Sept. 2, 1958 R. G. HERB 2,850,225

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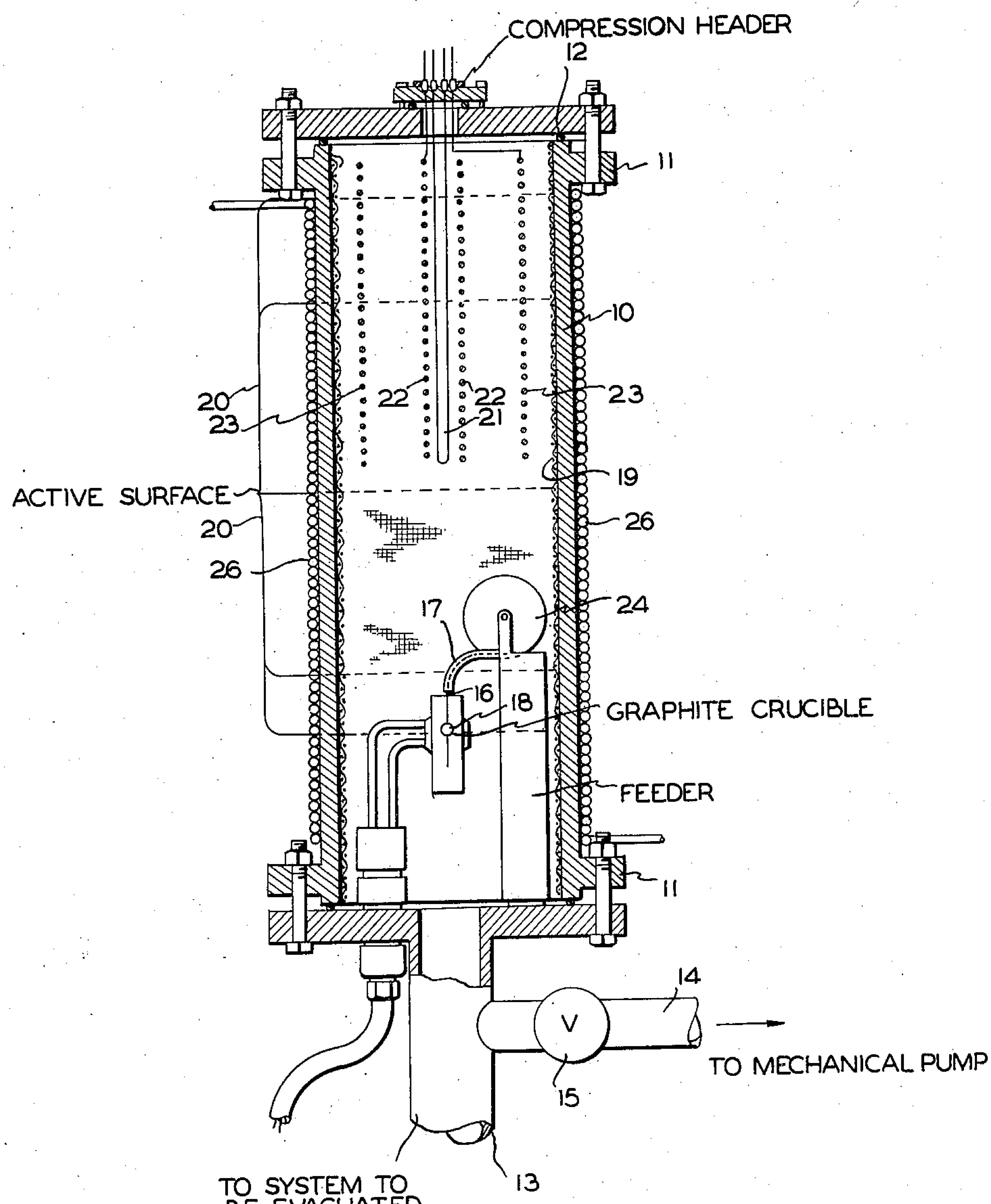
FIG. 1.



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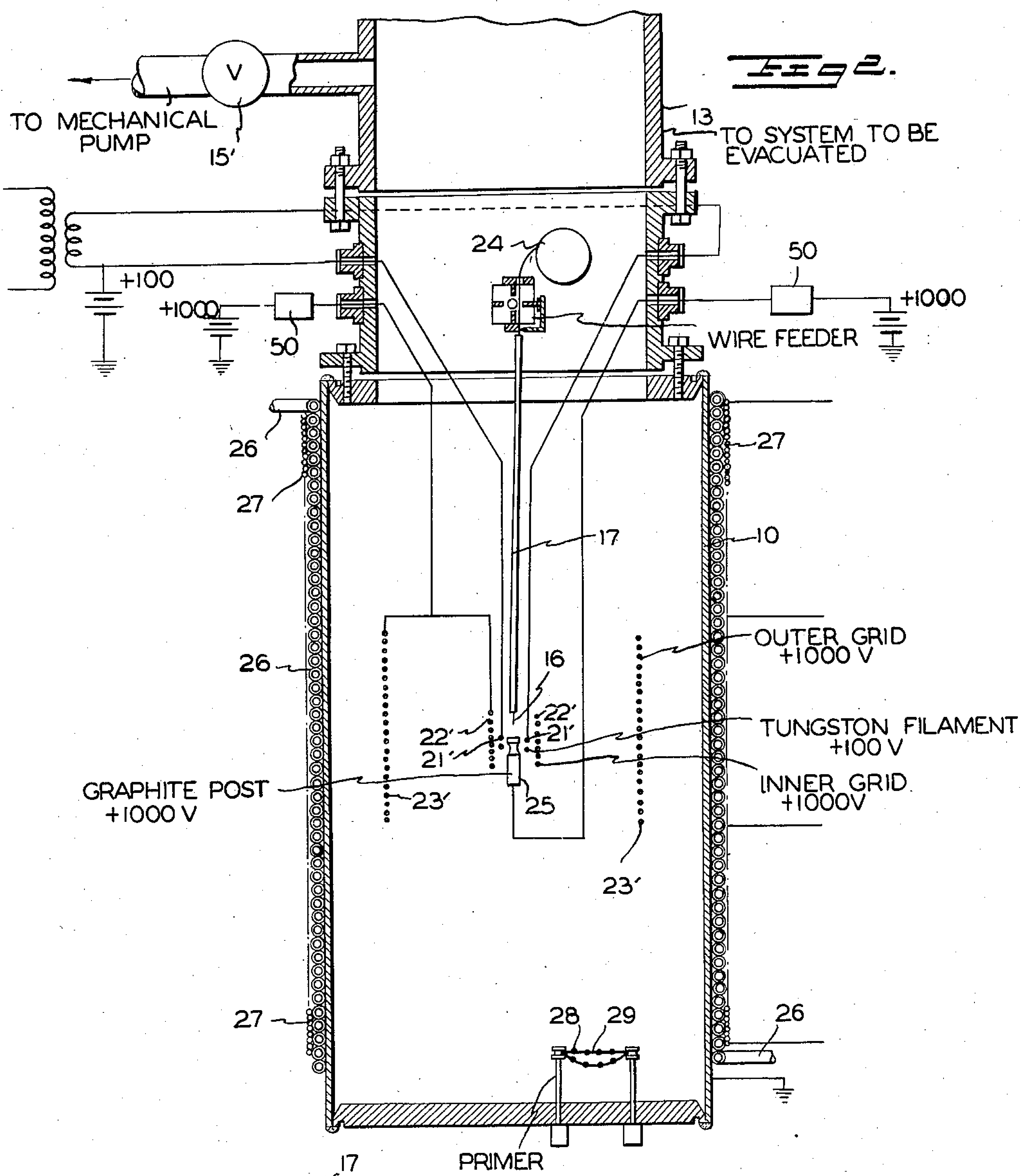

FIG. 2.

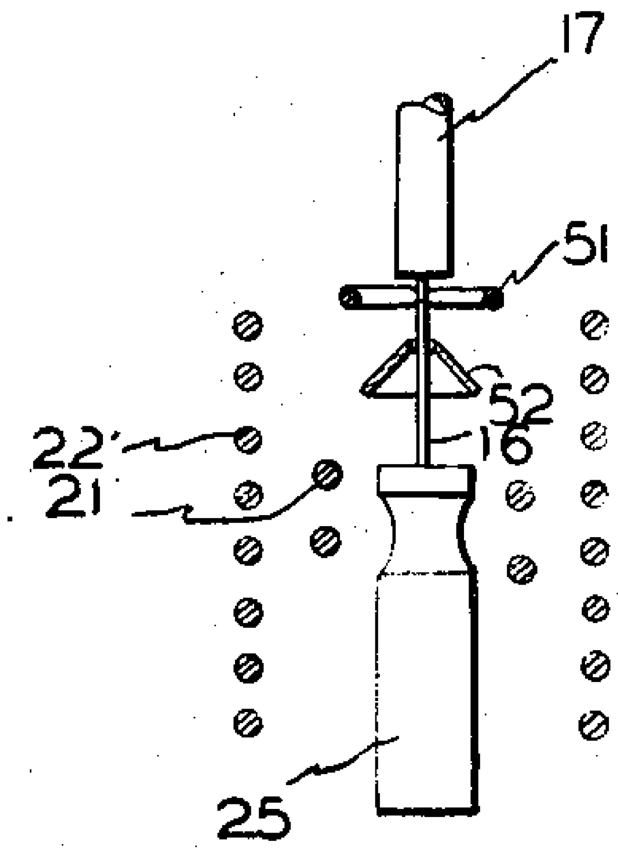

FIG. 3.

