** An ionization gauge comprising: an evacuable envelope having means for attaching the same to a system the pressure of which is to be measured; an apertured anode member supported therein and having oppositely disposed ends and longitudinal side walls; a pair of oppositely disposed cathode members, one disposed adjacent each of the ends of said anode member to define therewith an interaction space, one of said cathode members having a minute aperture therein decentered sufficiently to avoid the central portion thereof which is subject to deep erosion by positive ion bombardment during operation; means for supplying a burst of electrons within said interaction space to initiate therein a Penning-type electric discharge at very low pressures and including a thermionic filament located adjacent the aperture in said one cathode member and outside of said interaction space, means for supplying electric current to said filament, and means to temporarily energize said filament only until said discharge is initiated; means for impressing a magnetic field substantially parallel with the longitudinal axis of said anode, and means for applying a positive potential to said anode relative to said cathodes sufficient, in conjunction with said magnetic field, to sustain a Penning-type discharge within said interaction space upon entry therein of a pulse of electrons from said filament.

**11.** The ionization gauge of claim **10** wherein said anode member and said cathode members are formed of a relatively inert poorly sputtered material selected from the group consisting of stainless steel, tungsten, platinum, molybdenum and copper.

**12.** An ionization gauge comprising: an evacuable envelope having means for attaching the same to a system the pressure of which is to be measured; an apertured anode member supported therein and having oppositely disposed ends and longitudinal side walls; a pair of oppositely disposed cathode members, one disposed adjacent each of the ends of said anode member to define therewith an interaction space, one of said cathode members having a minute aperture therein decentered sufficiently to avoid the central portion thereof which is subject to deep erosion by positive ion bombardment during operation, the other of said cathodes having a substantially permeable gridded central portion to allow ions to escape therethrough; means for supplying a burst of electrons within said interaction space to initiate therein a Penning-type electric discharge at very low pressures and including a thermionic filament located adjacent the aperture in said one cathode and outside of said interaction space, means for supplying electric current to said filament, and means to temporarily energize said filament only until said discharge is initiated; means for impressing a magnetic field substantially parallel with the longitudinal axis of said anode; means for applying a positive potential to said anode relative to said cathodes

sufficient, in conjunction with said magnetic field, to sustain a Penning-type discharge within said interaction space upon entry therein of a pulse of electrons from said filament; positive ion focusing means colinear with the central axis of said anode for collimating and accelerating positive ions which escape through said gridded cathode member; and electron-ion multiplier means for amplifying the electron current caused by said escaping ions.

**13.** In an ionic device of the type including an evacuable envelope attachable to a vacuum system and including therein a pair of oppositely disposed cathode members and an interposed anode member defining with said cathode members an interaction space within which a Penning-type discharge may be maintained, one of said cathode members having an aperture therein and a thermionic filament adjacent said aperture and external to said interaction space; a method of starting which comprises energizing said thermionic cathode to cause the emission of electrons therefrom; applying a highly positive potential to said anode relative to said cathodes and to said filament to attract said electrons through said aperture into said interaction space so as to establish a Penning-type discharge



therein; and deenergizing said filament as soon as said discharge is established.


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