April 28, 1953 E. A. HERTZLER 2,636,664

HIGH VACUUM PUMPING METHOD, APPARATUS, AND TECHNIQUES

Filed Jan. 28, 1949 3 Sheets-Sheet 1

Fig. 1.

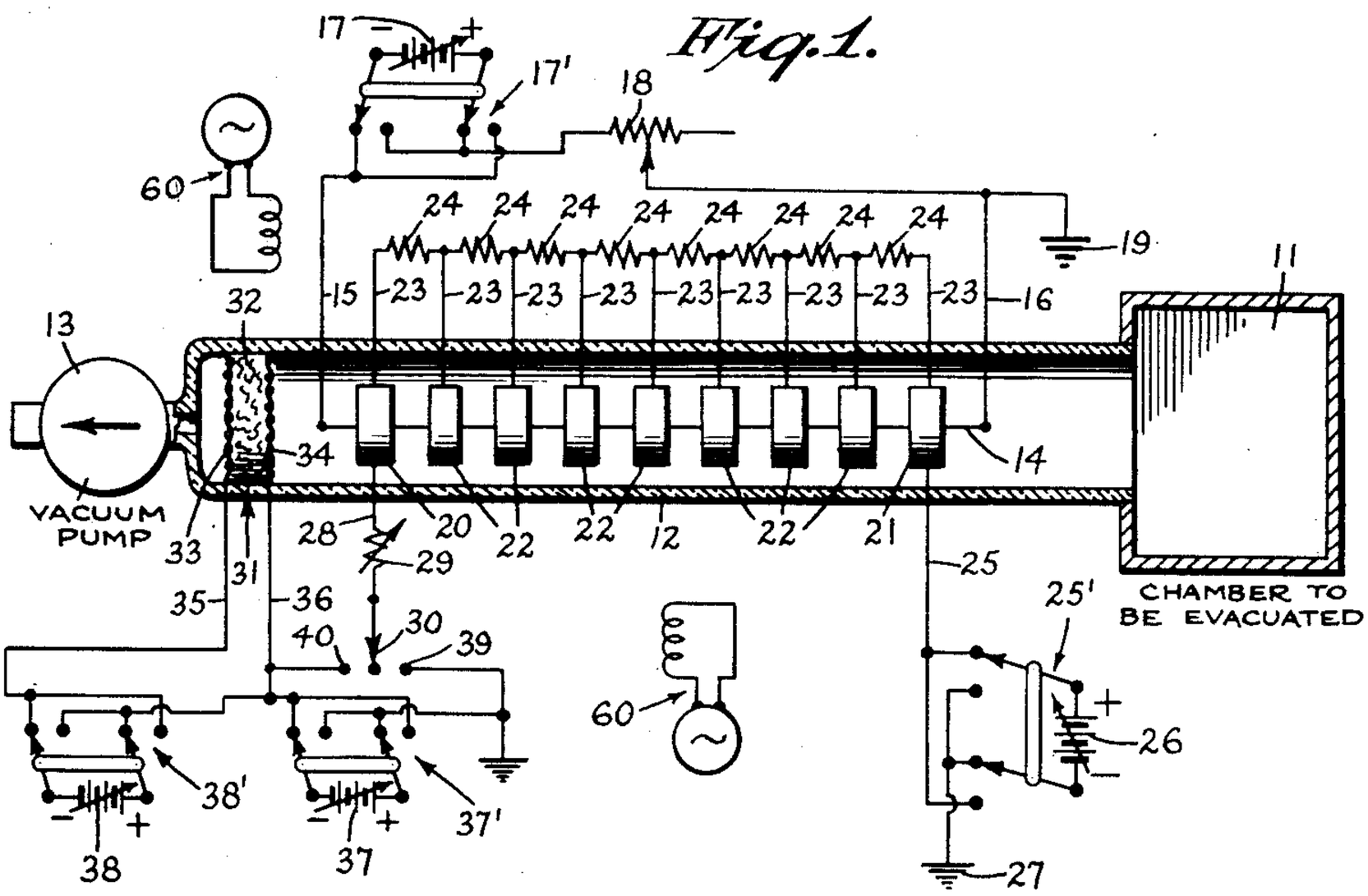


Fig. 2.

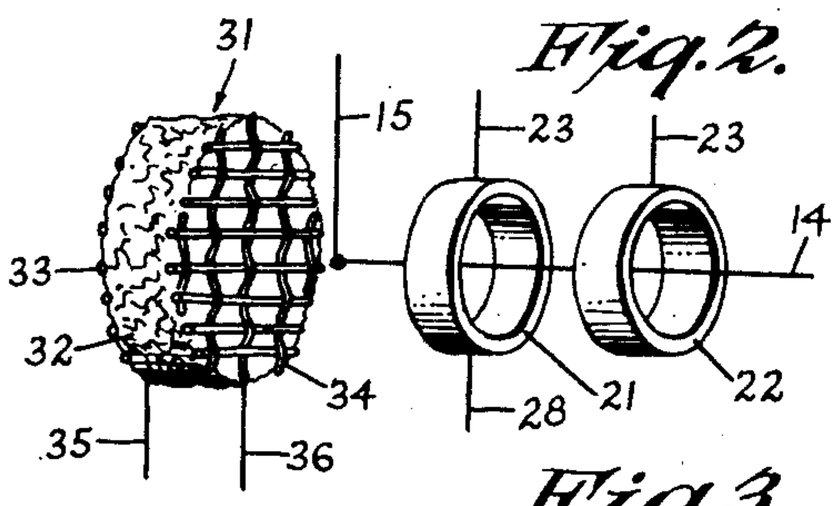


Fig. 3.

