Jan. 25, 1949. R. C. HERGENROTHER 2,460,175
IONIC VACUUM PUMP
Filed July 31, 1945 2 Sheets-Sheet 1

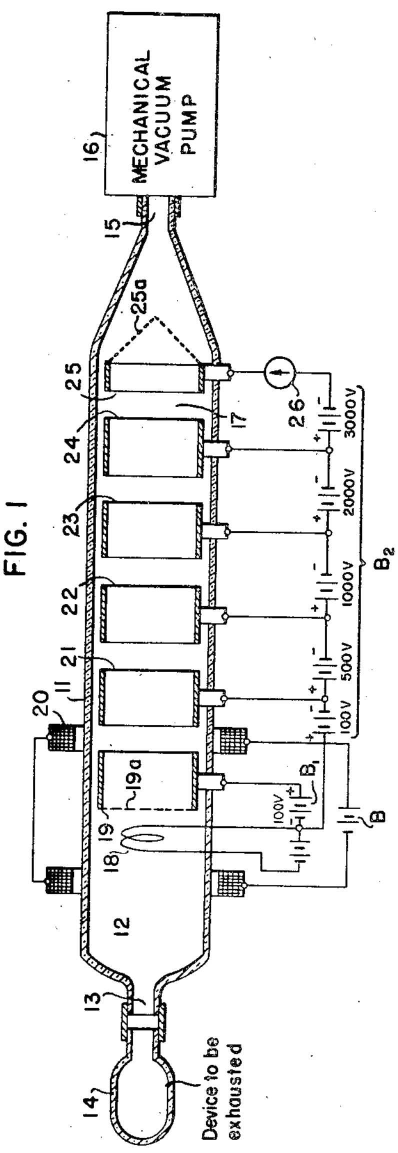

FIG. 1

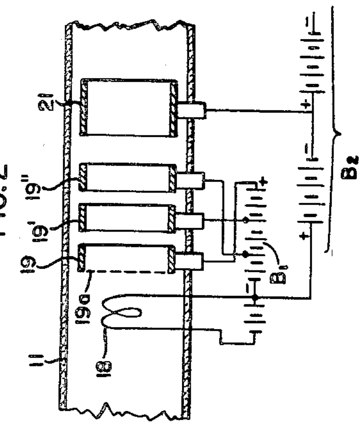
FIG. 2

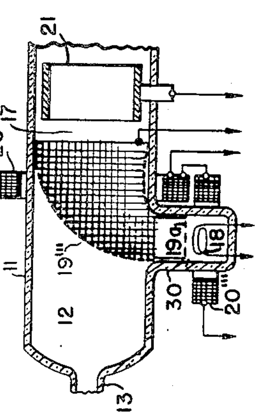
FIG. 3

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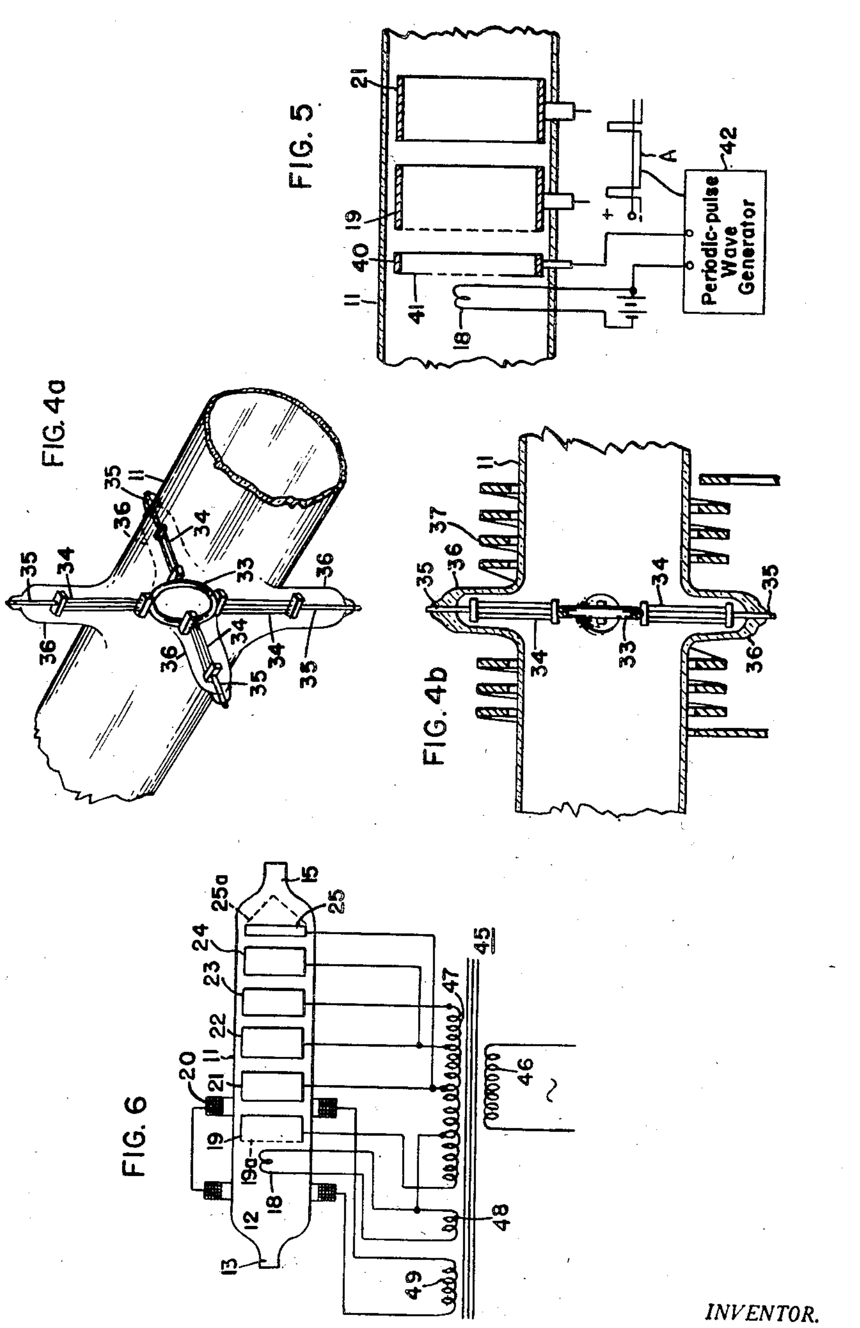