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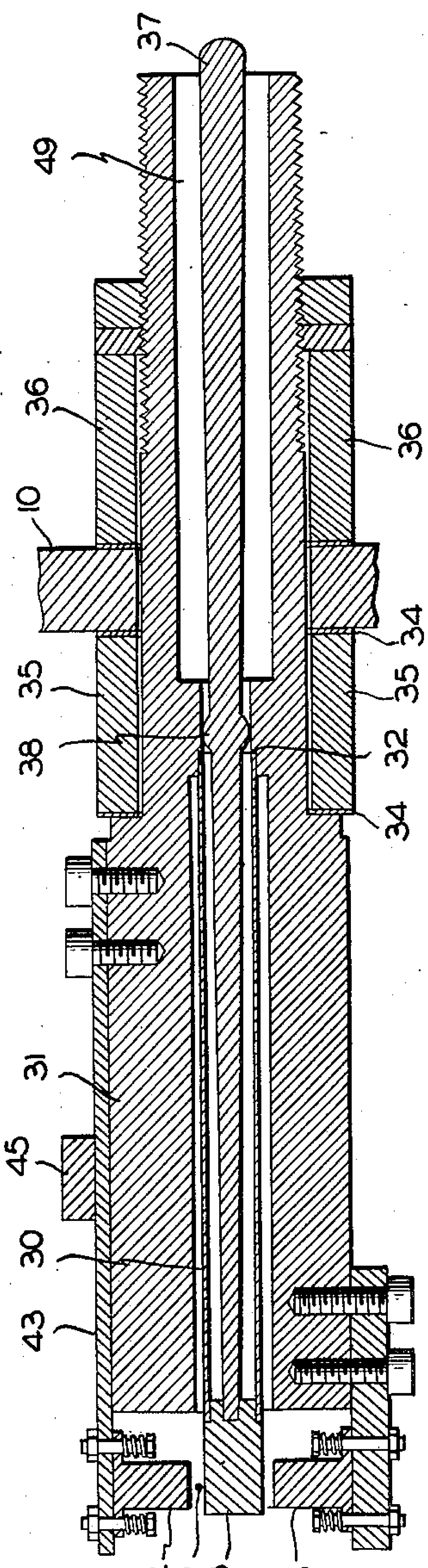

FIG. 4.

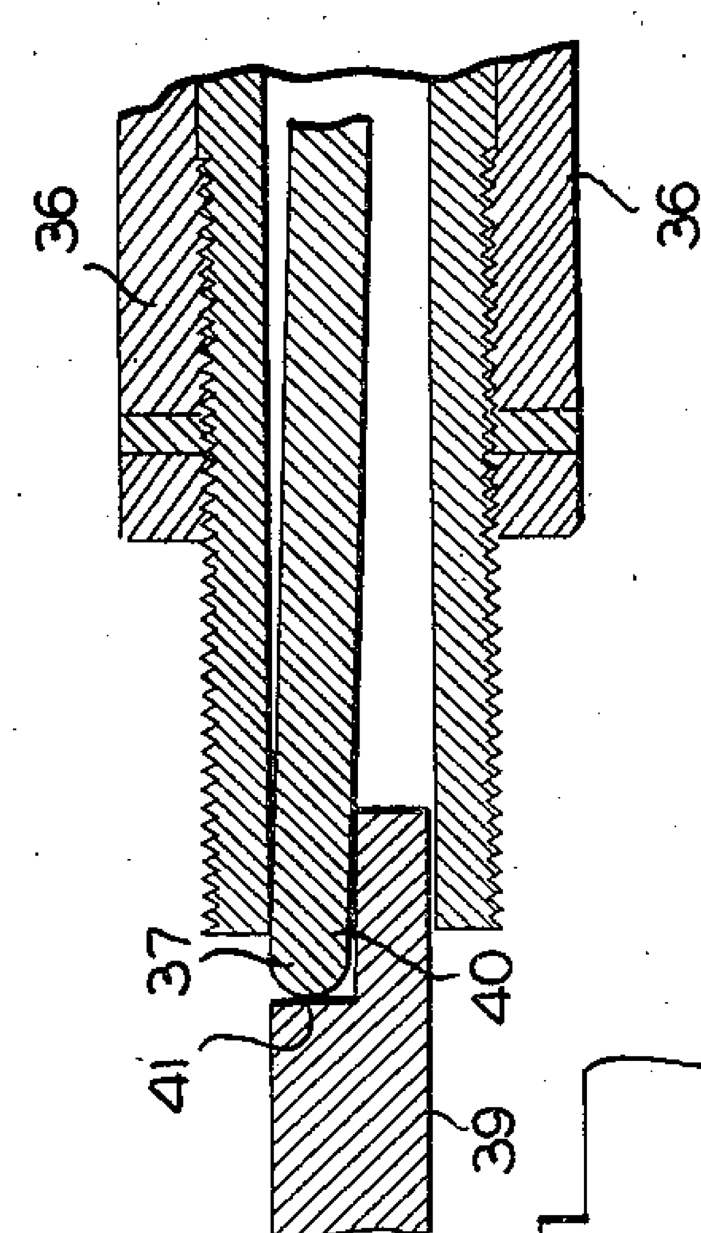

FIG. 6.

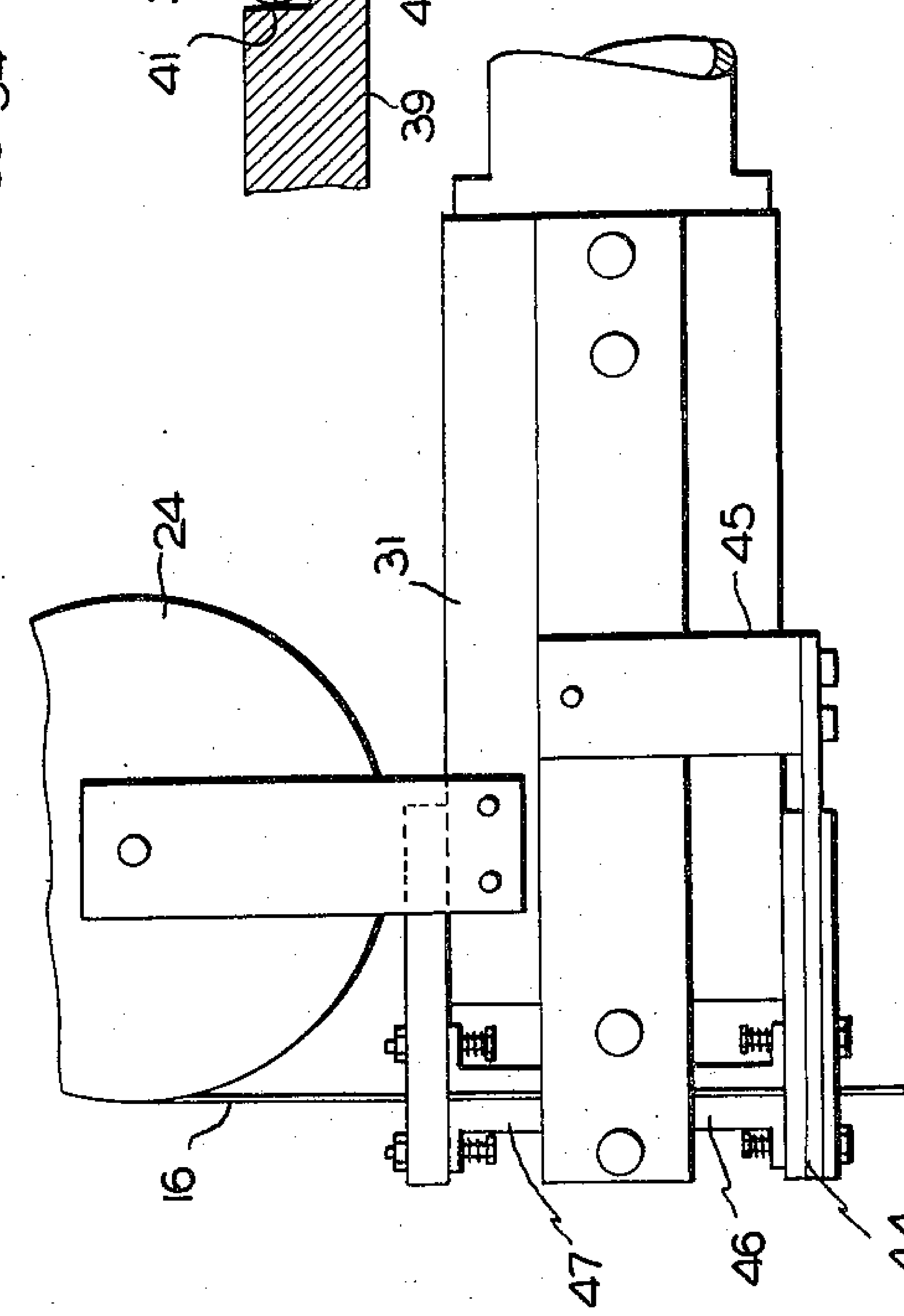

FIG. 5.

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FIG. 7.