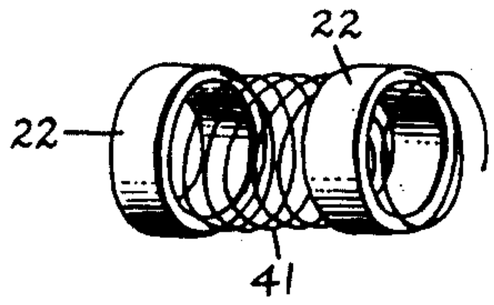
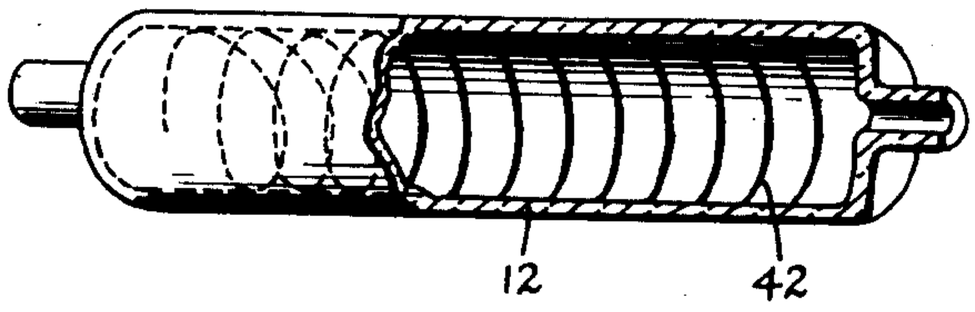


Fig. 4.



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HIGH VACUUM PUMPING METHOD, APPARATUS, AND TECHNIQUES

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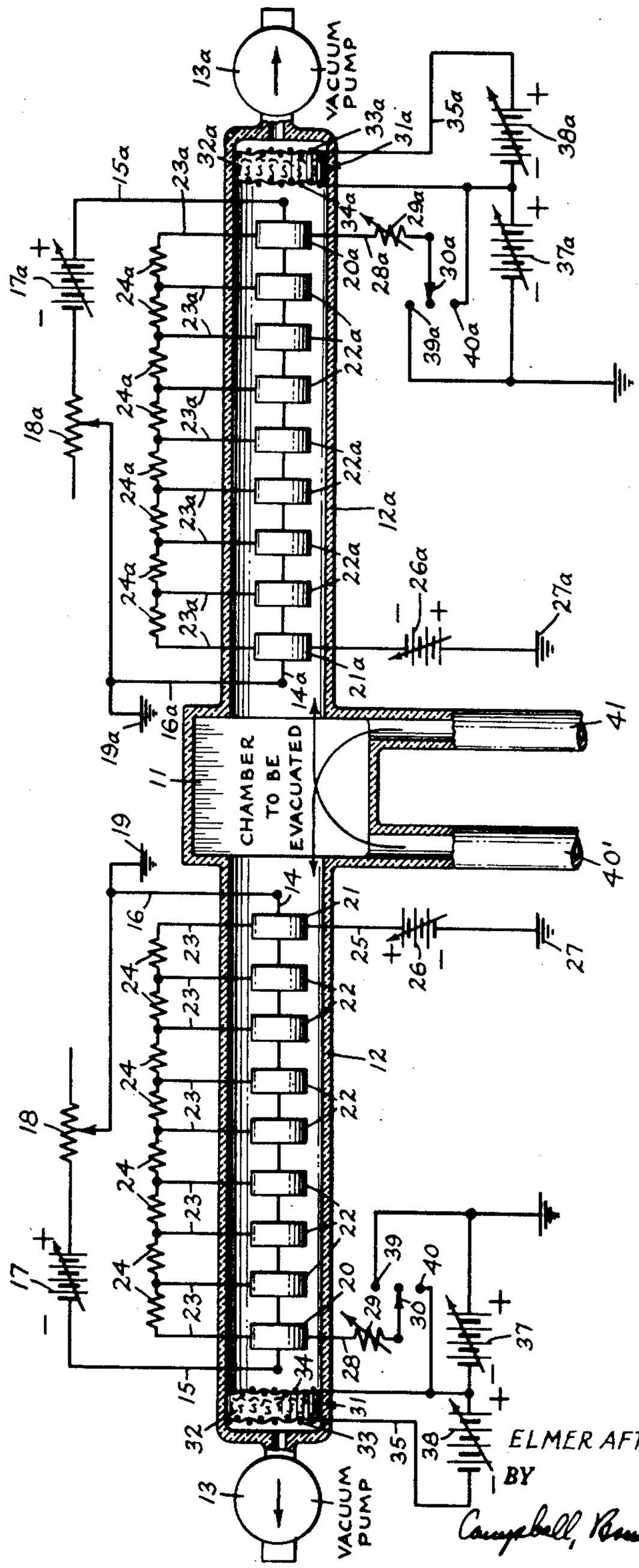
Fig. 5.



