

Oct. 24, 1944.

F. W. STALLMANN

2,361,245

VACUUM PUMP

Filed March 27, 1943

2 Sheets-Sheet 1

Fig. 1.

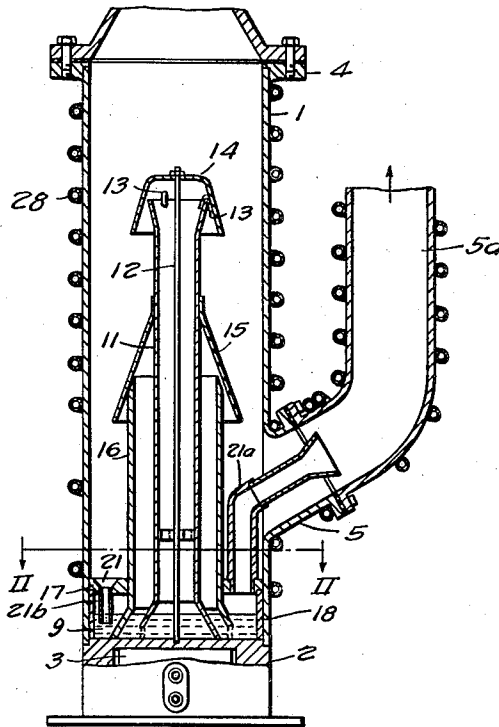
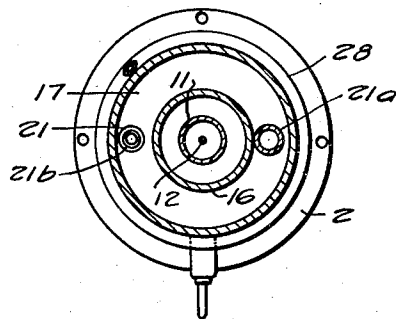


Fig. 2.



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2 Sheets-Sheet 2

Fig. 3.

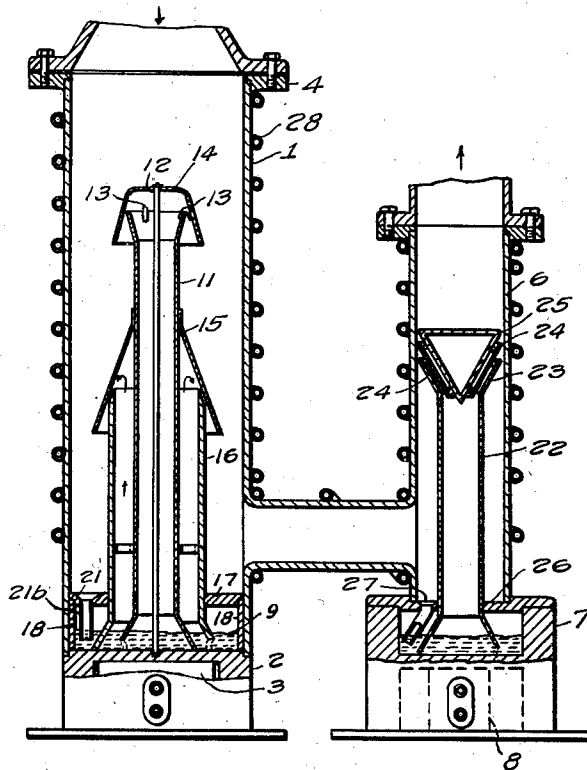


Fig. 4.

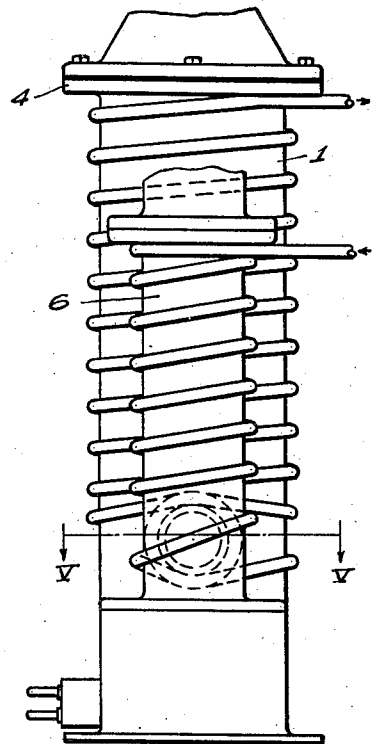


Fig. 6.