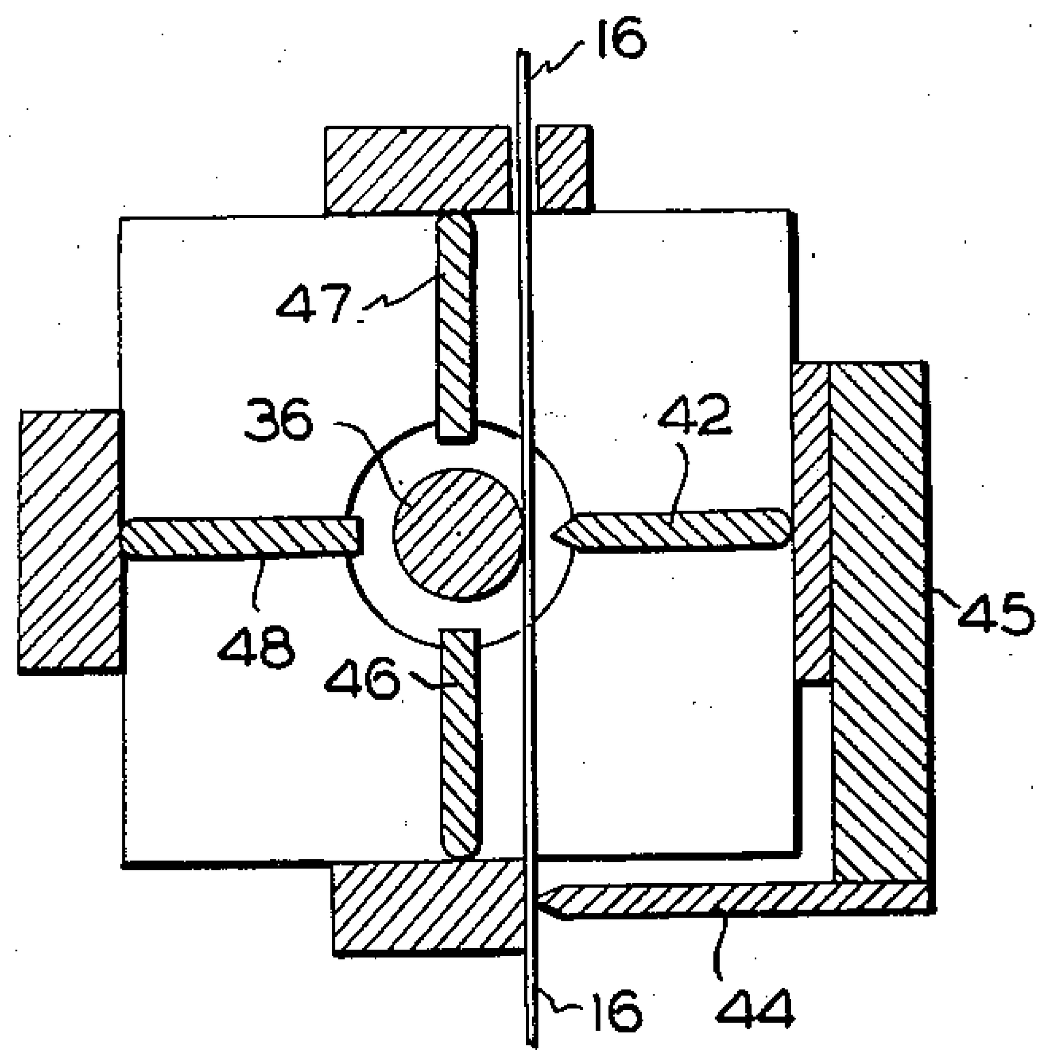


FIG. 8.

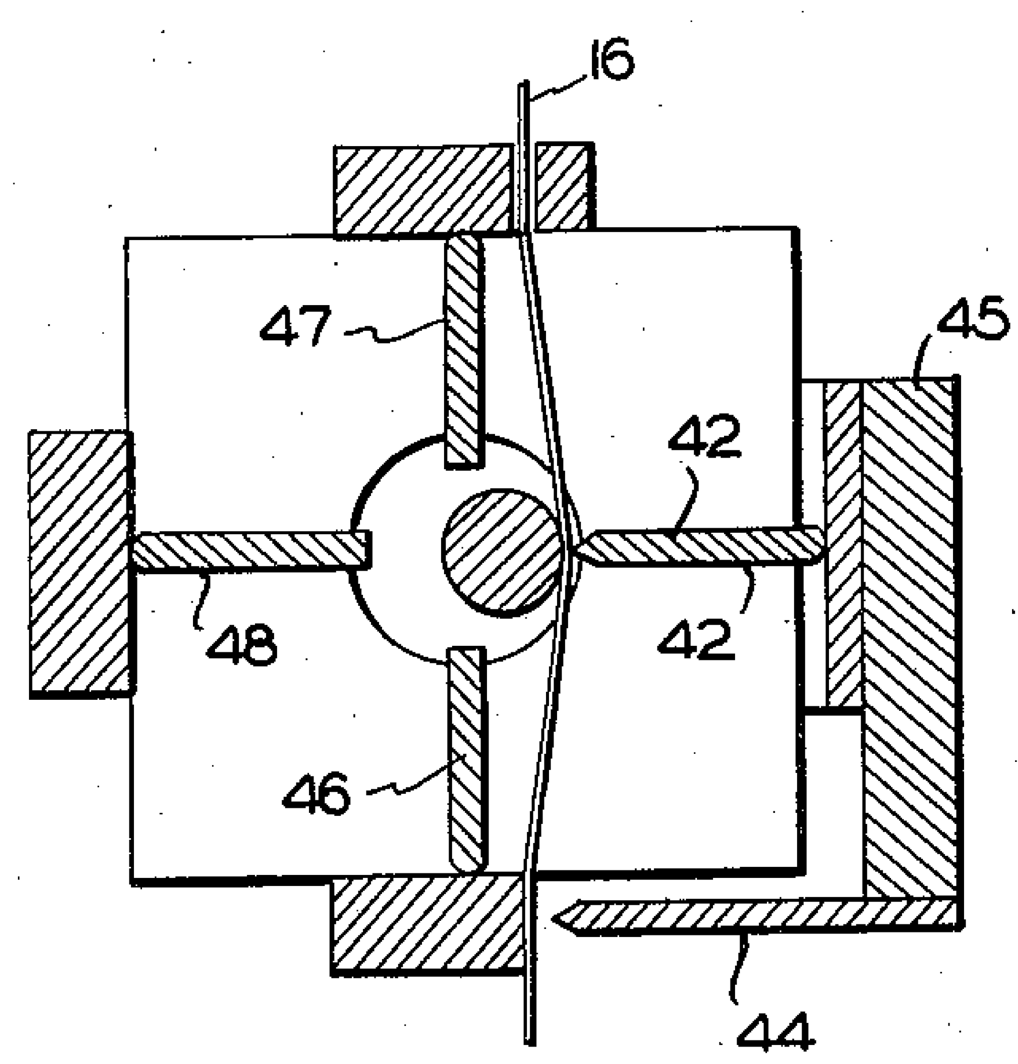


FIG. 9.

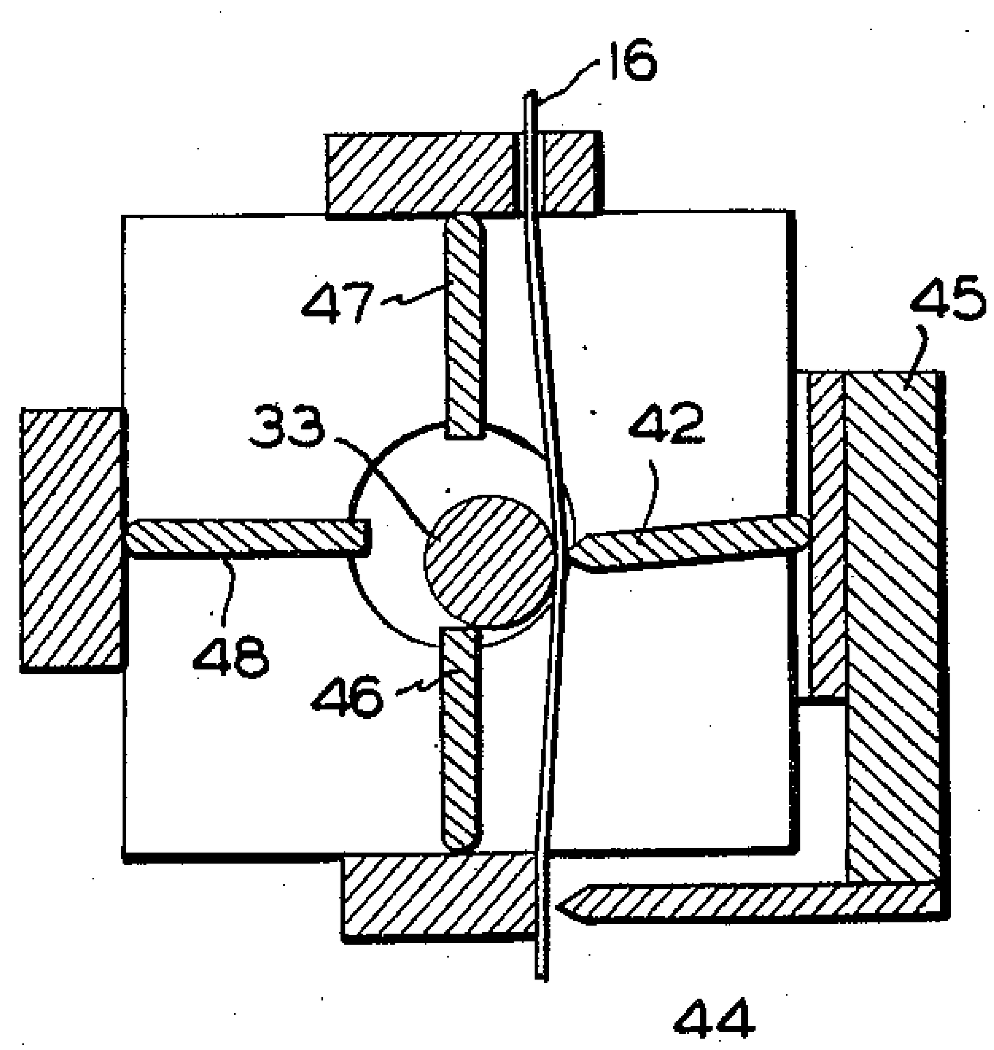
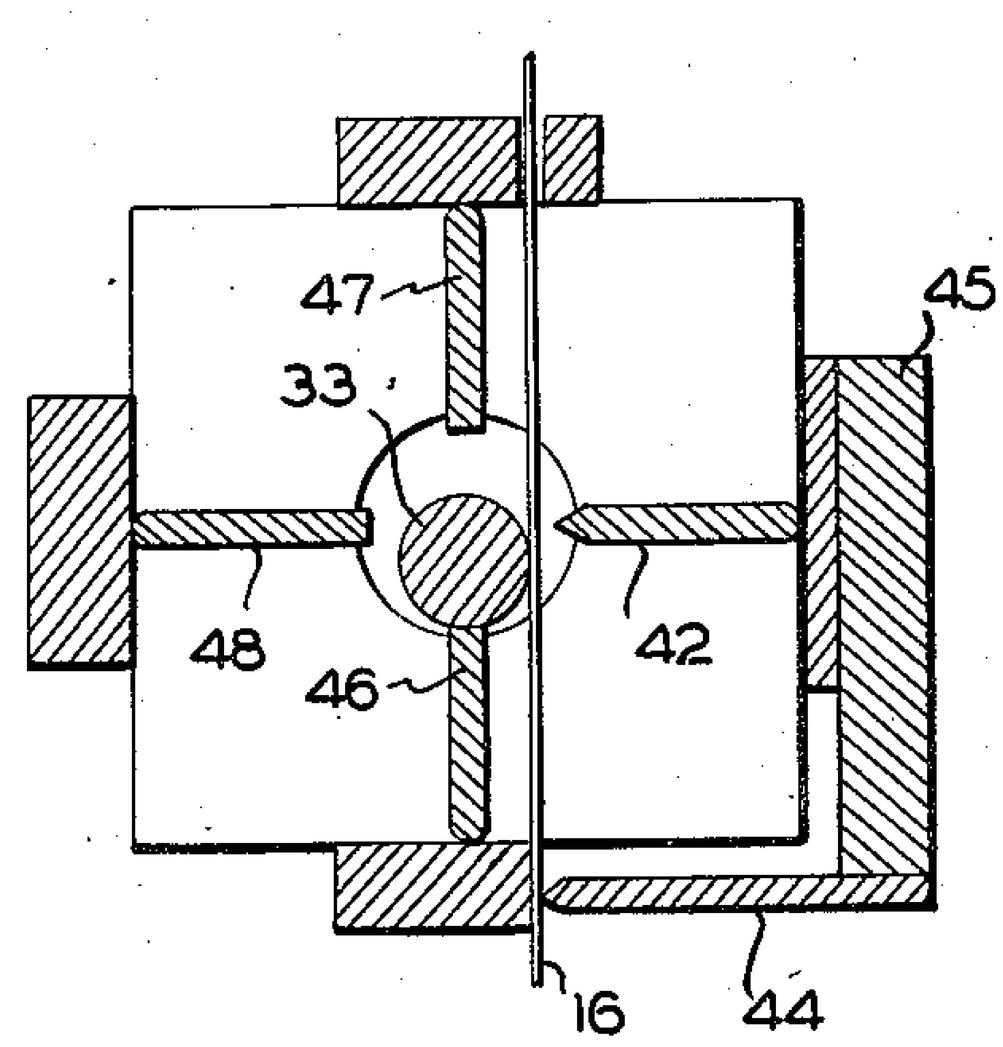