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2,460,175

IONIC VACUUM PUMP

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Application July 31, 1945, Serial No. 608,038

11 Claims. (Cl. 103—69)

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The present invention relates to ionic vacuum pumps and, particularly, to such pumps which are adapted to produce a relatively high vacuum in a vessel to be exhausted thereby.

Where it is desired to evacuate air or gas from a closed vessel to provide a very low internal pressure, it is conventional to utilize a mechanical vacuum pump of any of several well-known types coupled in tandem with one or more auxiliary vacuum pumps having a construction quite different from that of the mechanical pump.

It has been proposed in accordance with one prior arrangement that the auxiliary vacuum pump be of the so-called diffusion type. The Langmuir mercury-vapor diffusion pump is perhaps the earliest pump of this type widely used, but is being supplanted to a certain extent by the oil-vapor type of diffusion pump which involves the same construction as the Langmuir pump but utilizes a special oil for the fluid vapor. In this type of pump, oil or mercury is vaporized within a storage chamber and is discharged from this chamber as one or more blasts of vapor directed into a second chamber of the pump. The blast or blasts of vapor operate with an aspirator effect to propel molecules of gas from the vessel to be evacuated toward the discharge port of the second chamber. The propelled gas molecules accumulate and become sufficiently compressed at the discharge port as to enable their removal by the mechanical vacuum pump which is connected at this point. The walls of the second chamber are cooled by a first cooling system, as by forced circulation of water through a water jacket surrounding the second chamber, for purposes of condensing the vapor from the blast in order that it may be returned as a fluid to the storage chamber for further use and also to prevent the vapor from being withdrawn through the discharge port by the mechanical vacuum pump. A much more refined form of condenser is usually required between the inlet port of the diffusion pump and the vessel to be evacuated, it being the purpose of this condenser to prevent the vapor of the diffusion pump from diffusing into the vessel to be evacuated. The condenser last mentioned frequently comprises a conduit through which the evacuated gas is withdrawn to the diffusion pump, this conduit being surrounded by a vessel containing a liquefied gas such as liquid air or liquid nitrogen. When of this form, the condenser is commonly known as a "cold" trap.

A diffusion pump of the type described has numerous undesirable limitations and disadvantages. Quite aside from the disadvantage of having to provide a forced cooling system for the diffusion pump itself and a cold trap to prevent diffusion of the vapor from the pump into the vessel to be evacuated, there is the additional and important disadvantage that failure of the forced cooling system for any reason may result in the loss of all of the oil or mercury from the diffusion pump into the mechanical vacuum pump thus to cause partial or complete failure of the pumping system. Failure of the cold trap even in part, with consequent diffusion of the vapor into the vessel to be evacuated, may result in the requirement that the pumping period be greatly prolonged or may even, in certain instances, completely ruin the vessel to be evacuated, particularly where the latter cannot be placed in a baking oven to insure complete removal of all traces of the diffused vapor.

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Should the vacuum be suddenly accidentally broken on a diffusion pump during a pumping operation and while the latter is hot, the hot oil or mercury quickly oxidizes and it is usually necessary that the diffusion pump be completely dismantled and thoroughly cleaned before again being placed in operation. This disadvantage of the diffusion pump likewise gives rise to a serious limitation in the use thereof for those applications where the vacuum must be broken during successive evacuations of a plurality of individual vessels. In such case, it is necessary that the diffusion pump be cooled, either naturally or by an additional forced cooling system, to a reduced temperature at which the fluid of the diffusion pump does not experience serious oxidation. Once the vacuum is broken on a diffusion pump, there is the further disadvantage that the walls and inner elements of the pump absorb gas and, since the pump cannot be placed in a baking oven to degasify the pump of the absorbed gas, a prolonged pumping period is required before the diffusion pump can again attain the high vacuum of which it is capable.