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HIGH VACUUM PUMPING METHOD, APPARATUS, AND TECHNIQUES

Filed Jan. 28, 1949 3 Sheets-Sheet 3

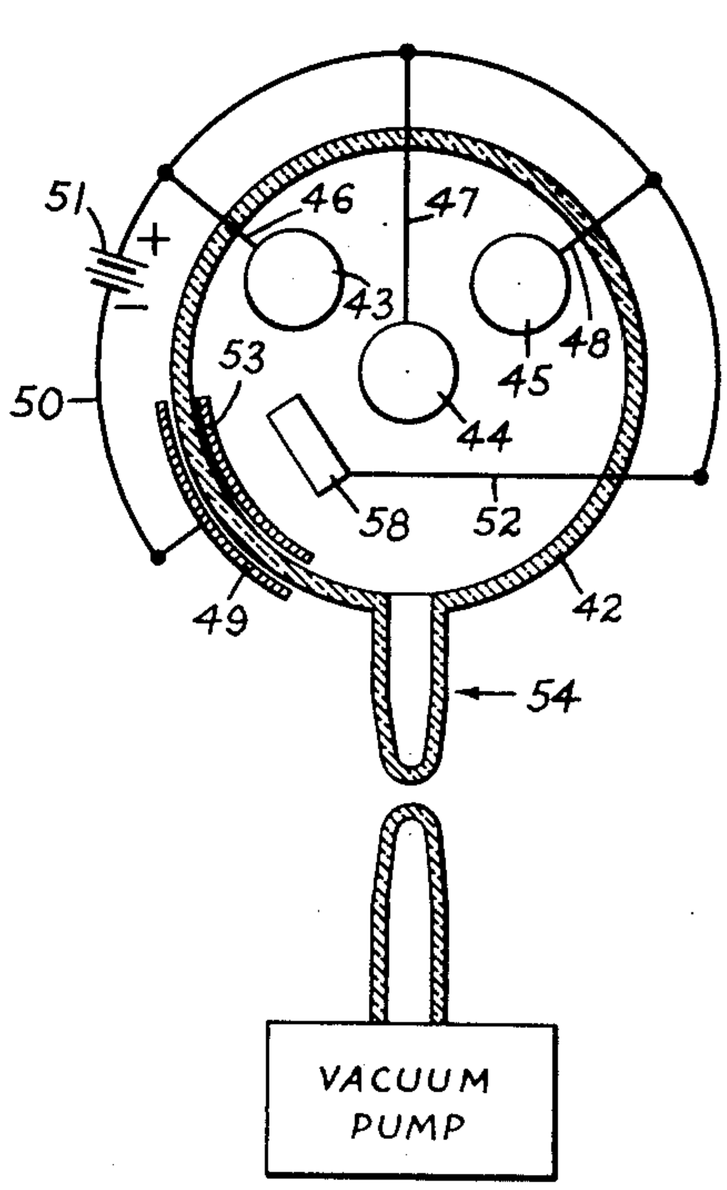

Fig. 6.

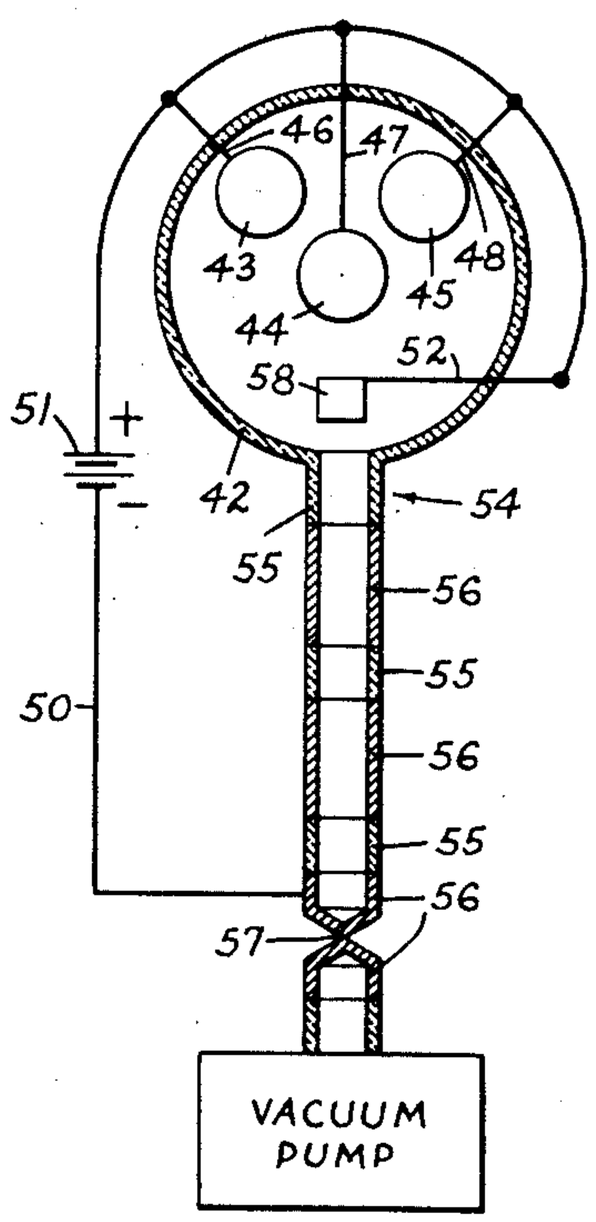

Fig. 7.

