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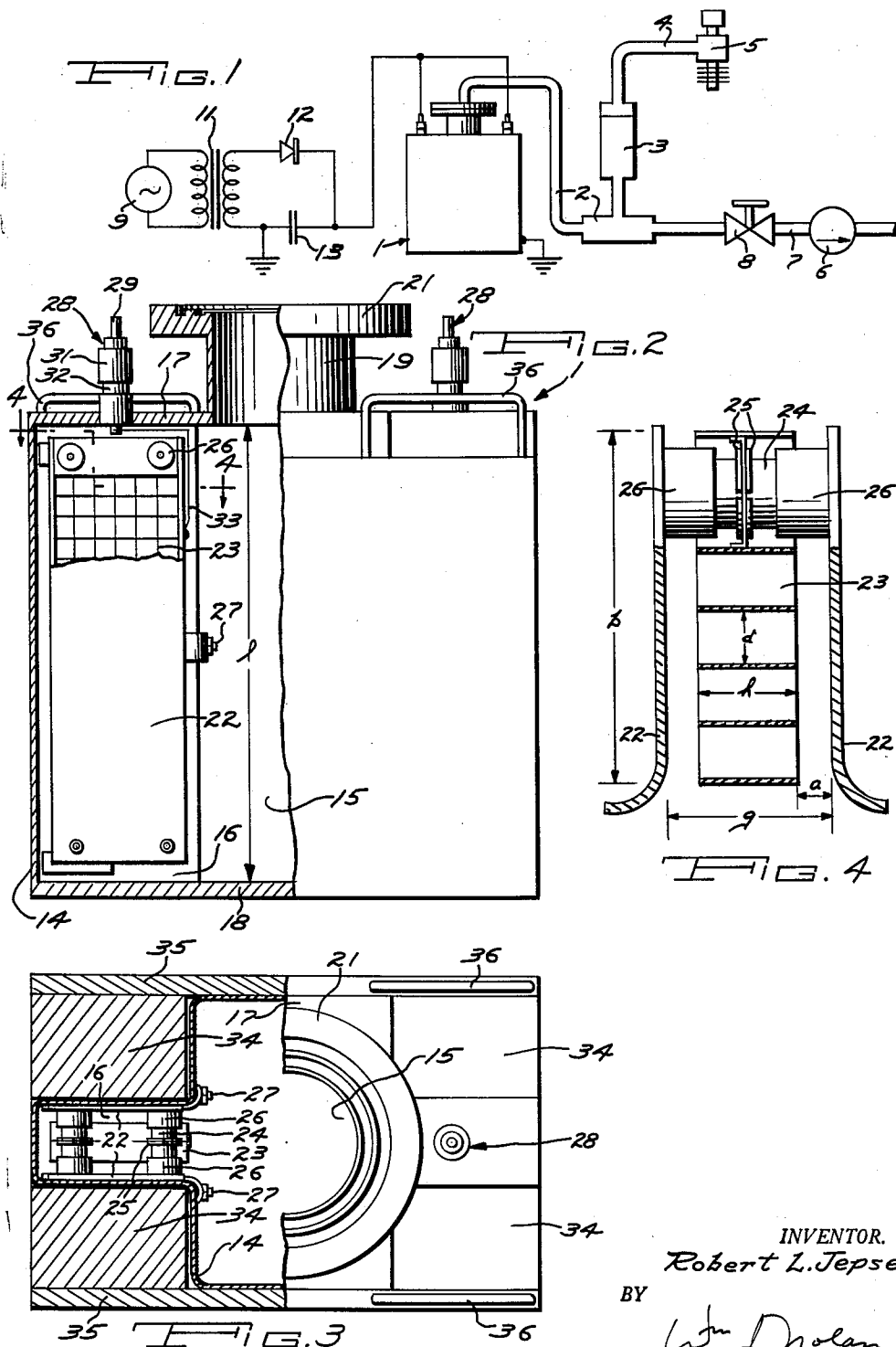
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3,094,639