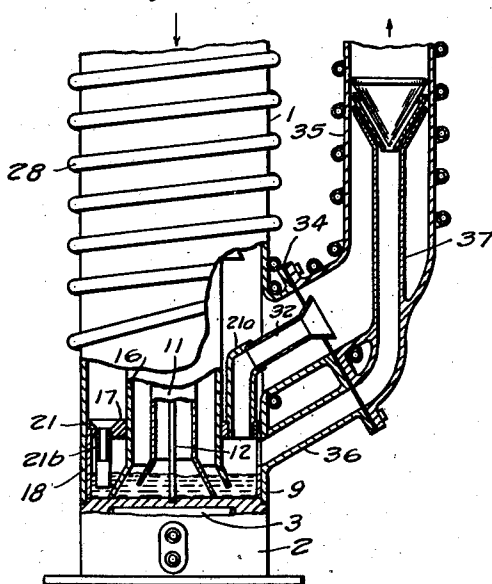
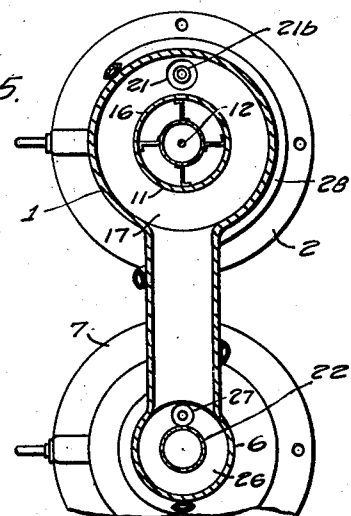


Fig. 5.



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VACUUM PUMP

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5 Claims. (Cl. 230—101)

My invention relates to vacuum pumps for producing the high vacua which are needed for certain types of electronic discharge apparatus, and in particular relates to vacuum pumps of the diffusion type. While the principles are of broader application, I illustrate the invention by an embodiment in which the working fluid producing the diffused vapor comprises an oil or other hydrocarbon.

Diffusion pumps of the general type illustrated in Patent 1,320,874 to Langmuir, and using oil as a working fluid in accordance with the disclosure of Crawford Patent 1,367,865 have come into wide use in the art of exhausting containers, notably electronic discharge tubes and the like, to pressures of the order of a small fraction of a micron, a micron being one millionth of the pressure of a column of mercury one meter high. Basically, such pumps make use of a stream of some vapor flowing through an orifice from a boiler, the orifice being so positioned that the vapor stream entrains gas molecules flowing from a container in which the vacuum is to be produced, and drives these molecules in the direction of a piping system issuing eventually into the atmosphere, the vapor itself being condensed on a properly cooled surface in the path of outflowing of the gases, and then being returned to the boiler for reuse. It is usually most economical to provide the offtake piping system with so-called backing-up pumps of the mechanical type which reduce the pressure at the outlet from the diffusion pump proper to a pressure of the order of 50 microns or less; and even in such cases it is usually found more efficient to design the diffusion pump so that a number of vapor jets operate in tandem or series with each other so that the total pressure rise from the intake to the offtake of the pump comprises a number of steps or stages. The type of pump by which I illustrate the broader principles of my invention herein comprises a plurality of such stages.

Multi-stage diffusion pumps are not in themselves novel as is shown, for example, by Nelson Patent 2,291,054, but I have devised certain features which greatly improve the operation of these prior art pumps in a way which will be explained more fully below. Typical examples of such features are the shape of nozzle or orifice through which the working vapor is ejected; the spacing between the orifices of successive stages; the division of the surface of the boiling liquid into a number of separate areas having certain specific ratios to each other and individual to various stages of the pump; and the mechanical assembly which makes it much easier to dismantle and clean my pump than such prior art pumps as I am familiar with.