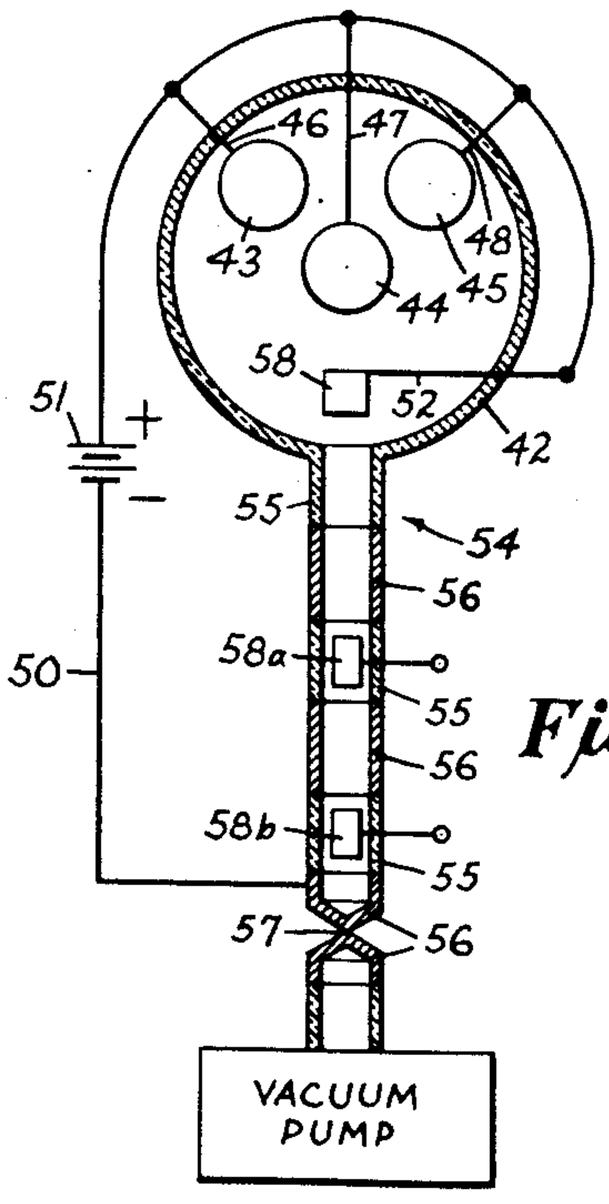

Fig. 8.

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Patented Apr. 28, 1953

2,636,664

UNITED STATES PATENT OFFICE

2,636,664

HIGH VACUUM PUMPING METHOD, APPARATUS, AND TECHNIQUES

Elmer Afton Hertzler, Brooklyn, N. Y.

Application January 28, 1949, Serial No. 73,318

13 Claims. (Cl. 230—1)

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The present invention relates to pumping methods and apparatus and more particularly to new and improved pumping methods and apparatus that are of exceptional utility at pressures approaching absolute vacuum.

At the present time, both mechanical and diffusion pumps are used for evacuating vessels to low pressures, i. e. pressures approaching absolute vacuum. The degree of vacuum obtainable with the former ranges from 10^{-2} to 10^{-4} mm. mercury, and pressures as low as 10^{-7} mm. mercury can be obtained with the latter. In commercial operations such as the manufacture of radio tubes, for example, it is customary to use diffusion pumps to obtain a relatively high degree of vacuum and then to employ so-called "getters" for the purpose of making residual gases inactive. However, it has not been possible, with these devices, to secure a vacuum greater than 10^{-8} mm. mercury, even under the best conditions.

It is an object of the invention, accordingly, to provide new and improved methods and apparatus for effectively evacuating a vessel to a much lower pressure than has been possible heretofore.

Another object of the invention is to provide new and improved pumping apparatus which is capable of acting separately and independently on individual molecules of a gas in a vessel.

According to one feature of the invention, the individual molecules of a gas are subjected to forces which cause them to move in a predetermined direction. The direction of travel may be for the purpose of circulating the gas molecules or for urging relatively widely separated molecules away from a vessel to be evacuated. More specifically, gas molecules in the vessel are ionized in any suitable manner as by collision with electrons, for example, positive and/or negative ions being formed in the process. These charged ions are subjected to a potential gradient which forces them to move in a desired direction which may be out of the vessel, for example. In this fashion, positive or negative ions may be directed to suitable baffle means where they may be concentrated to a density sufficient to be acted upon by conventional vacuum pumping means.

In one modification, an electromagnetic field may be employed to control the direction of movement of the colliding electrons and of the positive and/or negative ions produced when the electrons collide with gas molecules. By virtue of this construction, the probability of any gas

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molecule being struck is increased, and any tendency of the ions to follow random paths is reduced.

Obviously, either positive or negative ions can be removed by assigning the proper polarity to the potential gradient to which the gas molecules are subjected. Also, both kinds of ions can be removed simultaneously by establishing in the device two potential gradients of opposite polarites, as will be described hereinafter. The invention also provides means for removing any uncharged or neutral particles that may be present.

According to another feature of the invention, a vessel is evacuated to a very high degree of vacuum by utilizing the method outlined briefly above to produce a concentration of gas ions at a predetermined location, and then removing the concentrated gas ions by means of new and improved "getter" techniques.

It will be apparent, therefore, that the invention enables a vessel to be evacuated to a considerably higher degree of vacuum than has been possible heretofore. By ionizing the gas molecules and utilizing a potential gradient, with or without a magnetic field, to force the gas ions to move in a desired direction, more of such residual molecules can be removed than is possible with any prior apparatus. As a result, a degree of vacuum can be secured which is of the order of one thousand or more times the best degree of evacuation hitherto thought to be obtainable.