GLOW DISCHARGE METHOD AND APPARATUS

Filed Oct. 6, 1960

2 Sheets-Sheet 1



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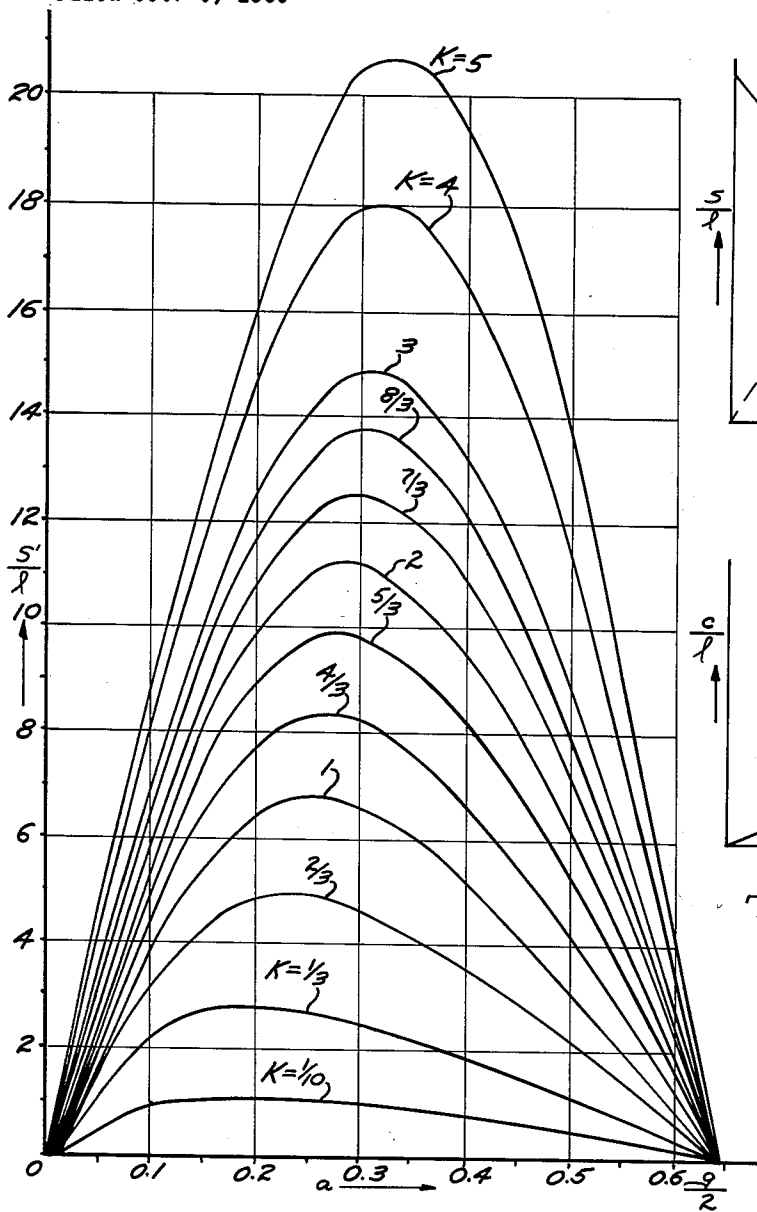


FIG. 7

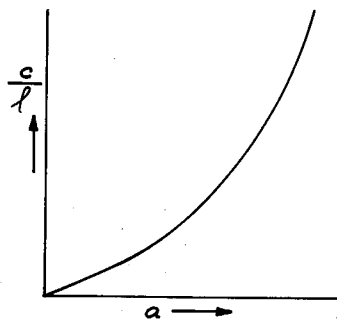
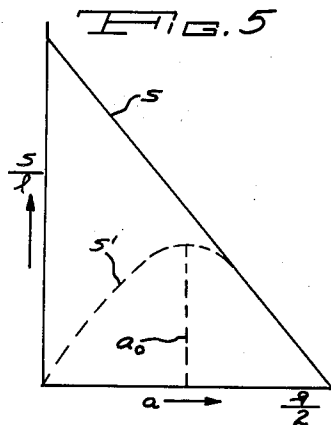