FIG. 10.



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United States Patent Office

2,850,225

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2,850,225

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Application November 10, 1955, Serial No. 546,025

33 Claims. (Cl. 230—69)

The present invention relates to vacuum pumps which are capable of producing and maintaining a high vacuum free of organic vapors. Excluding noble gases, pumps embodying this invention have proven in practice to have pumping speeds about ten times greater than those of ordinary oil-diffusion pumps of the same physical size. Systems evacuated by the usual combination of an oil or mercury diffusion pump in series with a mechanical fore pump are contaminated by organic vapors from oils always present in mechanical pumps. Where the oil type diffusion pump is used, the diffusion pump is also a source of organic vapors. Other organic components, such as rubber O rings and plastic parts, also contribute to the presence of organic vapors. The use of water-cooled baffles and liquid air-cooled traps reduces, but does not eliminate the contamination by organic vapors. In addition to organic vapor considerations, mercury type diffusion pumps require elaborate liquid air-cooled traps to prevent mercury vapor from entering the system to be evacuated.

In many systems, the presence of organic vapors is undesirable since the vapors may condense on the interior surfaces forming a chemical impurity and changing the properties of those surfaces. The improved pumps of the present invention can pump at exceptional speeds while maintaining a high vacuum entirely free of organic or mercurial vapors without the use of traps or baffles of any kind.

In the present invention, a suitable apparatus for the continuous or intermittent evaporation of a gettering substance, called a "getter," is located in a container or chamber or other enclosed space so that the vaporized getter condenses on interior surfaces therein and forms an active surface. The getter to be evaporated is chosen so that gases in the chamber combine either chemically or physically or both with the condensed getter and are removed from the gaseous state. With evaporation and condensation of new gettering substance, an active surface is provided and a pumping action results.

The mechanism involved in the removal of the gas by the gettering substance depends on the type of getter evaporated and the kinds of gases present in the pumping system. Chemical combination, adsorption, absorption, gas-metal solutions, and solutions of compounds of the gas in the gettering metal and various combinations of the same are possible means of initial trapping of a gas which is subsequently buried under new condensing metal.

As the attraction between the gas molecules and the freshly condensed active surface of the getter is insufficient to trap all types of gas molecules until they are securely buried by new getter, means are provided in this invention to increases the affinity of the gas molecules for the active surface by ionization, dissociation or a combination of these such that the products are more effectively trapped. To further improve the trapping action, means are also provided to drive the gaseous ions into the active surface sufficiently deep to prevent escape before burial by new getter condensing on the surface.

Any one of a number of metals or alloys may serve as the gettering substance or material in practicing the invention. Titanium, zirconium, uranium and other metals particularly in groups IV and V of the periodic table, for example, can be employed. Aluminum, alkaline earth metals (calcium, barium, etc.) and the alkali metals (sodium, potassium, etc.) are other gettering substances which can be used to advantage as, for example, for pumping water vapor. Various combinations of different getters also can be used individually or as mixtures or alloys as noted above. Titanium (Ti) is a preferred gettering metal as it provides the desired active surface and forms stable solids with very low vapor pressures. In an embodiment where titanium was used as the getter in the pump illustrated in Figure 2, pumping speeds were measured and are given in the following table.

Table

Temperature of active surface=approximately 20° C.
Rate of evaporation of Ti=7 mgm./min.
Lowest pressure obtained=approximately 1×10^{-7} mm. Hg.

Gas	Pumping speeds (liters/second)	Ion gauge pressure in mm. of Hg
Hydrogen	7,000–8,000	1.5×10^{-6}
Nitrogen	6,500–7,500	1.5×10^{-6}
Oxygen	6,500–7,500	1.5×10^{-6}
Air	1,000	1.5×10^{-6}
Argon	9	5×10^{-6}
Helium	4	5×10^{-6}

These pumping speeds were measured by bleeding in gas at a known rate through a small tube ending near the geometrical center of the pump. Except for argon and helium, the pumping speeds are about ten times those for an oil diffusion pump of the same physical dimensions.

Embodiments illustrating my invention are shown in the drawings.

Figure 1 is a side elevation in section with portions thereof being in elevation showing a pump using a resistance heated crucible for evaporation of the getter with apparatus for the ionization and dissociation of gas molecules and the acceleration of gaseous ions formed by electron bombardment into the wall or collector surface.

Figure 2 is a side elevation in section with portions thereof being in elevation showing a preferred modification of the invention where the evaporation is from a post heated by electron bombardment and one filament provides electrons for both evaporation and ionization.

Figure 3 is an enlarged fragmentary sectional view of a modified structure of that shown in Figure 2 provided with a shield and a reflector.

Figure 4 is a horizontal cross section of the wire feeding device shown in Figure 2.

Figure 5 is a fragmentary side elevational view of the wire feeding device as seen from the right hand side in Figure 2.

Figure 6 is a sectional view showing the outer end of the feeding device in cross section illustrating the engagement thereof with an external rotary actuator.

Figure 7 is an enlarged detailed sectional view of the wire feeder as seen in Figure 2.

Figure 8 is a view of the wire feeder similar to that shown in Figure 7 illustrating the position of the cooperating parts of the device in one phase of its operation.

Figure 9 is a view similar to Figure 8 illustrating a different operating position of the device.

Figure 10 is a view similar to that shown in Figures 8 and 9 illustrating a third operating position of the device.

Considering Figure 1 in detail, the pumping vessel is a metal (steel) housing or cylinder **10** capped off by flanges 11 as shown in the drawing utilizing copper gasket vacuum seals 12. The connection to the system to be evacuated is through inlet port or conduit 13. A mechanical roughing pump is connected to the pumping vessel by outlet port or conduit 14 through vacuum valve 15. Titanium wire 16 is continuously or intermittently fed through the guide tube 17 by a feeder mechanism (shown in more detail in Figures 4–10) into a crucible 18 machined out of graphite rod. The crucible is heated to a temperature of about 2000° C. by passing a current through it via copper electrodes not shown. Titanium is evaporated from the crucible and condenses on the cylindrical interior of the pumping vessel, forming the active surface at 20. Thermionic electrons are emitted from a cathode consisting of a hair pin filament 21 and are accelerated outward by placing the inner grid or cylindrical anode 22 at a suitable positive potential with respect to the cathode. The anode 22 presents a relatively small cross-sectional area to the incident electrons so that most of the electrons pass through into the region between anode 22 and the outer grid or cylindrical anode 23. Anode 23, also of small cross-sectional area, is electrically connected to anode 22 so that the electrons coast across the field-free region between the anode at full ionizing energy. The cathode 21 is at a sufficiently positive potential with respect to the wall of the pumping vessel so that the electrons which pass through anode 23 are repelled from the wall and return to the above-mentioned field-free region without loss of energy. After traversing the field-free region, the reversed electrons enter the volume enclosed by anode 22 where they are again reversed in direction unless they strike the filament. This is not probable because of the small area subtended by the filament. Thus the electrons take up an oscillatory motion through both anodes resulting in a long path length before capture by the anodes or the filament. The energized electrons ionize or dissociate the gas into components which can be taken up by the titanium or other gettering substance. Since the volume enclosed by anode 22 is small compared to that of anode 23, thermal motion in the field-free region will most likely bring the ions to the region between anode 23 and the wall rather than to the interior of anode 22. The high positive potential of anode 23 with respect to the wall drives the ions into the active layer 20 where they are trapped long enough to be buried by new condensing metal or gettering substance. A small amount of additional gas may be removed by combination of the gas with the hot filament. Hydrogen, nitrogen, oxygen, carbon diaxide, Freon, sulfurhexafluoride, ethane, methane, ammonia, argon, helium, and air were pumped by this embodiment without the assistance of any other vacuum-producing device.