Additional objects and advantages of the invention will be apparent from the following detailed description of several typical embodiments, taken in conjunction with the accompanying drawings, in which:

Fig. 1 is a schematic diagram, partly in section, of pumping apparatus constructed according to the invention;

Fig. 2 is an enlarged fragmentary view, in perspective, of a portion of the apparatus shown in Fig. 1;

Fig. 3 is a fragmentary view, also in perspective, of a modified form of the invention;

Fig. 4 is a fragmentary perspective view of another modification;

Fig. 5 is a schematic diagram of another embodiment designed to act upon both positive and negative particles in a vessel;

Fig. 6 illustrates schematically a typical way of evacuating a chamber in accordance with the invention;

Fig. 7 is a schematic diagram of a modified

form of evacuating technique embodying the invention; and

Fig. 8 is a schematic showing of another modification of the technique illustrated in Fig. 7.

Referring to Fig. 1, a chamber 11, which is to be evacuated, is connected through an enclosure 12, which may be cylindrical in shape, for example, to a conventional vacuum pump 13. The latter may be of any desired and well known form of construction and it need not be described in detail herein.

The pump 13 is used to evacuate the chamber 11 to the degree obtainable with pumps of known and conventional construction, which may be, say, 10^{-8} mm. mercury, for example. After evacuation in this manner, a certain number of gas molecules will still remain within the closed system comprising the chamber 11 and cylindrical pump enclosure 12. These molecules move in the ordinary random manner of gas molecules and if a few of them should be drawn off by the pump 13, the effect on the remaining molecules will be relatively slight.

In order to concentrate the remaining molecules and to urge them toward the pump 13, the molecules may be ionized by collision with electrons provided by an electrical conductor 14 which may extend longitudinally within the cylindrical enclosure 12 substantially along the axis thereof. The conductor 14 is shown supported by the lead wires 15 and 16 which extend to the exterior of the enclosure 12. The enclosure 12 may be made of glass, for example, in which event the lead wires 15 and 16 should preferably be made of a material having an appropriate thermal coefficient of expansion. The conductor 14 may be heated by any suitable source of electrical energy such as a battery 17, for example, through a reversing switch 17', its temperature being controllable in any appropriate manner as by a variable resistor 18 included in the circuit of the lead wire 15. The lead wire 16 is shown grounded at 19. The surface of the conductor 14 may be treated in any suitable manner to render it highly emissive of electrons.

Ions thus produced in the chamber 11 and/or the cylindrical pump enclosure 12 are caused to move in a desired direction by subjecting them to an electric field of suitable potential gradient to effect this result. The electric field may be produced in any desired manner, as for example, by disposing a plurality of annular anodes comprising end anodes 20 and 21 and intermediate anodes 22 in spaced relationship along the interior of the cylinder pump enclosure 12, substantially concentrically both with respect to the conductor 14 and to the enclosure 12. Extending from each of the annular anodes 20, 21 and 22 is a lead wire 23, each pair of adjacent lead wires 23 being shown connected together through a resistor 24.

The anode 21 is shown connected by a further lead wire 25 through a suitable reversing switch 25' to the positive terminal of a suitable source of anode potential indicated diagrammatically as a battery 26, the negative terminal of which is shown grounded at 27. The other end anode 20 is shown connected by a lead wire 28 through an adjustable resistor 29 to a three-position switch 30.

At one end of pump enclosure 12 is shown a baffle 31 (Figs. 1 and 2) which may comprise, for example a disc of ion permeable material 32 interposed between two grid-shaped electrodes 33 and 34 from which lead wires 35 and 36, respectively, extend to the exterior of pump enclosure 12. The ion permeable material 32 may be any suitable porous material capable of withstanding the potential difference between the electrodes 33 and 34, such as glass wool, for example. The grid 34 is shown maintained negative with respect to ground by a suitable source of potential indicated as a battery 37, and the grid 35 is maintained at a potential more negative than the grid 34 by means indicated diagrammatically as a further battery 38, suitable reversing switches 37' and 38' being provided to facilitate the reversal of the potentials applied to the grids 34 and 33, respectively.

In operation, let it be assumed that the switch 25' is positioned as shown in Fig. 1, so that a positive potential is impressed upon the conductor 25 with respect to ground; the switch 30 is in the neutral position as shown; and the switches 37' and 38' are in the positions shown so that the grid 33 is made more negative than the grid 34, while the latter is also negative with respect to ground. Under these conditions, electrons emitted by the filament 14 are attracted to the several anodes 20, 21 and 22 by reason of the positive potential applied thereto by the source 26. In the case of the intermediate anodes 22 and the end anode 20, the resulting current flow reduces the magnitude of the positive potential by reason of the cumulative potential drops in the several resistors 24. This renders the end anode 20 negative with respect to the other end anode 21, the intermediate anodes 22 being negative with respect to end anode 21 in varying degrees depending upon the number of intervening resistors 24. This establishes a potential gradient within cylindrical enclosure 12 such that the left end is appreciably more negative than the right end.

The switch 17' should preferably be positioned as shown in Fig. 1, so that the left end of conductor 14 is connected to the negative terminal of source 17. When so connected, if the conductor 14 is heated from a unidirectional current source, the potential gradient along its length will be in the same direction as that established by the anodes, although not necessarily of the same magnitude.