To avoid the disadvantages and limitations of the diffusion type of pump described, it has been proposed in accordance with another prior arrangement that the low pressure auxiliary vacuum pump be of a type in which the molecules of gas to be evacuated are ionized and are then withdrawn by utilizing the phenomenon that a force of attraction exists between such ionized molecules and a conductive member energized with a negative potential. These ionic vacuum pumps have an ionization chamber including a thermionic cathode to provide a source of electrons and an anode electrode for attracting electrons emitted by the cathode. The gas molecules appearing in the ionization chamber are ionized by impact of electrons therewith as the electrons move from the cathode to the anode. The ionized molecules are attracted toward the cathode and tend to accumulate in the region thereof, thereby building up a gas pressure at this point of the ionization chamber sufficient to permit a mechanical vacuum pump to remove them. There has heretofore been the serious disadvantage with this type of ionic pump that the electrons traverse the gas-discharge path at the ionization chamber only once in their movement from cathode to anode. As a result, there are a substantial number of electrons that do not impact gas molecules and, therefore, do not contribute to the desired pumping action. Consequently, the pumping rate is so much smaller than that of the diffusion type of pump as to render this prior type of ionic pump impractical for many applications. To increase the probability of impact of each electron in transit with a gas molecule, thereby to increase the pumping efficiency, it has been proposed that the spacing between the cathode and the electron-collecting portion of the anode be made relatively large and that the electrons in transit be restrained by a magnetic field from impacting any portion of the anode except the electron-collecting area thereof. While this arrangement may theoretically slightly increase the pumping efficiency, the efficiency nevertheless is still much lower than is desirable in comparison with that of the diffusion pump.

It is an object of the present invention to provide a new and improved ionic pump which avoids one or more of the disadvantages and limitations of prior pumps of the type described.

It is an additional object of the invention to provide a new and improved ionic pump of relatively simple and compact construction.

It is a further object of the invention to provide a new and improved ionic pump which has a faster pumping rate, at any given gas pressure, than has readily been obtained in prior pumps of this type.

In accordance with one form of the present invention, an ionic vacuum pump comprises a housing having a chamber including an inlet port for connecting the chamber to a device to be evacuated and an outlet port for connecting the chamber to an external vacuum pump. The chamber provides a gas-discharge path between the inlet and outlet ports. The pump includes means for providing a flow of electrons directed into the gas-discharge path in the chamber to ionize gas molecules therein, and means tending to confine the movement of the electrons to provide an electron stream in the gas-discharge path. The last-mentioned means co-operates with the first-mentioned means to cause a substantial number of the electrons repeatedly to traverse the electron stream in longitudinal forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in the gas-discharge path by the repeated traversals of the electrons therethrough. The last-mentioned means includes means for attracting the ionized gas molecules toward the outlet port to render them potentially accessible for evacuaion by the external vacuum pump.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring to the drawings, Fig. 1 is a longitudinal section through an ionic vacuum pump embodying the present invention in a particular form; Figs. 2 and 3 are longitudinal sectional views of a portion of an ionic vacuum pump embodying modified forms of the invention; Figs. 4*a* and 4*b* are respectively a perspective view and a longitudinal cross-sectional view of a portion of an ionic vacuum pump embodying the invention but having a modified form of cathode structure; Fig. 5 is a longitudinal sectional view of a portion of an ionic vacuum pump embodying an additionally modified form of the invention; and Fig. 6 represents schematically a method of energizing an ionic pump of the invention by the use of alternating potentials.

Referring now more particularly to Fig. 1 of the drawings, there is represented in cross-sectional view an ionic pump embodying the present invention in a particular form. This pump includes a housing 11, which may for example be of glass, having a chamber 12 which includes an inlet port 13 for connecting the chamber 12 in conventional manner with a device 14 to be evacuated and an outlet port 15 for connecting the chamber in conventional manner to an external mechanical vacuum pump 16. The chamber 12 provides a gas-discharge path 17 between the inlet and outlet ports. The pump also includes means comprising a thermionic cathode electrode 18 for providing a flow of electrons directed into the gas-discharge path 17 to ionize gas molecules therein. The cathode electrode 18 preferably has a configuration which permits optimum electron current flow, yet one which minimizes any physical obstruction presented thereby to the flow of molecules through the gas-discharge path. Where the ionic pump is normally to be operated to evacuate air or other gas containing oxygen from a relatively small vessel 14 and the maximum gas pressure will not exceed about one micron, the cathode 18 may comprise a relatively fine tungsten filament having a planar helical configuration with the nominal plane of the filament normal to the axis of the housing 11. The last-mentioned means also includes an anode electrode 19 for attracting electrons from the cathode 18, the anode preferably having a cylindrical configuration with a grid or other electron-permeable structure 19*a* closing the end thereof adjacent the cathode and being disposed relatively near the cathode but enclosing the gas-discharge path 17. The anode 19 has applied thereto a positive unidirectional bias from a source of potential, indicated as a battery B_1.

The ionic vacuum pump also includes means tending to confine the movement of the electrons to provide an electron stream in the gas-discharge path 17. This means comprises a cylindrical electromagnet 20 positioned around the path of electron flow between the cathode 18 and the anode 19. The electromagnet 20 is energized from a source of unidirectional current, indicated as a battery B. The last-mentioned means also includes a cylindrical electrode 21 positioned adjacent the anode 19 but between the anode and the discharge port 15, the electrode 21 having applied thereto a negative bias from a source of potential, indicated as a portion of a battery B_2. This electrode, with the electromagnet 20, co-operates with the cathode 18 and anode 19 to cause a substantial number of the electrons repeatedly to traverse the electron stream in longitudinal forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in the gas-discharge path 17 by repeated traversals of the electrons therethrough.

The last-mentioned means additionally includes means for attracting the ionized gas molecules toward the outlet port 15 to render them potentially accessible for evacuation by the external vacuum pump 16. This means comprises the electrode 21 together with a plurality of similar electrodes 22, 23, 24 and 25 spaced along the gas-discharge path 17 toward the discharge port 15 and energized to progressively increasing negative potentials from the battery B_2.