To put this embodiment in operation, a rough vacuum is established by connecting a mechanical pump to the pumping vessel through valve 15. The crucible is heated to outgas the graphite. When a pressure of about 10^{-3} mm. of Hg is reached, the filament 21 is heated and outgassed. Feeding of titanium wire 16 is started from spool 24, through guide tube 17 and at the same time the anodes 22 and 23 are raised to voltages of about 1000 volts. Valve 15 is closed and the pressure steadily decreases to about 3×10^{-7} mm. Hg. Outgassing by heating of the pumping vessel while the roughing pump is connected can be employed to reduce the virtual leak of gases coming out of old titanium layers and other metal parts.

In Figure 2 which is a preferred embodiment of the present invention, titanium or other gettering substance is evaporated from a graphite post 25 which is heated by electron bombardment. This method of evaporation improves the lifetime of pump components and reduces the power requirements. The geometry of this embodiment is also such that the getter is evaporated onto a larger area and the active layer is more uniform. The same cathode, in the form of a spiral filament 21′ is used as an electron source for electron bombardment, ionization, and dissociation. The electrons used for ionization and dissociation are drawn outward from the cathode 21′ by placing inner grid or anode 22′ at a positive potential of 900 volts with respect to the cathode. The anode 22′ is constructed to present a minimum cross-sectional area to the electrons so that most of the electrons pass into the region between anode 22′ and outer grid or anode 23′. Anode 23′, which is also constructed to capture a minimum number of incident electrons, is electrically connected to anode 22′ and thus the electrons maintain full ionizing energy until they pass through anode 23′. Outside anode 23′, the electrons are reversed in direction due to a potential drop of 1000 volts from anode 23′ to the wall. The electrons travel back through the volume between the anodes and are reversed again, unless they suffer a collision with the filament. This, as pointed out above, is not probable because of the small cross-sectional area presented by the filament. Thus the electrons oscillate over long path lengths before being captured by the anodes or the filament. Because of the small volume enclosed by anode 22′ compared to that of anode 23′, most ions formed between the anodes will not intercept anode 22′, but escape with thermal velocities into the region between anode 23′ and the wall. Outside anode 23′, the ions are accelerated to high velocities and are driven into the active layer 20 where they are trapped and buried.

Illustrative pumping speeds and pressures obtained with this embodiment are given in the table referred to above. Except for argon, helium and air (since air contains 1% argon) pumping speeds are high compared to those for oil diffusion pumps of about the same physical dimensions. With the pump shown in Figure 2, this system is started most easily by placing a furnace around the pumping vessel 10 and outgassing the pumping vessel at about 300° C. while the roughing pump is connected through valve 15′. When a pressure of about 10^{-3} mm. of Hg is obtained, the furnace is removed and the roughing pump is disconnected by closing valve 15′. The post and anodes are raised to proper voltages such as those shown in the drawings. The filament heating current is turned up until a suitable electron current is drawn to the post and to the anodes. When the post is hot enough to evaporate the gettering substance, the feeder is turned on and evaporation commences. For this and other embodiments, it is desirable to cool the active surface once the system is started to about 100° C. and below. The values in the table above were measured with water-cooled walls to provide an active surface at about 20° C. This can be readily done by cooling coils 26 shown in Figures 1 and 2.

To improve the pumping speed for argon and helium, which must be ionized and driven into the surface, a magnetic field can be imposed to increase the path length of the ionizing electrons. A magnetic field can be provided by use of a magnetic coil as, for example, by wrapping casing or cylinder 10 made of non-magnetic stainless steel with insulated copper wire 27 as shown in Figure 2. In a preferred arrangement, by using fewer turns at the center of the coil or by controlling the current going to portions of the coil, the field in the center of the coil is made relatively weak compared to the fields at the end of the coil. An oscillating electric field also can be used to make the electrons execute oscillatory paths of increased length. Higher acceleration voltages will increase the penetration of the ions into the surface and may improve pumping speeds and the ultimate vacuum. Outgassing of the gettering substance before it is used also may increase its ability to take up gas and thus improve the pumping speeds and ultimate vacuum.

In the embodiment of Figures 1 and 2, the getter to be evaporated is in wire form. The choice of feeding mechanism used to move the wire 16 from the spool 24 to the evaporation device is somewhat arbitrary providing the mechanism has a positive feeding action capable of overcoming the frictional resistance met by the wire in moving through the guide tube. In addition, the feeding mechanism must transmit motion into the vacuum system without the use of organic gaskets or grease-packed seals. Since frictional forces increase in a vacuum, a feeding mechanism free of sliding surfaces in the vacuum is desirable.

A preferred wire feeding device used in the embodiments of Figures 1 and 2 is shown in Figures 4–10. The action of this mechanism is positive, and it contains no organic components or sliding surfaces in the vacuum.

As shown in Figures 4, 5 and 6, a flexible thin-walled tube **30** is mounted on a shouldered in a hole through a steel block **31** by a rigid, vacuum-tight silver solder joint **32**. The top of the tube is capped off by a driving plug **33** which is silver soldered into the tube. Under normal pumping conditions, atmospheric pressure exists inside the flexible tube while a vacuum is maintained outside. Aluminum or copper gaskets **34** on each end of the ceramic cylinder **35** provide the vacuum seal between the block **31** and the pump wall of the pumping vessel **10**. Ceramic cylinders **35** and **36** electrically insulate the feeding mechanism from the wall of the pumping vessel **10** and prevent grounding of the evaporation device through the feeding mechanism when the wire contacts the evaporation device. Such insulation is necessary in the embodiment of Figure 2 where the evaporation device is not at ground potential.

Motion is imparted to the wire **16** by the proper manipulation of the wobble stick **37** which pivots on bearing surface **38** at the base of the flexible tube **30** with one end of the stick in a loose fitting hole in the driving plug **33** and the other end extending a suitable distance out of the clearance hole **49**. The shape of the wobble stick in the flexible tube maximizes the rigidity of the stick but permits flexure of the tube and stick without binding. When the outer end of the wobble stick is displaced from the relaxed position on the axis of the clearance hole (Figure 6), the stick pivots on bearing **38** and the upper end of the stick displaces the driving plug in the opposite direction causing the tube to bend. Since the wobble stick exerts a deflecting force at the end of the tube, the flexure of the tube is that of a simple cantilever beam loaded at the end. By exerting the deflecting force at the end of the tube rather than at some point between the end and the base a maximum displacement of the driving plug is obtained. For a given displacement of the driving plug, exertion of the deflecting force at the end of the tube minimizes the stresses in the tube wall and the resulting strains are well below the elastic limit of the metal used in the tube.

In operation, the outer end ofthe wobble stick is driven in a circular path by a solid steel rod **39** which has been cut flat on one side **40** to accommodate the outer end of the wobble stick between the flat on the rod and the wall of the clearance hole. The rod is of the same diameter as the clearance hole, and the step **41** formed by cutting the flat is used to hold the wobble stick in position. An electric motor (not shown) rotates the rod, and the flat on the rod carries the outer end of the wobble stick around in a circular path. The wobble stick does not revolve about its own axis, but rather pivots on bearing **38** in such a way that both ends trace a circular path, neglecting constraining leaves **46**, **47** and **48**.

The circular motion impressed on the driving plug imparts linear motion to the wire in a cycle of events as shown in Figures 8–10. Figure 7 shows the position of the driving plug **33** when in inoperative position prior to engagement of wobble stick **37** with flat **40** of rotary rod **39**. The driving plug presses the wire against the driving leaf **42**, which is hinged on spring **43**, with sufficient force to bend spring **43** away from the block **31**. The locking arm **44** mounted on spring **43** by holder **45** is thus lifted from the wire and the wire is free to move as shown in Figure 8. The driving plug thrusts the wire forward, carrying the hinged driving leaf along under enough force to keep the locking arm withdrawn. Figure 9 shows the end of the thrust. As the driving plug disengages the wire, spring **43** forces the locking arm against the wire preventing the wire from slipping back as shown in Figure 10. The driving plug presses against the hinged constraining leaf **46** as it moves away from the wire. Constraining leaves **46** and **47** determine the length of the thrust by limiting the travel of the driving plug parallel to the wire. Upon disengaging constraining leaf **46**, the driving plug engages hinged constraining leaf **48** which prevents the driving plug from swinging too far out to engage leaf **47** properly. After engaging leaf **47**, the driving plug binds the wire against driving leaf **42** and the cycle is repeated. Because of the constraining and driving leaves, the driving plug moves in a rectangular rather than circular path. The wire moves forward in increments of about $\frac{1}{16}$ of an inch, and the number of increments or rod rotations per minute can be varied, for example, from $\frac{1}{4}$ to 20 to provide adequate control of the getter to be evaporated.

When the getter is in wire form and is fed from a spool **24** as shown above, it was found that the wire had a tendency to resume its prior curvature on leaving the end of the guide tube. This characteristic of the wire made it difficult to accurately bring the wire to the hot crucible or post for evaporation. With continued investigation it was discovered that the wire lost all tendency to resume its prior curvature when the guide tube or a part of the guide tube was heated. With a heated guide tube, for example, it was found that the wire proceeded unsupported from the end of the tube in a straight line striking the evaporation device accurately at the desired spot even though the distance between the evaporation device and the tube end was sufficiently great to minimize the amount of metal condensing on the tube end. The guide tube or a portion thereof can be heated by any means including electrical means such as conduction heating or electron bombardment, etc. The lower section of the guide tube can also be heated by radiation from the evaporation device. The optimum positioning of the guide tube to prevent plugging by condensing getter and the optimum temperature at which the guide tube should be heated can be readily ascertained by preliminary test. In all cases, the temperature of the guide tube should be below the point at which the getter loses its wire form or melts.