The sources of potential difference 26, 37 and 38 should preferably be variable (adjustable) because the ionization potential or potentials of the gases within the chamber and within the cylindrical pump enclosure 12 will be quite different for different pressures of the gases. By way of example, the several potentials supplied by the sources 26, 37 and 38, respectively, might be continuously and independently variable (adjustable) from zero to say 100,000 volts. These values are not critical but can be varied depending upon the operating conditions desired.

Some of the electrons which are emitted from the conductor 14 strike gas molecules in traveling toward the anodes. These collisions liberate electrons from the gas molecules causing them to become positively charged ions. These positive ions are acted upon by the potential gradient within pump enclosure 12 and are urged toward the left end thereof, away from the chamber 11 which is to be evacuated. It will be apparent that it is not necessary for the molecules to be present in sufficient numbers to build up any gas pressure as in pumps hitherto known. It will suffice if the structure is so arranged that the probability of every molecule within the pump enclosure 12 being struck by an electron and

thereby becoming ionized is relatively high. As soon as the gas is ionized, each positive gas ion will be urged leftwardly toward the outlet end of the pump.

On traveling toward the left, the positive ions will be drawn towards the baffle 31 by reason of the additional negative potential applied to electrode 34. Upon reaching the ion permeable mass 32, the ions will be drawn towards the electrode 33 to which a further negative potential is applied by the battery 38. The ions will thus be drawn through the mass 32 with their freedom of movement restricted and their velocity retarded so that they may no longer recirculate within the pump enclosure 12. After traversing the mass 32 they may be deionized and form neutral gas molecules, and these gas molecules may concentrate to a density sufficient to be acted upon by the conventional vacuum pump 13.

Under the conditions described, the values of the several resistors 24 may be proportioned to obtain the desired potential gradient in the presence of current flow resulting from the attraction of electrons by the anodes 20, 21 and 22. If desired, however, the switch 30 may be positioned to the right so that it makes contact with the contact 39. This establishes a circuit from the source 26 through the conductor 25, the resistors 24 and the adjustable resistor 29 to ground. The resistor 29 may then be so adjusted that a potential gradient will be obtained even in the complete absence of current flow resulting from the attraction of electrons by the several anodes. An even greater negative potential may be applied to the anode 20 by throwing the switch 30 to the left, thereby establishing contact with the contact 40 which is connected to the negative terminal of the source 37.

Fig. 3 shows a modified form of the invention utilizing an electromagnetic field which is preferably directed longitudinally of the conductor 14. This field, in combination with the electric field, tends to cause the electrons emitted by the conductor 14 to travel in substantially linear paths towards the right, whereas the positive ions tend to move in similar linear paths extending towards the left. The former condition increases the probability of any gas molecule being struck. Similarly, the latter condition reduces any tendency of positive ions to follow random paths.

The magnetic field may be obtained in any suitable manner as by positioning one or more coils 41 (Fig. 3) intermediate adjacent anodes, for example. The coil 41 is shown diagrammatically as comprising a relatively few turns. In practice, however, it may consist of a relatively large number of turns of fine resistance wire, thus serving both as a coil and as one of the resistors 24. The coil should preferably be built up of materials whose properties do not tend to cause adherence or retention of gas molecules.

In Fig. 4 is shown a further modification in which the anodes are replaced by an electrically conductive coating 42 helically applied to the inner surface of the pump enclosure 12. The coating may have electrically resistive properties which result in the production of the desired potential gradient and it may consist of a large number of spaced turns forming the helix, thereby producing a relaitvely strong longitudinal magnetic field. The filament 14 and the various lead wires have been omitted from Figs. 3 and 4 for clarity of illustration.

Preferably the pump comprising the present invention should be kept hot in operation so that

any (all) gas molecules touching any surface within the pump will be given sufficient energy that such gas molecules cannot become occluded upon any surface within the pump, including any (all) inner surfaces of the baffle 31. The pump apparatus may be kept hot in any desired manner as by electric induction heaters 60 (Fig. 1), for example. Also, the conductive coating 42 shown in Fig. 4 may be designed to generate heat. Other heating means will suggest themselves to those skilled in the art.

In some cases, negative ions may be formed by ionization of the gas in the enclosure 12 as where a gas like O_2, N_2 or H_2 is present. Any negative ions thus formed may be removed by reversing the polarity of the potential gradient established by the anodes 20, 21 and 22, at the same time reversing the polarities of the potentials applied to the grids 33 and 34 of the baffle 31. Further, by alternately applying positive and negative potentials for successive periods of time, both positive and negative ions may be removed by means of the apparatus shown in Fig. 1.

It is also possible to remove both positive and negative ions simultaneously by connecting two pump enclosures 12 and 12*a*, designed to remove positive and negative ions, respectively, from a chamber 11 to be evacuated, as shown in Fig. 5. In this figure, the elements associated with the enclosure 12 are substantially identical with those shown in Fig. 1 and are designated by like reference characters. The elements associated with the enclosure 12*a* are also substantially identical with those of Fig. 1, and like parts have been designated by like reference characters with the subscript *a*. The manner of operation of this modification will be readily apparent from the operative description of Fig. 1, which is given above.