The principles of my invention will be pointed

out in more detail in connection with the description of the drawings, in which:

Figure 1 is a view partly in elevation and partly in cross section of one embodiment of my invention,

Fig. 2 is a sectional view taken along the line II—II thereof.

Fig. 3 is a view similar to Fig. 1 of a different modification of my invention.

Fig. 4 is an elevational view at right angles to Fig. 3.

Fig. 5 is a horizontal sectional view taken along the line IV—IV in Fig. 4; and

Fig. 6 is a view partly in elevation and partly in section of another embodiment of my invention.

Referring in detail to Fig. 1, the main body of my pump comprises a vertical cylindrical casing 1 closed at its lower end by a base 2 having an electrical heating element 3 of a type too well-known to need a detailed description in good thermal contact with the floor of the cylinder 1. If desired, the elements 1 and 2 may be made of iron or steel, although either may alternatively comprise aluminum. The upper end of the container 1 is provided with a flange 4 to which can be bolted by a vacuum tight connection an intake for gases from the piping system which is to be evacuated. Roughly one fifth of the height of the flange 4 above the base 2, an offtake pipe 5 leading to a backing-pump (not shown) is connected vacuum tight through a flanged connection 5a to the cylinder 1.

The bottom portion of the cylinder 1 contains the working fluid 9 for the pump, the latter being heated by the electrical heater already described to a sufficient temperature to cause a copious off-flow of vapor.

Centrally positioned in the cylinder 1 is a cylindrical vertical pipe 11 which may, if desired, be of the same material as the cylinder 1, and which is preferably flared outward at its lower end to rest on the base 2. The cylinder 11 is likewise provided with an outwardly flared portion at its upper end as will be described in more detail below. A tie rod 12 may be positioned in the central axis of the cylinder 11, its lower end screwing into the base 2.

Upon the upper end of the cylinder 11 I support, preferably by means of three small spacing pieces 13 overlapping its edges, a cap 14 roughly in the form of a truncated cone. The precise form of the cap will be discussed in detail below. The cap 14 is held firmly against the spacers 13 by a nut threaded on the end of the tie rod 12.

It will be evident that the upper portion of the cylinder 11 together with the cap 14 constitutes what may be termed an annular nozzle or orifice from which vapor emitted by the central part of the liquid 9 and flowing through the cylinder 11 is

discharged into the annular space between the walls of the cylinder 11 and the cylindrical container 1. The diameter of the inner cylinder 11 is made roughly of the order of $\frac{1}{4}$ of that of the cylinder 1 in order to provide a suitably large volume for the annular space into which the vapor issues from the above-mentioned annular orifice. While it might be possible to make the cylinder 11 of a diameter smaller than that just mentioned, such reduction in diameter would not greatly add to the available annular space surrounding the cylinder 11 but would materially reduce the pressure of the vapor at the inlet side of the above-mentioned annular orifice. Beyond these general limitations the diameter of the cylinder 11 is not a critical dimension but failure to realize the importance of even these general limitations has resulted in inefficiency in many pumps of the prior art, of which I am acquainted.

A hood or umbrella 15 of conical form is fastened to the cylinder 11 at a distance below the lower end of the cap 14 which is roughly equal to the mean free path of the molecules of the vapor issuing from the upper end of cylinder 11.

Surrounding the cylinder 11 is a second and shorter cylinder 16 which may be of the same material as cylinder 11 and the lower end of which rests on the base 2. The diameter of the cylinder 16 should be in the neighborhood of $\frac{2}{3}$ that of the cylinder 1, the principal limitation on this dimension being that, if too small, it will reduce the vapor pressure at the orifice issuing from its upper end, and that if too large it will leave too little space for gases to flow from the space above the umbrella 15 to the offtake conduit 5.