Investigations with pumps of various geometries have demonstrated certain factors to be essential for good pumping speeds. One of these is that the grids should be characterized by high transparency as pumping speeds have been found to go up as grid transparency increases. For effective pumping, for example, the grid must have a transparency over 25% and for pumping at reasonably high speeds should be over 50% transparency with a 75% on up transparency being preferred. Using fine wire of a 0.002 inch diameter, 0.25 of an inch apart, provides a highly satisfactory grid with about 98% transparency. With properly spaced grids of this type, electron paths are relatively long and the electrons traverse the chamber many times before hitting the grids. In addition, all leads to grids and to post and all other conducting surfaces at a positive potential with respect to ground should be either shielded to prevent collection of electrons or should be reduced in size to present a very small area on which the electrons can be trapped. Another important factor for good pumping is that the geometry of the grids should be such as to provide a substantial volume of space at a high positive potential with respect to the walls or surfaces on which the vaporized getter is condensing. With the grids enclosing a large field free or relatively field free space ionization is improved and the positive ions formed by electron bombardment move slowly in this space and keep down or reduce space charge. In addition, more of the positive ions formed will have their full energy when they move out of the field free region and are driven into the wall. The space available to be enclosed by the grids will vary depending on the pump, but in all cases it should be comparatively substantial in proportion to the size of the pump. In other words, to provide the largest possible space enclosed by the grids it is preferred to have the inner grid as close to the filament and the outer grid as close to the wall as possible but with sufficient clearance to avoid short circuiting.

Still another factor of importance to good pumping is the relationship between the potentials on the filament or cathode, the grids or anodes and the wall or inner surface on which the getter is condensing. The filament generally should have a positive potential with respect to the wall, examples being +30 to +250 volts on the filament with the wall grounded at neutral or zero potential. With the positive potential on the filament with respect to the wall the electrons liberated by the filament are repelled by and cannot reach the wall. Actually this has not proven as critical in practice as anticipated for with the filament at −50 volts and the wall at zero potential, pumping speeds have been reasonably high although at this negative potential the electrons do hit the wall. The reason for this apparent lack of effect on pumping is not known but it may be due to the generation of electrons by secondary emission on hitting the wall. It is preferred, however, to have the filament biased to a positive potential with respect to the wall to promote the oscillation of the electrons within the pump.

The potential on the grids should be positive with respect to both the wall and the filament and ordinarily should have a value of over +100 volts with respect to the wall and over +50 volts with respect to the filament. These values are normally required for good ionization efficiencies of the electrons and also for driving various types of positive ions into the wall with good possibilities that they will stick. Grids of different potentials can also be employed to drive the ions in any desired direction. An arrangement with a top part of the grid at +1100 volts with respect to the wall and the other parts of the grid at +1000 volts with respect to the wall, for example, can be used to urge positive ions downward.

Certain gases such as oxygen and hydrogen form negative ions and these ions can be pumped by maintaining the grids and filament both negative within the relationship described above. For general operations, however, the use of positive potentials is ordinarily preferred.

To improve the pumping action the surfaces on which the getter is condensing can be increased by the use of corrugated walls, fins and the like. Screens such as wire mesh screen **19** shown in Figure 1 can be placed close to the walls to break up the getter, i. e., form discontinuous films of getter. Also, if the screen is of the form of the under and over-woven type long filaments of the getter material cannot form on the screen wire. A large outer grid also can be fabricated so as to break up the getter. These features are important as they prevent the formation of large continuous sheets or long filaments of getter which on peeling may cause short circuits in the pump. Replaceable liners on which the getter condenses can also be used to advantage.

The use of various types of primers (see Figure 2) can also be employed to aid in the starting of the pumps. A primer, for example, may comprise a getter such as titanium wire wrapped around a graphite or tungsten heating rod. Titanium wire about .02 inch diameter wrapped on graphite rods of about .125 inch diameter or tungsten rods about .04–.05 inch diameter are illustrative examples. In practice it was found that evaporation was generally poor when the getter was wrapped continuously along the length of the rod due to the tendency of the melted getter to pull together into one or two large globules. This can be avoided as shown in Figure 2 by wrapping the getter **28** in short separated segments on rod **29**. Titanium segments of about 0.5–1.0 inch in length and separated by ⅛–¼ inch are illustrative examples of primers found to give good evaporation and without excessive deterioration of the heater rod. A total of eight inches of titanium wire is adequate for starting and in a number of instances one primer charge has served for several startings of the pump. The use of multiple, two, three or more, primer rods can also be employed to avoid reloading each time the pump is started. A primer charge of getter can also be evaporated from the crucible or post at the start of the pumping operation.

If the primer is near ground potential it should be located so as to avoid electron current from the primer to any metal part at post or grid potential. Such current can cause outgassing of massive parts and can drain power from the post supply. Uncooled surfaces closer than one inch from the primer rod may become heated by radiation to where evolution of gas makes the problem of the primer more difficult. For best results the primer should be located so that a reasonable fraction of the titanium is deposited on distant cooled surfaces.

A preferred procedure for starting the pump with a primer is as follows. Pressure is first reduced by means of a forepump. The filament is then bought up to temperature and the post power supply turned on. A low voltage gaseous discharge sets in. Power to the primer is then turned on and the primer is brought up to temperature for evaporation of the getter. As the getter evaporates the pressure decreases, the gaseous discharge proceeds with greater difficulty and the post voltage rises. This results in increased post temperature with further outgassing of the post. When the post temperature is sufficiently high the wire feeding is started and the pump is in operation.

The bombardment of noble gas atoms by electrons is necessary, as stated above, for high pumping speeds where gases of this type are present. The same is true of complex molecules which may be organic in character and which are not readily bound by the gettering action of the condensing getter. The complex molecules may be dissociated by the electrons or dissociated by contact with hot surfaces, e. g. promoted by suitable catalysts, into components which are readily bound by the getter. The complex molecules may also be ionized or dissociated into components which are ionized and then driven into the wall or collector surface where they are buried by the condensing getter.

The electron source for ionization by electron bombardment is preferably in the form of a hot filament with or without means for electron multiplication, electron generation by secondary emission, etc. The electrons can be generated outside and beamed into the ionization chamber or be generated by various means as, for example, by high voltage discharge. For best results, it is preferred to generate the electrons in the same chamber in which the getter is evaporated and condensed. In addition to electron bombardment, the gas can be ionized by ultra-violet light or by radiation from radio active materials. When electron bombardment is employed to heat the crucible or post in or on which the getter is vaporized, it has proven important when starting the pump under relatively high pressure to initially use a primer charge of getter of the type described above vaporized by conduction or induction to avoid high voltage electrical discharge in the pump. After the pressure is lowered by the primer charge, evaporation of the getter by electron bombardment can then be started without danger of electrical discharge. Thus a preferred pump should be provided with a primer with means other than electron bombardment e. g. conduction heating, for initially vaporizing the getter when starting the pump along with the means for relatively continuous vaporization of the getter with electron bombardment after the starting operation. The source of electrons for heating the crucible or post and for ionizing the gases can be the same or different, e. g. by use of one or separate filaments.

In practice it was found that current from filament to post tended to increase with an increase in rate of titanium evaporation (caused, for example, by a build-up of molten getter on the post before evaporation), and that the resulting surge in current tended to deteriorate the filament. This can be eliminated as shown in Figure 2 by the use of current regulators 50 such as ordinary 110-volt tungsten filament light bulbs as the resistance of tungsten increases rapidly with increase in temperature. The light bulbs can be connected in the primary or secondary circuits of the high voltage supplies. For various pumps, the adequate or optimum number of bulbs to be employed for dependable current regulation can be readily ascertained. Any of the other current regulators such as a saturated reactor or current regulating circuits can also be employed in the present invention.

The pumps of the present invention can also be provided with a shield to protect the getter wire and guide tube from electron bombardment. Excessive bombardment of the guide tube, for example, may cause the getter wire to melt back to the end of the guide tube where it fuses and jams and stops the feeding of the getter. Installation of a metal shield maintained at or near ground potential eliminates this difficulty. The shield can be in the form of a wire ring 51 as shown in Figure 3, or a plate with a hole in it or any other form that gives satisfactory electrical shielding of the tip of the guide tube from the electron source.

The pumps of the present invention can also be provided with reflectors to direct the evaporation of the getter downward and thus avoid the formation of relatively thick deposits of getter that tend to form on parts above and near the source of evaporation. The reflector 52 made of molybdenum or the like and which may be lamp shade in form and be positioned above the post as shown in Figure 3, is maintained at approximately the same temperature as the post. The getter which collects on the underside is reevaporated and much of it is directed downward. This type of arrangement improves the angular distribution of the getter and greatly reduces difficulties (e. g. electrical short circuits) that may result due to the formation of heavy deposits of getter. The posts may also be positioned (e. g. be placed at an angle) or shaped (e. g. be egg-like in shape) to aid the molten getter in flowing to the end or underside where evaporation tends to take place downwardly. The use of the reflector, however, is preferred.

The reflector described above may be dispensed with by a proper geometric arrangement of parts as, for example, by elimination of parts close to the upper hemisphere of the post, i. e. the area of evaporation. In one such arrangement the post is located near the bottom of the container (pump) and evaporation is upward. Space above the post is as free as possible of obstacles which might collect getter. The guide tube is small and tapered and subtends little area at the post to minimize the buildup of getter. The filament is positioned below the top of the post and is exposed to a minimum of getter vapor. The positioning of the filament in this manner also reduces the bombardment of the wire and the tip of the guide tube making the shield not needed.