Considering now the operation of the ionic vacuum pump just described, assume at the outset that the device 14 initially filled with air to be evacuated has been connected in conventional manner to the inlet port 13 of the ionic vacuum pump, and that the mechanical pump 16 has also been connected in conventional manner to the exhaust port 15 of the latter. Assume further that the cathode 18 of the ionic pump is de-energized and that the mechanical vacuum pump has exhausted the device 14 and chamber 12 of the ionic vacuum pump to a sufficiently low gas pressure that the cathode 18 may safely be energized without undue impairment to the longevity of life expected of it. Assume lastly that, at this time, the cathode 18, the anode 19, the electrodes 21–25, inclusive, and the electromagnet 20 are energized from the several energizing sources B, B_1 and B_2.

The electrons emitted by the cathode 18 are attracted toward the anode 19, but the magnetic field developed by the electromagnet 20 is axial of the housing 11 and thus tends so to restrain the movement of the electrons in well-known manner that they move together in spiral paths as a stream of electrons directed longitudinally along the gas-discharge path 17. When the electrons are so constrained in their movement, few of them are able to impact the anode 19 immediately but instead travel into and through the equipotential space interiorly of the anode 19 and emerge therefrom toward the electrode 21. Each of the majority of the electrons of this electron stream continues along the gas-discharge path 17 and eventually approaches a region of zero potential established between the electrodes 19 and 21 by virtue of their differences of potential. By a region of zero potential is meant a region having the same potential as the point of connection of the cathode energizing circuit to the electrode energizing sources B_1 and B_2; that is, a region having a potential the same as that of the junction of the batteries B_1 and B_2. The velocity of the electron becomes zero in this region and the electron is then reattracted by the positive electric field established by the anode 19. The electron thereupon moves toward the anode 19 but again is constrained to move longitudinally of the gas-discharge path 17 by the action of the magnetic field developed by the electromagnet 20. The electron continues through the equipotential space within the anode 19 and eventually returns to the vicinity of the cathode 18 where it either impacts the cathode or has its velocity reduced to zero by a region of zero potential. Should the electron not impact the surface of the cathode 18, it is again reattracted toward the anode 19 and continues through the cycle of motion described eventually again to return to the vicinity of the cathode 18.

This repeated traversal of the electrons in the electron stream in longitudinal forward and backward directions along the discharge path 17 continues either until the electron impacts the cathode 18 or the anode 19. Due to the action of the magnetic field developed by the electromagnet 20, the great majority of electrons emitted by the cathode 18 effect this repeated traversal of the discharge path 17, thereby substantially to increase the probability of ionization of gas molecules in the gas-discharge path. The probability of ionization is further enhanced by the fact that, as is well known, any electron moving axially of a magnetic field as here described does not follow a linear path but rather follows a spiral, whose axis extends along the magnetic lines of force. The radius of the spiral is proportional to the component of the electron's velocity perpendicular to the magnetic field, and the pitch of the spiral is proportional to the component of the electron's velocity parallel to the magnetic field. The spiral pitch and radius are both inversely proportional to the magnetic field strength.

Upon impact of an electron was a gas molecule, the latter gives up one or more electrons and becomes positively charged or ionized. The electrons thus given up by the ionized molecules may join and become a part of the moving electron stream and thus are themselves available for ionization of additional gas molecules. This augmentation of the electron stream by the electrons of ionization is very small when the gas pressure is very low. However, it can become important and appreciably improve the pumping efficiency during the initial moments of operation of the ionic pump when the gas pressure is relatively high and the electron emission of the cathode 18 thereby somewhat impaired.

The ionized gas molecules, being positively charged, are attracted toward the negatively biased electrode 21. The electric field established between the electrodes 19 and 21 is such, however, that an electric-lens action occurs. The relative energizations, lengths and spacings of the electrodes 19 and 21 are preferably so selected that this lens action tends to restrain the movement of the ionized gas molecules in general to a path centrally of the gas-discharge path 17 so that the majority of the ionized molecules are not able to impact the electrode 21. The electrodes 22, 23 and 24 have similarly selected energizations, lengths and spacings to provide similar lens actions so that the ionized molecules move with progressively increasing velocity by virtue of the progressively increasing energization of the electrodes 21–25, inclusive, toward the terminal electrode 25. The latter is closed by a gas-permeable conductive screen *25a* to which the majority of ionized gas molecules are attracted. Upon impact of an ionized molecule with any of the electrodes 21–25, inclusive, the molecule receives one or more electrons as required to render it again a neutral gas molecule. Some of the neutral gas molecules which appear along the gas-discharge path 17 in the region within the electrodes 21–25, inclusive, are also moved toward the electrode 25 under impact therewith of ionized gas molecules which are moving under acceleration of the electric fields of the electrodes 21–25, inclusive. The neutral gas molecules in the region of the terminal electrode 25 become compressed toward the outlet port 15 of the ionic vacuum pump, thereby to increase the gas pressure at the outlet port to a value sufficient for the high pressure mechanical vacuum pump 16 to withdraw them. The meter 26 is useful for measuring the approximate rate of evacuation, and thus to a certain extent the gas pressure, at any given time, since the current through the meter varies proportionately to the deionization current of the electrode 25.