The upper end of the cylinder 16 is bevelled and spaced slightly away from the umbrella 15 to provide an annular orifice from which vapors rising from the surface of the liquid 9 into the space between the cylinders 11 and 16 can be ejected into the annular space intervening between the cylinders 16 and 1.

Approximately $\frac{1}{16}$ of the length of the cylinder 1 above the base 2 is provided a horizontal partition 17 which may conveniently be screwed into threads cut on the interior wall of the cylinder 1 and which covers the space between the cylinder 16 and the outer wall of the cylinder 1. This partition 17 is provided with a groove in its lower face which fits the upper end portion of a liner 18 for the interior wall of the lower portion of cylinder 1.

The partition 17 is likewise provided with a bevelled hole 21 issuing into a small spout 22 which is intended to dip below the surface of the liquid 9, and to return the latter to the condensate of the vapor which has been condensed on the inner surface of the cylinder 1.

A bent cylinder or nozzle 21a is removably inserted in the disc 17 and extends to eject vapor into offtake 5.

The exterior wall of the casing 1 and 5 is surrounded by a helical pipe 28 through which water or other cooling fluid flows to maintain the temperature of such walls at a sufficiently low temperature to condense the vapor flowing from the orifices and nozzles already described.

The general mode of operation of the above described pump structure is as follows: The fluid 9 which may be any suitable material described in the art as useable in diffusion pumps, but for which I preferably employ a hydrocarbon of the ring-compound type such as molecular lubricant is heated and the resulting vapor flows up from its surface through the respective cylinders 11, 16 and 21a. It will be noted that the ends of the

first two of these cylinders cooperate respectively with the cap 14 and the umbrella 15 to form annular orifices through which a stream of vapor flows out into the annular space surrounding such cylinders. These streams of vapor molecules entrain any gases present in the space adjacent their outlets, and the principal component of velocity of these molecules being substantially parallel to the axis of the respective cylinders they impart a similar velocity to any gases which they entrain. Thus the vapor flowing from the orifice at the upper end of the cylinder 21a will entrain any gas in the annular space between its upper end and the wall of pipe 5 and drive it upward in the direction of the arrow appearing above pipe 5a. The backing pump connected to the upper end of the pipe 5a will then carry this gas away and reject it to the atmosphere. However, the vapor flowing from the orifice of cylinder 21a will quickly strike the cold walls of the cylinder 6 and be condensed. It will thereafter gradually travel back down the interior wall of the pipe 5 to the spout 21b to be reused in the boiler energized by heater 3. Thereupon any gas or vapor present in the annular space between the nozzle 21a and pipe 5 below the upper end of nozzle 21a will diffuse into the space just described as evacuated by the gas entrained through the efficiency of the vapor jet and hence the orifice at the upper end of nozzle 21a constitutes a pump which continually tends to decrease the pressure within the pipe 5, and the lower portion of cylinder 1. In effect, therefore, the pipe 5 may be considered to constitute a backing pump evacuating gas from the lowest portion of the pump cylinder 1.

Similarly, vapor emanating from the portion of the liquid 9 between the cylinders 11 and 16 flows out through the annular orifice between the upper end of cylinder 16 and the umbrella 15; its molecules have a principal velocity component in the downward direction toward the inlet to pipe 5 and so impart a downward velocity to any gas in the region of the lower edge of the umbrella 15, thereby tending to evacuate this region. The molecules of this vapor stream, however, quickly acquire enough random velocity in the horizontal direction to be projected into contact with the cool wall of cylinder 1. They are, accordingly, condensed on the latter and travel down the wall thereof to the partition 17 and back into the liquid 9 through the spout 21b. The orifice about the upper end of the cylinder 16 thus constitutes in effect a backing pump for evacuating any permanent gas molecules present in the region of the lower edge of umbrella 15. Consequently, any such gaseous molecules present in the annular space above the umbrella 15 will tend to diffuse into the space below the lower edge of the umbrella 15 and be carried away through the pipe 5 to the outlet of the system.