With this arrangement it has been found advantageous to electrically connect the guide tube to the post through a resistance. Power to the wire and to the tip of the guide tube can be adjusted by adjusting the series resistance. When this resistance is properly chosen the wire is heated sufficiently to hang straight and consistently hit near the center of the post. Heating is not sufficiently intense to melt the wire back to the guide tube.

In another geometric arrangement the filament as well as the inner grid are positioned below the top surface of the post. With this arrangement the electrons pulled downward are reflected by suitable shielding and the lower portion of the post is electrically shielded to prevent overheating.

Evaporation surfaces such as crucibles, posts and the like, when used in the present invention to evaporate the getter can be made of various materials in addition to graphite. Illustrative materials include molybdenum, an alloy of tantalum and tungsten (Tantung or Tantaloy), tungsten carbide (Carboloy), titanium carbide, titanium nitride, tungsten, etc. In practice it has been found important to have the surface for evaporation, compared to the cross section of the getter wire, relatively large so as to provide an extended surface over which the molten getter can spread for evaporation after the wire makes contact with the hot surface.

The pumps of the present invention can also be operated without a crucible or post for evaporation of the getter. This can be accomplished in various ways as, for example, by bombarding the getter per se. In one such arrangement a getter wire, held at a high positive potential, was fed through a hole in a grounded shield plate, and a heated filament near ground potential supplied electrons to bombard and heat the getter to evaporation temperature. In another arrangement without a crucible or post, the getter wire is intertwined with another wire and wound on a storage spool. The composite wire is heated by conduction current or is passed through a region where it is heated by electron bombardment to a point where a reasonable fraction of the getter is evaporated. The wire remaining then passes to a second spool where it is re-wound. In a modification of this arrangement, titanium wire of about .02 inch diameter is wrapped with molybdenum wire of about .01 inch diameter. The composite wire is then bombarded with electrons and all or substantially all of the titanium evaporates from the hot surface of the molybdenum wire. The molybdenum wire can be collected or re-wound as indicated above or be eliminated by more intense bombardment as it proceeds to another position. Still in another arrangement without a crucible or post, the getter wire is heated by periodic intense pulses of electrons with pulse lengths so short in time that only a thin outer layer is heated to evaporation temperatures. In these arrangements reflectors as well as shields may be employed as described above.

The present invention may be practiced according to the embodiments described above, but it is to be distinctly understood that the invention is not limited to these illustrative embodiments. In particular, the geometries and proportions of the pumping vessel and inner components are not limited to those of the above embodiments or figures; where the same numerals indicate like elements. The optimum area for the active surface will vary from one application to another and can be increased by the use of fins and the like in the pumping vessel as indicated above. The gettering substance to be evaporated is not restricted to titanium, but may be any gettering substance, including lower melting substances and substances of inferior gettering activity with improved burying capacity. The use of a getter such as titanium which combines with gas both in its evaporated and condensed state is, however, generally preferred. In place of wire the getter can also be used in rod form as well as in the form pellets, chunks of wire or powder. The embodiments discussed are not to be construed as excluding other means of evaporation, such as sputtering, in practicing this invention. The evaporation process may be intermittent rather than continuous. It may be desirable in some embodiments, as noted above, to outgas the getter to be evaporated before it is used and thus increase the getter's capacity to take up gas. Suitable A. C. or D. C. magnetic fields, both constant and oscillating, with or without an alternating potential between the filament and grid, can be used to increase the electron path length and consequently improve the ionization. The electron accelerating voltage applied to the post and grids can also be constant or oscillatory. The voltages applied to the filament, the anodes, and the wall may differ from the illustrative values mentioned above, the optimum condition for a particular pump being readily ascertainable by preliminary tests. The optimum temperature of the active surface may vary in different systems and may be of different values for different parts of the active surface. This can be readily accomplished by the use of standard water jackets on the pump using water at different temperatures. Starting procedures will vary in different embodiments of the invention and can involve the rapid evaporation or "flash gettering" of a small amount of getter in an apparatus distinct from that for the continued evaporation, etc. Localized bake outs can also be employed in place of the bake out described above with reference to the operation of the pump illustrated in Figure 2. In the pumpdown operation, for example, nichrome wire can be used to heat the interior by radiation. Various other modifications coming within the spirit and scope of my invention will be obvious to those skilled in the art.

It will also be understood that the wire feeder described above is merely illustrative and that various getter feeding devices may be employed in the present invention. One such device employs a stainless steel strip or resistance wire attached to the top of the upper leg of an L-shaped member under spring tension. When the steel strip is heated by a conduction current the strip expands (lengthens). This results in the movement of the upper leg of the L-shaped member to the left and the movement of the lower leg of the L-shaped member upwardly. When the current is turned off the steel strip cools and contracts (shortens). This results in the movement of the upper leg of the L-shaped member to the right and the movement of the lower leg of the L-shaped member downwardly. This movement of the lower leg actuated by the expansion and contraction of the steel strip can be readily employed to feed the getter wire when the lower leg is provided with means for gripping the wire on the downward movement. This means may be an ordinary strip of spring steel positioned against a block so that the spring steel strip will slide up the wire on the upward movement and grip the wire on the downward movement. Similar means positioned above the lower leg may also be employed to prevent the upward movement of the wire and to assure that the wire movement will only be down. The feed rate can be readily controlled by adjustment of either the cycling rate or the magnitude of the heating current. Various other getter feeding means may be employed in the present invention.

The pumps of the present invention, known by the name "Evapor-ion" pumps (a trademark of the Consolidated Engineering Corporation), operate as shown above, without organic or mercury fluids, without jet assembly, and without continuous mechanical pump forepressure. They need no refrigerated traps or baffles (which inhibit maximum pumping speed) to produce low ultimate pressures of 10^{-9} mm. Hg. They are ideal for non-cyclic vacuum systems like those of Van de Graaffs, synchrotrons, and other high-voltage particle accelerators. The applications of the pumps of the present invention also include evacuation of electron power tubes, color TV tubes, large X-ray tubes, and mass spectrometers. They also can be used to advantage as a leak detecting instrument or device in place of the well-known helium leak detectors.

The present application is a continuation-in-part of my earlier application, Serial No. 393,836, filed on November 23, 1953.

I claim:

1. A pump comprising a housing having a chamber with surfaces therein for receiving a gettering substance condensing from the vapor state, and including an inlet port for connecting said chamber to a vessel to be evacuated, means for removing gas from the gaseous state in said chamber comprising means located in said chamber for vaporizing a gettering substance in said chamber, means located in said chamber for providing a flow of electrons in said chamber to ionize gas therein, and means located in said chamber for driving gas ionized by said electrons to said surfaces for receiving the gettering substance where gas trapped thereon will be buried by condensing vaporized getter.

2. A pump in accordance with claim 1 where the gettering substance which is vaporized in said chamber is titanium.

3. A pump in accordance with claim 1 where the gettering substance which is vaporized in said chamber is in wire form and the means for vaporizing the gettering substance comprises a hot surface located in said chamber and heated to a temperature sufficiently high to vaporize the wire getter upon contact with said hot surface.

4. A pump in accordance with claim 1 where the gettering substance which is vaporized in said chamber is in wire form and the means for vaporizing the gettering substance comprises a hot surface located in said chamber and heated by electron bombardment to a temperature sufficiently high to vaporize the wire getter upon contact with said hot surface.

5. A pump in accordance with claim 1 where the means for vaporizing the gettering substance which is vaporized in said chamber comprises a spool of the gettering substance in wire form, a guide tube and a surface for evaporation, and includes means for feeding the wire getter from said spool through said guide tube to said evaporation surface, means for heating at least a portion of said guide tube to a temperature such that the wire passing through said tube maintains its wire form but loses its tendency to resume the prior curvature of said spool, and means for heating said evaporation surface to a temperature sufficient to vaporize the gettering substance.

6. A pump in accordance with claim 5 where the gettering substance which is vaporized in said chamber is titanium wire and the surface for evaporation is an electrically heated crucible.

7. A pump in accordance with claim 5 where the gettering substance which is vaporized in said chamber is titanium wire, the surface for evaporation is in the form of a post located inside said chamber, and the means for heating the post is electron bombardment.

8. A pump in accordance with claim 1, where the means of vaporizing the gettering substance which is vaporized in said chamber is by electron bombardment.

9. A pump in accordance with claim 1 where the means for providing a flow of electrons for ionizing gas comprises a cathode provided with a positive potential with respect to the inner surfaces into which the ionized gas is driven and buried by the vaporized getter condensing thereon.

10. A pump in accordance with claim 9 where the cathode provides electrons for vaporizing the gettering substance by electron bombardment and for ionizing the gas.

11. A pump in accordance with claim 1 where the means for providing a flow of electrons for ionizing gas comprises a cathode located inside said chamber and provided with a positive potential with respect to the said surfaces for receiving the gettering substance in the chamber, and the means for driving the ionized gas to the said surfaces for receiving the gettering substance comprises transparent anodes located inside said cham-

ber and provided with positive potentials with respect to both the cathode and the said surfaces for receiving the gettering substance.

12. A pump in accordance with claim 11 where the anodes comprise cylindrical inner and outer grids, the inner grid being positioned close to and enclosing the cathode, and the outer grid being positioned close to the said surfaces for receiving the gettering substance in said chamber, said grids being made of fine wire providing a grid transparency of at least 75 percent.

13. Vacuum producing apparatus comprising a housing having a chamber with inner surfaces and including an inlet port connecting said chamber to the system to be evacuated and an outlet for initial evacuation, means for removing gas from the gaseous state from the space in said chamber comprising means located in said chamber for vaporizing a gettering substance, means for ionizing gas by impact with electrons comprising a cathode located in said chamber as a source of electrons, means located in said chamber adjacent the cathode for oscillating electrons liberated by said cathode and for driving gas ionized by said electrons to said inner surfaces comprising anodes of high transparency, and means intercoupling said cathode and said anodes and said inner surfaces for impressing potentials on said cathode and said anodes with respect to said inner surfaces.