If any electrically neutral particles are formed in the chamber 11, in addition to positive and negative ions, such neutral particles may be removed by introducing a positive ion forming gas or vapor such as mercury, for example, into the chamber 11 from a conduit 40' (Fig. 5). Ionization of this gas in the enclosures 12 and/or 12*a* produces positive ions which move leftwardly through each/either of the enclosures 12 and/or 12*a* and through the chamber 11 in Fig. 5 and carry along with them any neutral particles that may be present.

Neutral particles can also be removed by introducing a negative ion producing fluid into the chamber 11 through a conduit 41. Upon ionization of such fluid in each/either of the enclosures 12 and/or 12*a* (Fig. 5) negative ions move towards the right and carry with them neutral particles that may exist in each/either of the enclosures 12 and/or 12*a* and in the chamber 11. Obviously, neutral particles may be removed by simultaneously introducing both positive ion forming and negative ion producing fluids through the conduits 40' and 41, respectively, as shown.

The novel evacuating procedures described above may be combined with new and improved getter techniques, as shown in Fig. 6, to achieve a degree of vacuum higher than is possible with existing methods. In Fig. 6 is shown a vessel 42 which is to be evacuated to a high degree of vacuum. The vessel 42 may be, for example, the glass envelope of an electron tube having one or more electrodes 43, 44 and 45 provided with leads 46, 47 and 48, respectively, extending through the wall of the chamber 42 to the exterior thereof.

According to the invention, an electrode 49 is placed over a portion of the outer wall of the chamber 42 corresponding approximately to the area over which the getter material is to be deposited. The electrode 49 is connected by a conductor 50 to the negative terminal of a suitable source 51 of high voltage D. C., the positive terminal of which is connected to the leads 46, 47 and 48 of the electrodes 43, 44 and 45, respectively. Also mounted within the chamber 42 and connected by a conductor 52 to the positive terminal of the source 51 is a getter holder 58. The latter is so mounted that when the getter is flashed, the getter material will be deposited upon the inner wall of the chamber 42 directly under the electrode 49.

In operation, the chamber 42 is first evacuated to a relatively high degree of vacuum by any known pumping means connected to the exhaust tube 54. A D. C. potential of several thousand volts negative (6,000 volts has given very satisfactory results in receiving size electron tubes) is then applied to the electrode 49 by the source 51. This causes a strong negative charge to be induced on the inside wall of the chamber 42 beneath the electrode 49. Meanwhile, the electrodes 43, 44 and 45, and the wall of the chamber 42 (except where the getter deposit is formed) are being heated by suitable means such as, for example, an electric induction heater or Bunsen burner, to drive off and to ionize occluded gases. The positive gas ions thus formed are influenced by the electric field existing in the chamber 42 and move to the region of the inner wall thereof directly under the electrode 49. The getter is then flashed in the usual manner. Since the getter particles are positively charged, they also tend to move toward the wall area under the electrode 49, under the influence of the electric field.

Since the unwanted gas molecules in the chamber 42 are also concentrated at the region of the inner wall beneath the electrode 49 when the flashed getter particles arrive there, a thorough mixing of the getter and the gas takes place. In addition, the concentration of gas molecules is trapped and held between the getter deposit 53 and the inner wall of the chamber 42. This results in a much higher degree of vacuum than is obtainable with the standard methods now employed. Furthermore, the undesired gas is held more firmly by the getter than it is when the gas is merely occluded upon the inner surface of the getter deposit 53, as in the usual practice.

Obviously, the same results can be achieved by mounting the electrode 49 on the inside wall of the chamber 42, a connection being made therefrom to an external terminal through the wall of the chamber 42. In this case, the gas and the getter will both be deposited upon the electrode 49.

In the modification shown in Fig. 7, the exhaust tube 54 is made of alternate sections of glass tubing 55 and copper tubing 56. In this embodiment, the vacuum within the chamber 42 is reduced to the lowest possible degree obtainable with a standard vacuum pump, whereupon the copper tubing 56 is pinched at 57 to close and seal off the exhaust tube 54. As before, the chamber 42 and the elements contained therein are heated to drive off, and to ionize occluded gas. With the getter holder 58 aimed towards the exhaust tube 54 and the negative terminal of the D. C. source 51 connected to the pinched off segment 56 of copper tubing, the getter is flashed in the usual manner. As a result of this action, the unwanted gas molecules are trapped on the inside wall of the lowermost segment 56 of copper tubing, where the flashed getter material is deposited. By pinching the next segment of copper tubing 56 directly above the initial pinch, these trapped molecules can be removed.

If, after operation for a period of time, some gas molecules leak into the chamber 42, the getter can be flashed again and the next segment 56 of copper tubing pinched to remove trapped gas molecules and restore the vacuum to its original high condition.

As a further modification, additional getter holders 58*a* and 58*b* may be placed at different positions within the exhaust tube 54 where they can be flashed at different subsequent times to restore the desired vacuum conditions to the chamber 42 after periods of use, as shown in Fig. 8.

From the foregoing, it will be apparent that the invention provides highly effective methods and apparatus for evacuating a vessel to a high degree of vacuum i. e., a vacuum approaching absolute vacuum. By ionizing gas molecules within the chamber and influencing the ions thus produced with an electric field, the ions may be caused to move in a predetermined direction to a collection point in order that they may be removed. Further, by combining this vacuum pumping procedure with the improved "getter" techniques described above, degrees of vaccum can be secured that are far higher than any obtainable with prior methods and apparatus.