In a similar manner, the annular space between the upper end of the cylinder 11 and the cap 14 constitutes an annular orifice through which vapor flows with its molecules having a high component of velocity downward parallel to the axis of cylinder 1. These vapor molecules will impart a similar downward component of velocity to any gas present in the annular space about the lower edge of cap 14 and tend to drive this gas into the space below the umbrella 15. Gas molecules present in the space above the lower edge of the cap 14 will, therefore, diffuse into the space evacuated by the molecules below the edge of cap 14 and a continuous stream of gas will consequently

flow from the apparatus to be evacuated which is attached to the flange 4. The vapor molecules flowing from the orifice about the upper end of cylinder 11 will quickly acquire components of horizontal velocity which will carry them into contact with the cooled walls of the cylinder 1 and they will then pass down the sides of the latter to the partition 17 and into the boiler through spout 21b.

It will be evident from the foregoing that the vapor jets flowing respectively from the upper end of cylinders 11, 16 and 21a constitute various stages of a pump for evacuating any containers connected to the flange 4; that the stream flowing from cylinder 11 constitutes the first, or lowest pressure, or highest vacuum stage of this pumping system; that the vapor flowing from the upper end of cylinder 16 constitutes an intermediate stage; and that the vapor flowing from the upper end of cylinder 21a constitutes the highest pressure or lowest vacuum stage.

In actual practice, it is found impossible to obtain pumping fluids which are literally and absolutely devoid of impurities; and in particular, while the hydrocarbon fluids such as I have proposed using have nearly uniform constitution, they are nevertheless found to have components of slightly different vapor pressures at any given temperature. The result of this is that the components having higher vapor pressures tend to boil away first and leave the components of lower vapor pressure behind. The ultimate vacuum obtainable about the outlet of the orifices in any stage of the pump is no greater than the vapor pressure of the material issuing from the orifice, and hence it is obviously desirable that the higher vapor pressure materials shall issue from the orifice at the top of the cylinder 16 rather than from the higher vacuum stage constituted by the orifice at the top of cylinder 11. With this in mind, I have arranged the cylinder 16 to have an opening in its lower wall beneath the level of the liquid 9 at one side of the pump, and the cylinder 11 to have a similar opening at a diametrical point. In this way what may be termed a labyrinth is formed between the cylinders 11 and 16 below the surface of the liquid 9 so that any liquid flowing down the walls of cylinder 1 to spout 21b must first flow into the space between cylinders 11 and 16 and be heated there before it can flow around and through the other opening into the interior of cylinder 11. Before the liquid 9 reaches the cylinder 11, therefore, the higher vapor pressure components are boiled away and the vapor used in the second stage of the pump is accordingly made up largely of the higher-pressure components. On the other hand, the vapor flowing through and from the upper end of cylinder 11 to constitute the first and highest vacuum stage of the pump is predominantly the low pressure component.

The umbrella 16 is made to extend a considerable distance below the upper end of the cylinder 16 and in designing a pump for use of the hydrocarbon molecular lubricant, I have found it desirable to flare the umbrella 15 at an angle of approximately 15° to the vertical. I have found a width of about $\frac{1}{8}$ of an inch for the throat of this orifice to give good results. However, the form and dimensions of the orifice constituted by the cylinder 16 and umbrella 15 is not so critical a matter as is the shaping of the members constituting the orifice at the upper end of cylinder 11.

In the case of the last mentioned orifice, I have effected a great improvement over prior art devices by flaring the upper end of the cylinder 11 outwardly and also flaring the lower end of the cap 14, each at an angle of approximately $12\frac{1}{2}^\circ$ to the vertical. I have found that with the particular hydrocarbon present mentioned above, an annular spacing of about $\frac{1}{8}$ of an inch between the end of cylinder 11 and cap 14 gives good results, and that the distance from the throat of this $\frac{1}{8}$ space to the lower edge of the cap 14 may suitably be made about 1". In this way, it will be noted that the central line of the vapor jet is substantially parallel to the axis of tube 1.