FIG. 6

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3,094,639

GLOW DISCHARGE METHOD AND APPARATUS
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5 Claims. (Cl. 313-7)

The present invention relates in general to glow discharge getter ion vacuum pump apparatus and more particularly to a method of improving the pumping speed of such devices. Such a vacuum pump is extremely useful for providing uncontaminated high vacuum as required in many devices.

Heretofore, vacuum pumps have been built having for their principle of operation the establishment of a glow discharge within the interior of each of a plurality of open-ended tubular anode cells disposed between and spaced apart from two cathode plates and having a magnetic field threaded through the anode cells. Positive ions produced by the glow discharge are directed against the cathode plate. In the pump, the impinging ions produce sputtering of a reactive cathode material. The sputtered material is collected upon the interior surfaces of the pump where it serves to entrap molecules in the gaseous state coming in contact therewith. Some atoms are buried in the cathode plates. In this manner, the gas pressure within the vessel enclosing the cathode and anode elements is reduced.

The pumping speed per unit of cathode area increases with increasing magnetic field intensity B assuming the cells can be aligned in the field B . In the interest of reducing leakage flux the gap width between cathode plates is preferably relatively short compared with the transverse dimension of the gap. For a given magnetic field intensity B and gap width the problem is to utilize the field B as efficiently as possible.

The intrinsic pumping speed of such pumps increases substantially linearly with the height of the anode cells, but as the height of the anode cells approaches the width of the gap between the cathode plates the usable pumping speed approaches zero because of conductance limitations.

According to the teachings of the present invention, once given the size of the magnet air gap in a getter ion vacuum pump the optimum spacing between the cathode and anode can be determined to obtain the maximum usable pumping speed.

The principal object of the present invention is to provide a novel improved glow discharge getter ion device with the proper electrode spacings for a given gap between cathode plates whereby the desired operating performance of the pump which is dependent upon gas access to the pumping assembly can be obtained.

One feature of the present invention is the provision of a method for selecting the cathode to anode spacing in a glow discharge getter ion pump so that the usable pumping speed of the vacuum pump is maximized.

Another feature of the present invention is the provision of a method for selecting the anode height in a glow discharge getter ion pump for a given gap between cathode plates so that the desired operating performance of the pump can be obtained.

Another feature of the present invention is the provision of a novel glow discharge getter ion pump with the cathode spacing in the range of 1.15 to 1.35 inches and with the cathode to anode spacing in the range .20 to .35 inch.

Other features and advantages of the present invention will become apparent upon a perusal of the specification

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taken in connection with the accompanying drawings, wherein:

FIG. 1 is a schematic block diagram depicting a typical evacuation system utilizing the novel vacuum pump of the present invention,

FIG. 2 is a side view partly in cross section of a novel electrical vacuum pump apparatus of the present invention,

FIG. 3 is a top view partly in cross section of a novel electrical vacuum pump apparatus of the present invention,

FIG. 4 is a cross sectional view of a portion of the structure of FIG. 2 taken along line 4-4 in the direction of the arrows,

FIG. 5 is a graph showing the pumping speed per unit of anode length vs. the cathode-anode spacing,

FIG. 6 is a graph showing the conductance into the anode cellular compartments as a function of the cathode-anode spacing, and

FIG. 7 is a graph of usable pumping speed per unit of anode length vs. the cathode-anode spacing for a given gap between cathode plates.