As is well known, when any gas is ionized by bombardment with electrons there is an optimum ionization voltage for maximum ionization per unit of time. That is to say, in the ionic pump of the present invention there is an optimum voltage with which the anode 19 should be energized to effect, for any given type of gas present in the gas-discharge path 17, maximum ionization per unit of time and thus maximum pumping efficiency. The optimum value of energization of the anode 19 may be readily ascertained during operation of the pump by adjustment of the value of the battery B_1 while watching the deionization current of the meter 28, optimum energization being indicated by the attainment of a maxima in the deionization current. In adjusting the energization of the electrodes 21–24, inclusive, to the effect the desired lens action provided by these electrodes on the ionized molecules of gas as heretofore mentioned, it is convenient to coat the inside surfaces of these electrodes with a fluorescent coating if the housing 11 is of transparent material, such as glass, so that any bombardment of these electrodes by the ionized gas molecules will indicate the point of impact by a fluorescing of the fluorescent material. The desired lens action is preferably such that the ionized molecules shall be focused to a point at about the center of each electrode and on the axis thereof.

While the electrodes 19 and 21–25, inclusive, have been shown as individual conductive elements positioned along the gas-discharge path 17 of the pump and spaced from the walls of the housing 11, it will be apparent that these electrodes may be comprised of conductive coatings sprayed or otherwise suitably formed directly on the inner wall of the housing 11 thus to simplify the construction of the ionic pump. It is, of course, necessary in such case either that the housing or its inner surface be of insulating material. Further, while the terminal electrode 25 has been shown as energized to a higher negative potential than the electrode 24, the terminal electrode will nevertheless perform its deionization function even though energized to a lesser negative potential than the electrode 24. The energization of the electrode 25 to a lesser negative potential than that of the electrode 24 may be desirable in certain instances, as for example to provide a lens action between the electrodes such that the ionized molecules are focused in large part to the inner wall of the electrode 25 rather than to the gas permeable screen 25a thereof.

In the operation of the ionic pump described, it is the purpose of the grid structure 19a, which closes one end of the anode 19, to advance in the direction of the cathode 18 the point along the gas-discharge path at which the positive potential gradient begins to decrease in the direction toward the electrode 21. The importance of this will be apparent when it is considered that the only ionized gas molecules, which are attracted toward the electrode 21, are those which lie in the region of decreasing electric-field gradient. Where a single anode element 19 is used, as in the Fig. 1 arrangement, the length of the anode element is a compromise between two opposing factors. One factor is that increasing the length of the anode element 19 effects an increase in the length of the gas-discharge path over which the electrons are caused to reciprocate, thus to increase the probability of ionization of the gas molecules by the electrons. On the other hand, as the anode 19 is increased in length, the point of decreasing potential gradient in the direction of the electrode 21 becomes more remotely situated from the cathode 18 so that those ionized gas molecules which lie without the region of decreasing potential gradient, must drift or be pushed by the gas flow further along the gas-discharge path before entering the latter region for acceleration toward the electrode 21.

The compromise last discussed in relation to the choice of the length of the anode 19 is obviated to a certain extent by the modified form of the invention illustrated in Fig. 2, which represents a portion of an ionic pump essentially similar to that of Fig. 1, similar elements being designated by similar reference numerals. In the Fig. 2 arrangement, there is provided means for producing, relative to the cathode 18 and along the gas-discharge path, a positive-potential gradient increasing rapidly to a first point relatively close to the cathode and then decreasing more slowly from the first point to a second point relatively remotely situated from the cathode for producing a flow of electrons directed into the gas-discharge path to ionize gas molecules therein. This means comprises the anode 19, which is selected to have a relatively short axial length, followed by a plurality of anode elements 19′ and 19″ which with the anode 19 are energized to decreasing positive potentials in the direction of the electrode 21. This effectively increases the length of the gas-discharge path along which an electron moves while, at the same time, positioning the region of decreasing potential gradient quite near the grid structure 19a. Thus, with this modified form of the invention, the probability of ionization of the gas molecules by the reciprocating electrons is substantially increased by increase of the path length over which the electrons move while at the same time the probability that ionized gas molecules will lie outside the region of decreasing potential gradient is decreased. This, of course, effects an improvement in the efficiency of the ionic pump.

Fig. 3 represents a cross-sectional view of a portion of an ionic vacuum pump embodying the present invention in a modified form. This modified form of the invention is essentially similar to the arrangement of Fig. 1, similar elements being designated by similar reference numerals and analogous elements by similar reference numerals triple primed, except that the cathode 18 is positioned in a recessed portion 30 of the housing 11 and the anode 19‴ is a 90°-angled funnel-shaped gas-permeable conductive electrode. The electromagnet 20‴ in the present embodiment includes two series-connected winding sections positioned with their axes normal to one another, one section being positioned over the recessed portion 30 of the housing 11 while the other section is positioned around the housing 11 near the terminal end of the anode 19‴. The magnetic field developed by the electromagnet 20‴ is curvilinear and the resultant restraining action on the movement of the electrons emitted by the cathode 18, and attracted toward the anode 19‴, is to restrain the electrons to move along paths approximately parallel to the curved axis of the anode 19‴. The electron stream is thus directed into the gas-discharge path 17 at an angle thereto. The action of the cathode 18, the anode 19''', the electrode 21, and the magnetic field developed by the electromagnet 20''' is similar to that described in connection with the Fig. 1 arrangement in that a substantial number of the electrons are caused, each repeatedly, to traverse the electron stream in longitudinal forward and backward directions therealong, the electron stream flowing generally along the lines of force of the magnetic field provided by the electromagnet 20'''. This repeated traversal of the electrons along the electron stream substantially increases the probability of ionization of additional molecules in the gas-discharge path 17 by the repeated traversals of the electrons therethrough. The operation of this modified form of the invention is otherwise essentially similar to that described in connection with the Fig. 1 arrangement and will not be repeated.