While I do not wish to be limited by such a theory, it is my present belief that it is highly important in attaining pumping efficiency to minimize turbulence in the stream of vapor outflowing from the orifice just mentioned, and that such turbulence is greatly reduced at the pressures prevailing with the materials I have mentioned by proportioning the structure as I have just described. While I doubt if the matter is critical, I will state that I have used these proportions in a pump in which the inside diameter of the cylinder 1 was about 4".

Another important feature of contour of the out-flow passage for gas at the upper end of the cylinder 11 is the rounding of the upper corner of the cap 14. It is my belief that the rounding of this corner tends to produce a streamlining effect which reduces turbulence in the gas stream; but at any rate I have found increased efficiency to result from so rounding the upper face of the passage above the narrow gap between cylinders 11 and 14.

Another feature of importance, probably also effecting a decrease of turbulence in the vapor stream is that of making the distance between the lower edge of the cap 14 and the umbrella 15 of the order of the mean free path of the vapor molecules flowing from the lowest pressure orifice. The mean free path of molecules of the vapor for the pressure corresponding to its vapor pressure at the temperature of the wall of cylinder 1 can readily be calculated from known data of physical chemistry. In the case of the 4" pump above mentioned, I have found this mean free path to be of the order of 5 or 6".

Another feature of importance tending to promote efficiency in the operation of such a diffusion pump as is the proper proportioning of the relative areas of the surface of liquid 9 which are included respectively inside the cylinder 11 and between the cylinders 11 and 16, and between cylinder 16 and the wall 1. While I suspect that this may vary with the composition of the working fluid used, I have found that for the fluid I have specifically described, the areas above mentioned should be respectively in the ratios $\frac{1}{2}:1:2$.

Another feature of importance in practical operation of pumps is that they shall be easily dismantled for cleaning. The pump which I have shown in Fig. 1 can very readily be dismantled by merely unbolting the flange 4 and then after removing cylindrical nozzle 5a, unscrewing the partition 17 and the nut at the top of the tie rod 12. All parts in the interior of the cylinder 1 can then be readily lifted out and the entire assemblage subjected to cleaning operations.

While I have described the cylinder 1 as, in effect, backed up by a second pump comprising

the nozzle 5a, it will be recognized that other forms of backing pumps may be substituted at the outlet of the offtake pipe 5, and that the nozzle 5a and its parts are merely illustrative of one convenient form of backing pump.

Figs. 3 and 4 show a modification of my invention in which the lowest vacuum stage nozzle 5a is replaced by an auxiliary pumping cylinder 6 somewhat similar, in general, but different in detail, from the cylinder 1. The cylinder 6 is provided at its lower end with a base 7 and an auxiliary heater 8 of the same general character already described in connection with cylinder 1. The upper end of the cylinder 6 is provided with a flange to which a vacuum tight connection from a backing-up pump, for example, of the mechanical type, may be connected.

Centrally positioned in the cylindrical casing 6 is a cylindrical pipe 22 flared at its lower end and resting on the base 7 to which it may be affixed by wedge or screw clips or other suitable means. The upper end of the cylinder 22 is flared outwardly and extends to within a short distance of the cylindrical wall 6. Uniformly spaced from the upper flared end of the cylinder 22 and conveniently separated therefrom by spacing members 23 so as to leave an annular channel for outflow of gases is a member 24 having the form of a truncated cone. Similarly supported upon and spaced from the member 24 is a conical member 25 which extends to leave a narrow annular channel between its rim and the cylinder wall 6. A partition 26 separates the liquid containing chamber in the base 7 from the interior of the cylinder 6 and this partition is provided with a spout 27 through which liquid condensed on the walls of the cylinder 6 may flow back into the boiler chamber.