Referring now to FIG. 1 there is shown in schematic block diagram form the novel electrical vacuum pump of the present invention as utilized for evacuating a given structure. More specifically, an electrical vacuum pump 1 is connected via a hollow conduit 2 to a compression port 3 and thence via a hollow conduit 4 to a structure 5 which it is desired to evacuate. The compression port 3 serves to provide a coupling whereby the structure 5 and associated conduit 4 may be removed and replaced by another structure and conduit for successive evacuation of a plurality of structures 5. A mechanical vane pump 6 is also connected to the compression port 3 via conduit 7 and pinch-off valve 8. To evacuate the structure 5, the mechanical vane pump is put into operation serving to reduce the pressure within the structure 5 to between 5 and 20 or lower microns at which point the valve 8 is closed and the electrical vacuum pump 1 started.

Pump 1 is supplied with operating potentials from a source 9 as, for example, a 60-cycle power line via transformer 11. The secondary of transformer 11 is provided with a rectifier 12 and a shunting smoothing capacitor 13 whereby a D.C. potential may be applied between anode and cathode members of the electrical vacuum pump 1, which will be more completely described below. Although a preferred embodiment utilizes a D.C. potential, A.C. potentials are also operable.

Referring now to FIGS. 2, 3 and 4, the electrical vacuum pump 1 includes a vacuum tight envelope 14 as of, for example, stainless steel. The envelope 14 is provided with a central rectangular chamber 15 having a pair of outwardly extending lesser rectangular chambers 16 communicating with the central rectangular chamber 15 through longitudinal openings in the side walls thereof. The ends of the envelope 14 are closed off by top and bottom end walls 17 and 18 respectively, suitably sealed to the side walls of the envelope 14 as by heliarc welding.

A cylindrical exhaust tubing 19 such as stainless steel, is fixedly secured in a vacuum tight manner to the top wall 17 surrounding an aperture therein and thereby communicates with the central chamber 15. An annular flange 21 is carried from the top end of the exhaust tubing 19 for connecting the exhaust tubing 19 and hence the electrical vacuum pump 1 in a vacuum tight manner to the hollow conduit 2. In practice the conduits 2, 4, and 7 will be as wide as the exhaust tubing 19 but are shown smaller in the drawing for sake of convenience.

The pumping assemblies of the electrical vacuum pump 1 are carried within the two lesser rectangular chambers 16. The pumping elements include two mutually parallel

spaced apart cathode plates 22 of a reactive material such as titanium and a rectangular cellular anode as of, for example, titanium 23. The cellular anode is carried between and spaced from the cathode plates 22 by means of a plurality of insulator spacers as of alumina ceramic. The anode 23 is held on the spacers 24 by means of a pair of snap rings 25 which snap into annular grooves in the outside surface of the spacers 24. The spacers 24 serve to insulate the anode from the cathode and present the correct spacing between the cathode plates 22 and the cellular anode 23. A hollow cylindrical sputter shield 26 is provided around each end of each spacer 24 to shield the insulator spacer 24 from sputtered cathode material which might otherwise coat the insulator spacers 24 and produce unwanted voltage breakdown or current leakage thereacross.

The pumping assembly is secured within one of the lesser rectangular chambers 16 by means of bolts 27 which pass through apertures in a portion of the cathode plates 22 which project from the main part of the pumping assembly and are curved to lie against a wall of the central rectangular chamber 15 when the remainder of the pumping assembly is positioned within one of the lesser chambers 16.

High voltage is supplied to the anode 23 within the electrical vacuum pump via the intermediary of a high voltage lead-through insulator assembly 28 including a conductive rod 29 adapted for connection to the power source 9 and vacuum sealed within a hollow cylindrical insulator 31 such as alumina ceramic. The hollow insulator 31 is connected to the vacuum envelope 14 in a vacuum tight manner by an annular insulator frame 32 such as Kovar. Within the vacuum tight envelope 14 a lead 33 connects the conductive rod 29 to the cellular anode 23.

A magnetic field, typically between 1,000 and 2,000 gauss, is applied perpendicularly to the cathode plates 22 by a plurality of rectangular magnets 34 such as ferrite magnets. The magnets 34 are fixedly secured to rectangular pole pieces 35, which are fixedly secured to the pump envelope 14 by any desired means. A pair of handles 36 are fixedly secured to each of the pole pieces 35 for easy handling of the pump.