It will be understood that the several representative embodiments described are susceptible of numerous modifications in form and detail within the spirit of the invention. For example, whereas only a single baffle 31 is shown in Fig. 1, in practice, one or more of such baffles might be employed. Also, although the getter techniques illustrated in Figs. 6–8, inclusive, are directed to the inactivation of positive ions, it will be understood that the same techniques with the appropriate polarities, would be applicable to the inactivation of negative ions. Other variations will occur to those skilled in the art. The specific embodiments described, therefore, are not to be regarded as limiting the scope of the following claims.

I claim:

1. In a device of the class described, means for causing the ionization of gas molecules, means for urging the ionized molecules in a predetermined direction, and nonconducting, ion permeable means disposed in the path of said ionized molecules for retaining the ionized molecules after movement in the predetermined direction for a predetermined distance.

2. In a device of the class described, an enclosure, ionization means arranged to ionize gas molecules within the enclosure, means for urging ionized molecules in a predetermined direction within the enclosure, and nonconducting, ion permeable means disposed in the path of said ionized molecules for retaining the ionized molecules after movement in the predetermined direction for a predetermined distance.

3. In a device of the class described, an enclosure, means arranged to ionize gas molecules within the enclosure, electrostatic means for producing a potential gradient within the enclosure for urging the ionized molecules in a predetermined direction and nonconducting, ion permeable

means disposed in the path of said ionized molecules for retaining the ionized molecules after movement in the predetermined direction for a predetermined distance.

4. In a device of the class described, an enclosure, an electron emitter within the enclosure, anode means for accelerating electrons from the emitter to cause ionization of gas molecules within the enclosure upon collision with said electrons, means for urging the ionized molecules in a predetermined direction within the enclosure, and nonconducting, ion permeable means disposed in the path of said ionized molecules for retaining the ionized molecules after movement in the predetermined direction for a predetermined distance.

5. In a device of the class described, the combination of a vessel to be evacuated, a pair of enclosures connected to said vessel, means for ionizing gas molecules in said enclosures, means in one of said enclosures for urging positive ions away from said vessel, nonconducting, ion permeable means disposed in the path of said positive ions for retaining molecules formed therefrom, means in the other of said enclosures for urging negative ions away from said vessel, and nonconducting, ion permeable means disposed in the path of said negative ions for retaining molecules formed therefrom.

6. In a device of the class described, the combination of a vessel to be evacuated, an enclosure connected to said vessel, means for ionizing gas molecules in said enclosure, means for urging ions in said enclosure away from said vessel, nonconducting, ion permeable means disposed in the path of said ions for retaining molecules formed therefrom, and means for introducing an ionizable fluid into said vessel.

7. In a device of the class described, the combination of a vessel to be evacuated, a pair of enclosures connected to said vessel, means for ionizing gas molecules in said enclosures, means in one of said enclosures for urging positive ions away from said vessel, nonconducting, ion permeable means disposed in the path of said positive ions for retaining molecules formed therefrom, means in the other of said enclosures for urging negative ions away from said vessel, nonconducting, ion permeable means disposed in the path of said negative ions for retaining molecules formed therefrom, and means for introducing both positive and negative ion forming fluids into said vessel.

8. In a method of circulating gas molecules, the steps of ionizing said gas molecules, influencing said ionized molecules with an electric field to cause ions to move in a predetermined direction to a reception position, and impeding the movement of said ions at said reception position by directing them to a nonconducting, ion permeable baffle member to produce a concentration of ions thereat.

9. In a method of evacuating a vessel containing gas, the steps of pumping said gas out of the vessel until only relatively few gas molecules remain, ionizing said gas molecules, creating an electric charge on a portion of the inner wall of said vessel, thereby causing ions to collect in the vicinity of said charge, disposing a getter in said vessel, and flashing said getter on said charged portion so as to trap the ions between the flashed getter and said charged portion of the wall of the vessel.

10. In a method of evacuating a vessel having an exhaust tube provided with a metallic portion and containing gas, the steps of pumping out said gas until only relatively few gas molecules remain, ionizing said gas molecules, establishing an electric charge on said exhaust tube metallic portion, thereby causing gas ions to collect thereat, flashing a getter over said collected ions, and pinching off said exhaust tube in the vicinity of said metallic portion to remove said collected gas ions.

11. In a device for moving gas molecules, the combination of an enclosure, an elongated electron emitter in the enclosure, a plurality of tubular electrodes mounted coaxially of said emitter and spaced apart therealong, resistance means electrically connected between adjacent tubular electrodes, a source of electrical energy connected to the emitter and to at least one of said tubular electrodes, a pair of longitudinally spaced apart screen electrodes mounted in said enclosure near one end of said emitter, a body of ion permeable material disposed between said screen electrodes, and means for controlling the potentials of said screen electrodes with respect to a reference potential.

12. A device as defined in claim 11 in which the resistance means electrically connected between adjacent tubular electrodes comprises a magnetizing winding disposed coaxially with respect to the electron emitter so as to establish a magnetic field coaxially of the emitter.

13. In a device of the class described, an enclosure, an electron emitter within the enclosure, anode means for accelerating electrons from the emitter to cause ionization of gas molecules within the enclosure upon collision with said electrons and electrical means connected to said anode means to establish a potential gradient within the enclosure for urging the ionized molecules in a predetermined direction, said anode means comprising helical coil means wound about an axis extending in said predetermined direction.

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