I have, however, found that with such a form of backing pump as cylinder 6, it is possible to discharge relatively large volumes of gas even though the pressure at the offtake side of pump 6 rises as high as 500 microns instead of the 50 microns backing pressure which I mentioned above. The pumping cylinder 6 has a very high pumping capacity even at extremely low pressures by reason of the large cross section of the annular vapor flows in its highest vacuum and intermediate vacuum stages. A backing pump of the type shown in cylinder 6 is able to discharge such large volumes of gas even against a pressure of 500 microns at its outlet side provided the distance between the upper edges of the cylinders 22 and elements 24 and 25 is of the order of $\frac{1}{16}$ of an inch and the spacing of member 24 from elements 25 and 22 likewise about $\frac{1}{16}$ of an inch.

Fig. 6 shows a slightly different modification of my pump in which the auxiliary pump 6 is replaced by a pair of pump elements. Thus the cylinder 1 may be similar to Fig. 1 except as follows. The partition 17 is provided at the side adjacent the outlet pipe with a conduit issuing into an orifice 32 having its upper end flared outwardly. The orifice 32 traversed by vapors boiling off from the surface of the fluid 9 constitutes what may be termed a third stage for backing up the first two stages embodied in cylinder 1 as already described in connection with Fig. 1. The conduit 32 is made readily detachable from the partition 17 so that it may be removed through the flanged opening of the offtake pipe 34 when it is desired to dismantle the pump section 1 by unscrewing partition 17. The flanged pipe 34 is provided for connecting an offtake pipe 35 which

is provided with the elements of a backing pump similar to that already described in connection with cylinder 6 of Fig. 1. This backing pump in pipe 35 draws vapor from the fluid 9 by an auxiliary conduit 36, 37 of the form shown. In effect, therefore, the pump shown in Fig. 4 is of the 4-stage type.

While I have described particular embodiments illustrating my invention, it will be recognized that the principles thereof are of broad application in arrangements which will be evident to those skilled in the art.

I claim as my invention:

1. A diffusion pump comprising a container having a liquid at its lower end, a first cylinder having its lower end extending below the surface of said liquid and having an annular orifice about its upper end, a second cylinder surrounding said first cylinder which is shorter and of larger diameter than said first cylinder and having an annular orifice about its upper end, the distance between the first mentioned orifice and the second mentioned orifice being of the order of the mean free path of molecules of the vapor of said liquid at the operating temperature of said container.

2. A diffusion pump comprising a container having a liquid at its lower end, a cylinder having its lower end extending below the surface of said liquid and having an annular orifice about its upper end, the upper end of said cylinder being flared outwardly, a cap in the form of a truncated cone extending downwardly over said flared end and enclosing the same, both said flared end and said cone flaring at an angle of about $12\frac{1}{2}^\circ$ relative to the axis of said cylinder.

3. A diffusion pump comprising a container having a liquid at its lower end, a first cylinder having its lower end extending below the surface of said liquid and having an annular orifice about its upper end, the upper end of said cylinder being flared outwardly, a cap in the form of a truncated cone extending downwardly over said flared end and enclosing the same, both said flared end and said cone flaring at about the same angle relative to the axis of said cylinder, so as to direct a vapor stream substantially parallel to said axis.

4. A diffusion pump comprising a cylindrical casing closed at its bottom end, a first cylinder axially disposed in said casing, a second cylinder shorter and of larger diameter than said first cylinder surrounding the latter, the lower ends of said cylinders resting upon the lower end of said casing, the area of annular spacing between said casing and said outer cylinder being about twice the area of the annular space between said first cylinder and said second cylinder, and the area of the space within said first cylinder being about $\frac{1}{2}$ the area of the annular space between said second cylinder and said first cylinder.

5. A vacuum pump comprising a cylindrical outer casing having its lower end closed by a first transverse partition, a first cylinder axially disposed within said casing, a second shorter cylinder of larger diameter surrounding said first cylinder, both said cylinders having one end resting upon said partition and a detachable second partition enclosing a space around the lower ends of said cylinders, and detachable means extending to the region of the upper end of said casing for securing said cylinders to said first transverse partition.

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