In operation, a positive potential, typically between 3 and 10 kv., is supplied to the anode 23 via the conductive rod 29 and the lead 33. The vacuum envelope 14 and therefore the cathode plates 22 are preferably operated at ground potential to reduce hazard to operating personnel. With these potentials applied a region of intense electric field is produced between the cellular anode 23 and the cathode plates 22. This electric field produces a breakdown of the gas within the pump resulting in a glow discharge within the cellular anode 23 and between the anode 23 and cathode plates 22. The glow discharge results in positive ions being driven into the cathode plates 22 to produce dislodgment of reactive cathode material which is thereby sputtered onto the nearby anode 23 to produce gettering of molecules in the gaseous state coming in contact therewith. Other atoms bury themselves in the cathode plates. In this manner, molecules from the entire system flow into the region between the cathode plates 22 and are pumped, and the pressure within the vacuum envelope 14 and therefore structures communicating therewith is reduced.

Economics and other considerations as stated above will determine the magnet air gap. The width of the magnet air gap will essentially determine the width g of the gap between the cathode plates 22 because both the thickness of the envelope wall 14 and the thickness of the cathode plates are relatively standard in pumps with pumping speeds in the range of 100–5,000 l./sec., and which pump down to pressures on the order of 1×10^{-9} mm. of Hg. Typically, the envelope 14 will be 100 mils thick and the cathode plates 90–120 mils thick.

The intrinsic pumping speed S of an entire pumping assembly made up of N anode cellular compartments is

$$S = NS_0 \quad (1)$$

where S_0 is the intrinsic speed of a single cellular compartment. The intrinsic speed S_0 varies substantially linearly with the height h of the cellular compartment. Therefore, the following relation exists

$$S_0 = Kh = K(g - 2a) \quad (2)$$

where K is a function of the voltage V , the magnetic field intensity B , the cell geometry, the cathode material, the gas being pumped and its pressure and a is the cathode-anode spacing. Therefore, Equation 1 can be rewritten as follows:

$$S = NKh = NK(g - 2a) \quad (2)$$

The total number of cellular compartments N can be expressed as the product lN_1 where l is the length of the anode element (FIG. 2) and N_1 is the number of cellular compartments per unit of length. Thus, in rewritten form Equation 3 becomes

$$\frac{S}{l} = N_1 K (g - 2a) \quad (4)$$

This relationship is shown in FIG. 5 which is a graph showing the pumping speed S per unit of anode length l vs. the cathode-anode spacing a , assuming the width g between cathode plates is kept constant. The graph shows the substantially linear relationship between S/l and a .

However, the intrinsic speed S cannot in general be realized since as the anode height h increases, or in other words as the cathode-anode spacing a decreases, the conductance into the pumping region is continuously decreased, whence the rate at which molecules can be pumped is reduced from the rate that would exist in the absence of conductance limitation.

The conductance C into the cellular compartments can be approximated by assuming that the conductance C through the cathode-anode space is represented by a slab line in which case the conductance C (for air) for the two cathode-anode spaces is represented by the following expression:

$$C = 2 \times 200.8 \frac{a^2 l}{b} \quad (5)$$

or

$$\frac{C}{l} = 401.6 \frac{a^2}{b} \quad (6)$$

wherein b is the width of the cellular anode 23 (FIG. 4). FIG. 6 is a graph of conductance per unit of anode length l vs. the cathode-anode spacing.