14. Vacuum producing apparatus comprising a metal housing having a chamber with inner wall surfaces therein to receive titanium condensing from the vapor state, and including an inlet port connecting said chamber to the system to be evacuated and an outlet port for initial evacuation, means for removing gas from the gaseous state from the space in said chamber comprising means located inside said chamber for vaporizing titanium, means including a cathode located inside said chamber providing a source of electrons for ionizing gas, means including anodes of high transparency located in said chamber adjacent the cathode and cooperating with said electron source for oscillating electrons and for driving gas ionized by said electrons to the inner wall surfaces, means for burying gas trapped on said surfaces comprising vaporized titanium condensing thereon, and means intercoupling the cathode and the anodes and the wall surfaces for impressing potentials on the cathode and anodes with respect to the wall surfaces.

15. A vacuum producing apparatus comprising means including walls providing an enclosed space having interior surfaces therein and including an inlet port for connecting said space to a device to be evacuated and an outlet port for connecting said space to a cooperating vacuum producing device, means located in said enclosed space for vaporizing a gettering metal in said space, means including a cathode located in said enclosed space for emission of electrons and means located in said inclosed space adjacent the cathode for oscillating the electrons to bombard gas molecules in said space and for driving the resulting ions into a surface in said space.

16. A vacuum producing apparatus comprising means including walls providing an enclosed space having interior surfaces therein to receive titanium condensing from the vapor state, and including an inlet port for connecting said space to a device to be evacuated and an outlet port for connecting said space to a mechanical pump for initial evacuation, means coupled to the outlet port for closing said outlet port, means located in said enclosed space for vaporizing titanium in said space, means for ionizing gas in said space by electron bombardment comprising means including a hot cathode located in said enclosed space for emission of electrons and means including a grid located in said enclosed space adjacent the cathode and maintained at a high positive potential with respect to the cathode for oscillating the electrons emitted by said cathode, said grid also serving as means for driving gas ionized by electron bombardment into a surface in said space where the gas trapped in said surface will be buried by vaporized titanium condensing thereon.

17. A pump comprising a housing having a chamber with a surface therein for receiving a gettering substance condensing from the vapor state, and including an inlet port for connecting said chamber to a vessel to be evacuated, means for removing gas from the gaseous state in said chamber comprising means located in said chamber for vaporizing a gettering substance in said chamber, means located in said chamber for providing a flow of electrons in said chamber to bombard gas therein, and means located adjacent said surface for receiving the gettering substance for moving the products of bombardment to said surface where gas trapped thereon will be buried by condensing vaporized getter.

18. A pumping device comprising housing means defining a space from which gas is to be removed and having a surface therein for receiving a gettering substance condensing from the vapor state, a port for connecting said space to a vessel to be evacuated, means for removing gas from the gaseous state in said space comprising a gettering substance, means located inside said space for vaporizing a portion of said gettering substance in said space to provide an active surface of condensed gettering substance for trapping gas thereon, means located inside said space for providing a flow of electrons in said space to ionize and dissociate gas therein, means located inside said space and adjacent said surface for driving gas ionized by said electrons to said surface, and means located inside said space for vaporizing additional portions of said gettering substance in said space to provide a new active surface of condensed gettering substance and to bury gas previously trapped on said surfaces with the vaporized gettering substance condensing thereon.

19. A pumping device comprising housing means defining a space from which gas is to be removed and having surfaces therein for receiving titanium condensing from the vapor state, a port for connecting said space to a vessel to be evacuated and a port for connecting said space to a cooperating vacuum producing device, means for removing gas from the gaseous state in said space comprising titantium, means located in said space for vaporizing a portion of said titanium in said space to provide an active surface of condensed titanium for trapping gas thereon, means located in said space for providing a flow of electrons in said space to ionize and dissociate gas therein, means located in said space and adjacent said surfaces for driving gas ionized by said electrons to said surfaces, and located in said space means for vaporizing additional portions of said titanium in said space to provide a new active surface of condensed titanium and to bury gas previously trapped on said surfaces with vaporized titanium condensing thereon.

20. A pumping device comprising housing means defining a space from which gas is to be removed, means located in said space for bombarding gas in said space with electrons, a getter which in both its evaporated and its condensed state combines with gas which is to be removed from said space, a heated post located in said space, means for causing a portion of the getter to contact the post to evaporate a portion of the getter and cause it to pass through a portion of said space and to condense so as to cause combination of the gas molecules and of the products of bombardment with the condensed getter and so as to provide an active layer of condensed getter which continues to trap the gas molecules and the products of bombardment which impinge upon the condensed getter, and means located in said space for causing additional portions of the getter to contact the post to evaporate and to pass through a portion of said space and to condense to trap additional portions of the gas and to bury the gas previously trapped by the condensed getter.

21. A pumping device comprising housing means defining a space from which gas is to be removed, a collector

electrode located in the housing means and extending around at least a major portion of the space from which gas is to be removed, means located in said space for bombarding gas in said space with electrons, a getter which in both its evaporated and its condensed state combines with gas which is to be removed from said space, means located in said space for evaporating a portion of the getter and for causing it to pass through a portion of said space and to condense on the collector surface so as to cause combination of the gas molecules and of the products of bombardment with the condensed getter and so as to provide an active layer of condensed getter of large area which continues to trap the gas molecules and the products of bombardment which impinge upon the condensed getter, and means located in said space for subsequently evaporating additional portions of the getter and causing it to pass through a portion of said space and to condense to trap additional portions of the gas and to bury the gas previously trapped by the condensed getter.

22. A pumping device comprising a housing defining a chamber from which gas is to be removed, electrode means located in the chamber and defining a space which is substantially free of electric fields, means located inside the chamber for projecting electrons into the field-free space to ionize the gas in the space, a collector surface located adjacent said electrode means, means located inside the chamber and adjacent the collector surface for driving the ionized gas to the collector surface, and means located inside the chamber for evaporating a gettering substance and for causing the evaporated getter to pass through a portion of the chamber and to be deposited on said collector surface, so that the getter traps the gas and secures it to the collector surface and also buries the gas previously deposited on the collector surface.

23. A pumping device comprising a housing defining a chamber from which gas is to be removed, a source of electrons located in the chamber, electrode means located in the chamber and defining a space in the chamber which is substantially free of electric fields, means for establishing a potential between the source of electrons and the electrode means for projecting the electrons from said source into the field-free space which is defined by said electrode means to ionize the gas, a collector surface located adjacent said electrode means, means for establishing a potential between the electrode means and the collector surface for driving the ionized gas from the outer periphery of the field-free space to the collector surface, and means located in the chamber for evaporating a gettering substance in the chamber and for causing the evaporated getter to pass through the field-free space and to be deposited on said collector surface, so that the getter traps the gas and secures it to the collector surface.

24. A pumping device comprising housing means defining a chamber from which gas is to be removed, a source of electrons located in the chamber, a collector surface located in the housing for holding gas which is removed from the chamber, electrode means having a first electron-permeable portion located adjacent the source of electrons and having a second electron-permeable portion located adjacent the collector surface and defining a space between the two electron-permeable portions which is substantially free of electric fields, and means intercoupling the source of electrons and the electrode means and the collector surface for applying a positive potential to said electrode means with respect to the source of electrons and with respect to the collector surface to cause electrons to pass back and forth through the field-free space defined by the electrode means and to cause positive ions to be driven into the collector surface.

25. A pumping device comprising housing means defining a chamber from which gas is to be removed, a source of electrons located in the chamber, a collector surface located in the housing for holding gas which is removed from the chamber, electrode means having a first electron-permeable portion located adjacent the source of electrons and having a second electron-permeable portion located adjacent the collector surface and defining a space between the two electron-permeable portions which is substantially free of electric fields, means connected to the electrode means and the source of electrons and the collector surface for applying a positive potential to said electrode means with respect to the source of electrons and with respect to the collector surface to cause electrons to pass back and forth through the field-free space defined by the electrode means and to cause positive ions to be driven into the collector surface, and means located in the chamber for causing an evaporated gettering substance to pass through a portion of the chamber and to be deposited on the collector surface, so that the getter traps the gas and buries the gas previously deposited on the collector surface.

26. The pump of claim 1 further including means located in the chaber for vaporizing a primer charge of gettering substance.

27. The pump of claim 1 further including means located on the housing which defines the chamber from which gas is to be removed for controlling the temperature on the surfaces on which the vaporized gettering substance is condensing.

28. The pump of claim 1 further including means located on the housing which defines the chamber from which gas is to be removed for producing a magnetic field to increase electron path lengths and improve ionization.

29. The pump of claim 1 further including a wire mesh screen located adjacent the collector surface to break up the gettering substance condensing from the vapor state.

30. The pump of claim 3 where the hot surface is a large surface relative to the cross section of the wire over which the molten getter can spread for evaporation after the wire makes contact with the hot surface.

31. The pump of claim 5 further including a shield located between the guide tube and the means for providing electrons to protect the guide tube from electron bombardment.

32. The pump of claim 7 further including a reflector located adjacent the post to direct evaporation of the gettering substance from the post.

33. A vacuum producing apparatus for removing gas from a space comprising a housing defining said space and having collector surfaces on the inner surface thereof, at least a portion of the collector surfaces being electrically conductive, electrical means located in said space for ionizing the gas therein, means located in said space and cooperating with the electrically conductive portion of the collector surfaces for driving the ionized gas into the electrically conductive portion of the collector surfaces, and means located in said space for the repeated vaporization of gettering material and disposed to cause successive deposits of the gettering material to condense on the collector surfaces so that the getter traps and removes gas from said space and buries the gas previously trapped by the condenser getter.

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CERTIFICATE OF CORRECTION

Patent No. 2,850,225 September 2, 1958

Raymond G. Herb

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 16, line 21, for "chaber" read -- chamber --; line 61, for "condenser" read -- condensed --.

Signed and sealed this 18th day of November 1958.

(SEAL)

Attest:

KARL H. AXLINE
Attesting Officer

ROBERT C. WATSON
Commissioner of Patents