It will be apparent that the anode 19''' of the Fig. 3 arrangement may be constructed and energized as a plurality of segmental anodes as in Fig. 2 arrangement thus, additionally to have the advantages attendant upon the latter construction.

In the above description of the operation of the Fig. 1 ionic pump, it was assumed at the outset that the vessel 14 was initially filled with air to be evacuated and that the mechanical vacuum pump 16 had reduced the gas pressure in the vessel 14 and the chamber 12 of the pump to a relatively low value prior to energization of the cathode 18. This condition of reduced gas pressure in the chamber 12 of the ionic pump is made desirable for two reasons. The first of these is that the electron emission from the cathode 18 is reduced with increasing gas pressure. Hence, without regard to the constituents of the gas to be evacuated, it is necessary that the mechanical pump 16 reduce the gas pressure within the chamber 12 to a certain value before the electron emission from the cathode 18 can become sufficiently large that the ionic pump has appreciable pumping efficiency.

The second reason for reducing the gas pressure within the chamber 12 prior to energization of the ionic pump has importance only when the gas to be evacuated contains oxygen as a constituent thereof. For adequate electron emission of the cathode 18, the temperature thereof must be sufficiently high that oxidation of the cathode proceeds at a rapid rate in the presence of any appreciable quantity of oxygen in the gas to be evacuated. A thoriated tungsten cathode is quickly "poisioned" in the presence of oxygen; that is, its electron-emissive capacity becomes quickly impaired. A pure tungsten cathode does not become poisioned by the presence of oxygen but the latter in this case has the effect that the rate of evaporation of the tungsten cathode is substantially increased with increasing gas pressure. The reason for this is that tungsten oxide has a relatively low evaporation temperature, much lower than that of the tungsten itself, so that any tungsten oxide evaporates from the tungsten cathode as fast as it is formed. This "self-cleaning" action causes the tungsten always to present a clean or unoxidized surface to the oxygen with the result that oxidation proceeds unchecked and at a rapid rate. Where it is desired, as for convenience of energization, that the cathode be formed of a relatively fine tungsten wire and where it is desired that the ionic pump evacuate gases containing oxygen at a relatively high pressure, the relatively short life of the cathode makes it preferable to provide a quickly detachable supporting structure for the cathode in order that a new cathode may be quickly inserted in place of a defective one. Alternatively, several such cathodes may be permanently built into the ionic pump to provide adequate length of life therefor.

Figs. 4*a* and 4*b* illustrate respectively a perspective view and a longitudinal sectional view of a portion of an ionic vacuum pump embodying a modified form of cathode structure suitable for an ionic pump of the present invention This form of cathode structure is particularly useful where it is desired that the ionic pump evacuate gases containing oxygen at a relatively high pressure, for example at a gas pressure above 10 microns. Rapid evaporation of the tungsten cathode, for reasons pointed out above, is permissible with the present cathode structure which utilizes a substantial amount of cathode material sufficient to provide adequate cathode life under severe operating conditions. For simplicity, Figs. 4*a* and 4*b* show only the cathode structure and energizing winding therefor, but it will be understood that the remaining elements of the ionic pump are arranged as explained above in connection with Figs. 1 or 2. The cathode here comprises an electrically closed ring 33 of tungsten which is supported coaxially of the housing 11 by means of spaced systems of thin tungsten support wires 34 extending radially of the ring 33 and terminating in an anchoring structure 35 sealed through the end of a plurality of cylindrical projections 36 provided in the walls of the housing 11. The elements 34 and 35 essentially comprise supporting means having a relatively low thermal transmission characteristic for supporting the ring 33 within the housing 11 while, at the same time, ensuring that insufficient thermal energy is conducted to the anchoring structures 35 to endanger the seals where the latter pass through the projections 36 of the housing. As more clearly shown in Fig. 4*b*, the cathode 33 is inductively energized by a winding 37, which may be an edge-wound ribbon inductor, coupled to an alternating current source of energization, not shown, preferably of radio frequency.

As is well known, the ring cathode 33 essentially comprises a short-circuited secondary winding of a transformer, which includes the primary winding 37. Sufficient energy is induced in the ring cathode 33 to raise the temperature of the latter to a value suitable for adequate electron emission. The plane of each group of the support wires 34 preferably includes the axis of the winding 37 to minimize induced currents in the former. Those of the electron- and ion-accelerating electrodes, for example the electrodes 19 and 21–25, inclusive, of Fig 1, which are spaced from the winding 37 by a distance less than the diameter of the latter, should be suitably slotted axially of the housing 11 or otherwise arranged so that they do not form an electrically closed conductive loop. If desired, the winding 37 may be sufficiently elongated that it extends over the electron-accelerating anode or anodes to provide an electron-restraining magnetic field thus to dispense with the need of the electromagnet 20 which is employed in the Fig. 1 arrangement.