By dividing Equation 4 by Equation 6, we obtain the following expression:

$$\frac{S}{C} = \frac{N_1 K (g - 2a) b}{401.6 a^2} \quad (7)$$

This expression (7) does not give the actual usable speed S' of the pumping assembly at the entrance to the interaction region between the cathodes because some of the cellular compartments are distributed in a path leading away from the entrance to the interaction region. Thus, a greater volume of gas will flow to the cellular compartments positioned adjacent the entrance than those positioned a distance from the entrance. Taking this distributed pumping relationship into account, the actual usable speed S' of the pumping assembly is related to the intrinsic speed S of the pumping assembly by the following expression:

$$\frac{S'}{S} = \frac{\tanh \sqrt{\frac{S}{C}}}{\sqrt{\frac{S}{C}}} \quad (8)$$

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From Equation 8

$$\frac{S'}{l}$$

can be determined using the following relationship:

$$\frac{S'}{l} = \frac{S'}{S} \frac{S}{l} \quad (9)$$

The resulting Equation 9 will be in terms of a , b , g , N_1 and K . By measuring the speed of a single cell (where conductance is not a significant factor) for fixed g and a and the desired parameters on which K depends, K can be determined from Equation 2. Then the usable speed S' can be plotted vs. cathode-anode spacing a for the given b , g , N_1 and K from Equation 9. The dashed line in FIG. 5 shows the actual usable speed

$$\frac{S'}{l}$$

for the particular intrinsic speed

$$\frac{S}{l}$$

illustrated by the solid line in that figure. As illustrated there, the usable speed

$$\frac{S'}{l}$$

reaches an optimum at $a=a_0$.

Since the cathode-anode spacing a is directly related to the anode height h by the relationship $g=h+2a$, for any particular gap width g the optimum usable pumping speed S' could be selected in terms of the anode height h instead of the cathode-anode spacing a as outlined above.

In some instances such as extremely low pressures, it may not be desirable to operate at the optimum usable speed since the properties of the glow discharge may deteriorate for wide cathode anode spacings. Therefore, in selecting the cathode-anode spacing for pumps continuously operating at these low pressures, the usable speed S' can be plotted and a cathode-anode spacing a smaller than a_0 selected which does not sacrifice too much usable speed.

If it is desired to obtain the optimum cathode-anode spacing for a given gap where the parameters of magnetic field intensity B , voltage V , cell geometry, cathode material, pumped gas, and operating pressure of the pump may change or can be varied, the procedure outlined below can be followed. S'/l can be plotted vs. a for given b , g , and N_1 and a number of arbitrarily selected values of K over a broad range giving a family of curves as shown in FIG. 7. Therefore, the above-mentioned parameters can be varied as desired and with each particular combination an indication of the usable speed S'/l and the optimum cathode-anode spacing a_0 can be obtained by a measurement of the intrinsic speed of a single cell S_0 to determine the actual value of K .

By plotting a family of curves such as those illustrated in FIG. 7 a critical range for the cathode-anode spacing a can be determined which will provide optimum usable pumping speed S' over a wide range of K . FIG. 7 is an actual plot of

$$\frac{S'}{l} \text{ vs. } a$$

for a pumping assembly as described above with $g=1.25''$, $b=3''$, and $N_1=12$. As shown by the graph, if the value of a is located within the range of approximately $0.2''$ to $0.35''$ the usable pumping speed S' will be nearly maximum for an extremely wide range of K . A value of a midway of this range such as $0.275''$ will provide nearly maximum pumping speed S' for all values of K shown, and a can be adjusted up or down within this critical range of $0.20''$ to $0.35''$ when the value of K during operation of the pump is expected to be small

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or large, respectively. This critical range has been shown to hold true for gaps of $1.15''$ to $1.35''$. It is apparent from the curves in FIG. 7 that for the larger values of K it becomes more important to lie within this critical range for a since the slope of the curve of S'/l vs. a becomes greater adjacent the maximum point in the curve for greater values of K .

The results of tests on structures designed by the method outlined above agreed closely with the computed results. An electrical vacuum pump with a gap approximately the same as the gap for which the curves in FIG. 7 were drawn operated on a K level substantially the same as the curve for $K=\frac{1}{2}$ and had a cathode-to-anode gap of $a=0.32''$. According to FIG. 7 the pump was operating with a speed about 95% of its maximum usable speed. Prior pumps of this type with a gap approximately the same as the gap for which the curves in FIG. 7 were drawn operated on a K level substantially the same as the curve for $K=\frac{1}{2}$ and had a cathode-anode gap of $a=0.12''$. According to FIG. 7 those pumps were operating with a speed about 78% of their maximum usable speed.

The theory used to obtain the optimum cathode-anode spacing may be refined in the following ways: the effect of the aperture on conductance can be taken into account; a more precise form for the slab line conductance can be obtained graphically than is given by Equation 6; and empirically determined values of S_0 as a function of h or a can be employed instead of the simple expression of Equation 2. These refinements do not change the critical range of $0.20''$ - $0.35''$ for a for gaps between $1.15''$ and $1.35''$.

What is claimed is:

1. A glow discharge apparatus including an anode member subdivided into a plurality of lesser hollow open-ended cellular compartments, cathode members disposed opposite the open ends of said cellular compartments, and means for producing and directing a magnetic field coaxially of said lesser cellular compartments for enhancing the glow discharge current, said cathode members being spaced from one another by a value between $1.15''$ and $1.35''$ and the cathode-anode spaces being within the range of $0.2''$ to $0.35''$.

2. A glow discharge apparatus including an anode member subdivided into a plurality of lesser hollow open-ended circular compartments, cathode members disposed opposite and equally-spaced from the open ends of said cellular compartments, and means for producing and directing a magnetic field coaxially of said lesser cellular compartments for enhancing the glow discharge, said cathode members being spaced from one another by approximately $1.25''$ and each of said cathode members being spaced from said anode member by a distance of $0.2''$ to $0.35''$.

3. A glow discharge getter ion vacuum pump apparatus including a pair of parallel spaced apart cathode plates, an anode structure disposed midway between said cathode plates and having a plurality of glow discharge passageways therein, means for applying a high voltage between said anode structure and said cathode plates, said anode structure and said cathode plates adapted when energized by said high voltage means to produce a glow discharge therebetween for pumping gaseous matter, and means for producing and directing a magnetic field coaxially of said glow discharge passageways for enhancing the pumping speed of the pump, said cathode members being spaced from one another by a value between $1.15''$ and $1.35''$ and each of said cathode plates being spaced from said anode structure by a distance falling within the range of $0.2''$ to $0.35''$.

4. A glow discharge getter ion vacuum pump apparatus including a pair of parallel spaced apart cathode plates, an anode structure disposed midway between said cathode plates and having a plurality of glow discharge passageways therein, means for applying a high voltage

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between said anode structure and said cathode plates, said anode structure and said cathode plates adapted when energized by said high voltages means to produce a glow discharge therebetween for pumping gaseous matter, and means for producing and directing a magnetic field coaxially of said glow discharge passageways for enhancing the pumping speed of the pump, said cathode members being spaced from one another by approximately 1.25" and each of said cathode plates being spaced from said anode structure by a distance falling within the range of 0.2" to 0.35".

5. A glow discharge getter ion vacuum pump apparatus including, a pair of parallel cathode plates spaced apart a given distance g , an anode structure disposed midway between said cathode plates and having a plurality of glow discharge passageways therein, there being a given number N_1 passageways of given width b per unit of length l , means for applying a high voltage between said anode structure and said cathode plates adapted when energized by said high voltage means to produce

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a glow discharge therebetween for pumping gaseous matter, and means for producing and directing a magnetic field coaxially of said glow discharge passageways for enhancing the pumping speed of said pump, each of said cathode plates being spaced from said anode structure a determinable distance a so as to give maximum pumping speed when

$$\frac{S'}{l} = \frac{\tanh \sqrt{\frac{S}{c}}}{\sqrt{\frac{S}{c}}} (N_1 K (g - 2a))$$

is a maximum where

$$\frac{S}{c} = N_1 K (g - 2a) \frac{b}{(401.6 a^2)}$$

and K is a constant within the range of $\frac{1}{10}$ to 5 liters per inch second.

No references cited.