Fig. 5 represents a longitudinal sectional view of a portion of an ionic vacuum pump embodying an additionally modified form of the invention essentially similar to the arrangement of Fig. 1, similar elements being designated by similar reference numerals, except that the present arrangement includes an electrode 40 of ring configuration positioned between the cathode 18 and the anode 19. The end of the electrode 40 adjacent the cathode 18 is closed by a disc 41 having a central portion constructed as a grid-like structure or the like to be electron permeable. A periodic-pulse wave-generator 42 which generates a potential of periodic-pulse wave form as represented by curve A, has an output circuit coupled between the electrode 40 and the cathode 18. The operation of this modified form of the invention is essentially similar to that of Fig. 1, except that electrons are attracted from the cathode 18 into the region of the anode 19 only during the intervals when the potential wave of the generator 42 has a positive polarity, substantially no electron emission to the region of the anode 19 being permitted during the intervals when the potential wave of the generator 42 has negative polarity. This arrangement not only provides an ionic shield for the cathode 18, in that any ions in the gas-discharge path which are not attracted to the electrode 21 are in large part attracted to the electrode 40 during the relatively long intervals when the latter is negatively biased, but also has the effect of restraining the movements of the reciprocating electrons to that region lying between the electrodes 21 and 40. The duration of the positive pulses of the potential generated by the generator 42 is selected such that sufficient electrons are periodically drawn from the cathode 18 to replace the electrons withdrawn by the anode 19 during an immediately preceding pulse interval.

While the ionic pump of the present invention has heretofore been described and shown as energized throughout by unidirectional energizing potentials, the energization of the ionic pump may be provided by a source of alternating potential as long as the relationships between the potentials applied to the several electrodes are maintained. Fig. 6 represents schematically an ionic pump of the Fig. 1 type energized in the manner last mentioned. Elements of Fig. 6 corresponding to similar elements of Fig. 1 are designated by similar reference numerals. In the present arrangement, a transformer 45 has a primary winding 46 coupled to a source of alternating current having any convenient frequency from that of the commercial alternating current supply mains, such as 60 cycles to a much higher frequency such as a radio frequency, and includes a secondary winding 47 having one end terminal thereof connected to the anode electrode 19 with an adjacent tap on the winding 47 connected to the cathode 18. The winding 47 is provided with additional taps along its length and these are connected in order to the electrodes 21–23, inclusive, the electrode 24 being shown as connected to a tap in common with the electrode 22 and the terminal electrode being shown as connected in common with the electrode 21. The energization of the grouped electrodes 22, 24 and 25, 21 at the same individual potentials is simply shown here in illustration of the statement above made that the terminating terminal or terminals need not necessarily be energized to higher negative potentials than an immediately preceding electrode. While the energization of the electrodes in groups, as here shown, reduces the maximum voltage required of the high voltage supply system, a slight reduction in pumping rate may be experienced for the reason that the ionized gas molecules do not then have as high velocities at the terminal electrode, and thus, are not as effective in propelling by impact any neutral gas molecules which appear along the discharge path. The transformer 45 includes an additional secondary winding 48 which is connected to energize the cathode 18 of the pump and also includes a secondary winding 49 which is connected to supply an energizing current for the electromagnet 20. During those half cycles of the energizing potential which bias the anode 19 positive with respect to the cathode 18, the operation of the ionic pump is essentially similar to that described above in connection with Fig. 1. In the alternate half cycles of the energizing potential, the anode 19 is biased negatively with respect to the cathode 18 so that no electrons are drawn from the latter and the pumping action simply ceases. This, of course, somewhat reduces the pumping efficiency of the ionic pump, but such is not objectionable for many applications.

It will be apparent from the foregoing description of the invention that an ionic pump embodying the invention has a substantially improved efficiency over prior pumps of the ionic type and thus is capable of a faster pumping rate, at any given gas pressure, than has readily been effected heretofore in such pumps. In comparison with the diffusion type of pump, the ionic pump of the present invention has numerous important and outstanding advantages. The ionic pump does not require any coolants or cooling systems either at its inlet or its exhaust ports since it utilizes no vapors therein, thus dispensing with the inconvenience and operating expense consequent upon the use of such coolants. Additionally, the ionic pump may be placed bodily in a baking oven together with a vessel to be evacuated thus substantially to reduce the time required for evacuation by virtue of the fact that the baking oven accelerates the degassing of the walls and elements of the ionic pump in the same manner and at the same time that it degasses the walls of the vessel to be evacuated. This advantage is of particular importance where it is necessary that the vacuum of the low pressure pump be broken each time that a new vessel to be evacuated is connected thereto. Where successive evacuations are accomplished in the manner last suggested, the ionic vacuum pump has the important advantage that its vacuum may be broken immediately after the evacuation step is completed since the cathode thereof is simply de-energized and immediately cools to a safe temperature, thus completely avoiding the prolonged cooling-down period required of the diffusion pump under similar circumstances. There is the further important advantage with the ionic vacuum pump that, should the vacuum be accidentally broken while the pump is operating, the only effect will be to destroy the cathode of the pump but provision may readily be made for quickly employing a new cathode to enable the pump to be immediately placed again in service so that no prolonged delay will be encountered as occurs with the diffusion pump where, under the same circumstances, it is necessary to disassemble the diffusion pump and thoroughly clean it before placing it again in operation.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, means for providing a flow of electrons directed into said gas-discharge path to ionize gas molecules therein, and means tending to confine the movement of said electrons to provide an electron stream in said discharge path and co-operating with said first-mentioned means to cause a substantial number of said electrons each repeatedly to traverse said electron stream in longitudinal forward and backward direction therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, said last-mentioned means including means for attracting said ionized gas molecules toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

2. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, means for providing a flow of electrons directed into said gas-discharge path to ionize gas molecules therein, means for developing a magnetic field tending to confine the movement of said electrons to provide an electron stream in said discharge path, and means co-operating with both of said aforementioned means to cause a substantial number of said electrons each repeatedly to traverse said electron stream in longitudinal forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, said last-mentioned means including means for attracting said ionized gas molecules toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

3. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, means for providing a flow of electrons directed into said gas-discharge path to ionize gas molecules therein, and means tending to confine the movement of said electrons to provide an electron stream in said discharge path and co-operating with said first-mentioned means to cause a substantial number of said electrons each repeatedly to traverse said elector stream in longitudinal forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, said last-mentioned means including means for attracting said ionized gas molecules along said discharge path toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

4. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, means for providing a flow of electrons directed into said gas-discharge path to ionize gas molecules therein, and means tending to confine the movement of said electrons to provide an electron stream in said discharge path and co-operating with said first-mentioned means to cause a substantial number of said electrons each repeatedly to traverse said electron stream in longitudinal forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, said last-mentioned means including means for attracting said ionized gas molecules with a progressively increasing velocity along at least a portion of said discharge path to render them potentially accessible for evacuation by said external pump.

5. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, means for providing a flow of electrons directed angularly into said discharge path for ionizing gas molecules therein, and means tending to confine the movement of said electrons to provide an electron stream in said discharge path and co-operating with said first-mentioned means to cause a substantial number of said electrons each repeatedly to traverse said electron stream in forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, said last-mentioned means including means for attracting said ionized gas molecules toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

6. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, means for providing a flow of electrons directed angularly into said discharge path to ionize gas molecules therein, said means being disposed to one side of said gas-discharge path to minimize any obstruction presented thereby to the free flow of said gas molecules through said path, and means tending to confine the movement of said electrons to provide an electron stream in said discharge path and co-operating with said first-mentioned means to cause a substantial number of said electrons each repeatedly to traverse said electron stream in forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in

said discharge path by the repeated traversals of said electrons therethrough, said last-mentioned means including means for attracting said ionized gas molecules toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

7. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, a source of electrons, a positively energized electrode for producing a flow of electrons from said source directed into said gas-discharge path to ionize gas molecules therein, means tending to confine the movement of said electrons to provide an electron stream in said discharge path, and a negatively energized electrode co-operating with said source and said positively energized electrode for causing a substantial number of said electrons each repeatedly to traverse said electron stream in forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, said negatively energized electrode being also effective to attract said ionized molecules toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

8. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, a source of electrons, a positively energized electrode for producing a flow of electrons from said source directed into said gas-discharge path to ionize gas molecules therein, means for developing a magnetic field tending to confine the movement of said electrons to provide an electron stream in said discharge path, and a plurality of negatively energized electrodes spaced along said discharge path between said electrode and said outlet port, said electrodes and said source co-operating with said means to cause a substantial number of said electrons each repeatedly to traverse said electron stream in forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, at least certain of said negatively energized electrodes being energized progressively to higher negative potentials toward said outlet port to attract said ionized gas molecules with progressively increasing velocity toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

9. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, a source of electrons, means for producing relative to said source and along said gas-discharge path a positive-potential gradient increasing rapidly to a first point relatively close to said source and then decreasing more slowly from said first point to a second point relatively remotely situated from said source for producing a flow of electrons from said source directed into said gas-discharge path to ionize gas molecules therein, means tending to confine the movement of said electrons to provide an electron stream in said discharge path, and means for producing relative to said source and along said gas-discharge path a negative-potential gradient extending from said second point to a third point more remotely situated from said source, said last-mentioned means co-operating with said first-mentioned means for causing a substantial number of said electrons each repeatedly to traverse said electron stream in forward and backward directions therealong to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough and being effective to attract said ionized molecules toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

10. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, said chamber providing a gas-discharge path between said inlet and outlet ports, a source of electrons, a plurality of electrodes spaced along said gas-discharge path from the vicinity of said source and energized to individual positive potentials of progressively increasing magnitude in the direction toward said source for producing a flow of electrons from said source directed into said gas-discharge path to ionize gas molecules therein, means tending to confine the movement of said electrons to provide an electron stream in said discharge path, and a negatively energized electrode co-operating with said source and said positively energized electrodes for causing a substantial number of said electrons each repeatedly to traverse said electron stream in forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, said negatively energized electrode being also effective to attract said ionized molecules toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

11. An ionic vacuum pump comprising, a housing having a chamber and including an inlet port for connecting said chamber to a device to be evacuated and an outlet port for connecting said chamber to an external vacuum pump, an electrically closed ring of electron-emissive material, supporting means having a relatively low thermal transmission characteristic for supporting said ring within said housing, means inductively coupled to said ring for energization thereof to effect electron emission therefrom, means co-operating with said ring for producing a flow of electrons therefrom directed into said gas-discharge path to ionize gas molecules therein, and means tending to confine the movement of said electrons to provide an electron stream in said discharge path and co-operating with said last-mentioned means to cause a substantial number of said electrons each repeatedly to traverse said electron stream in forward and backward directions therealong, thereby substantially to increase the probability of ionization of additional molecules in said discharge path by the repeated traversals of said electrons therethrough, said last-mentioned means including means for at-

tracting said ionized gas molecules toward said outlet port to render them potentially accessible for evacuation by said external vacuum pump.

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