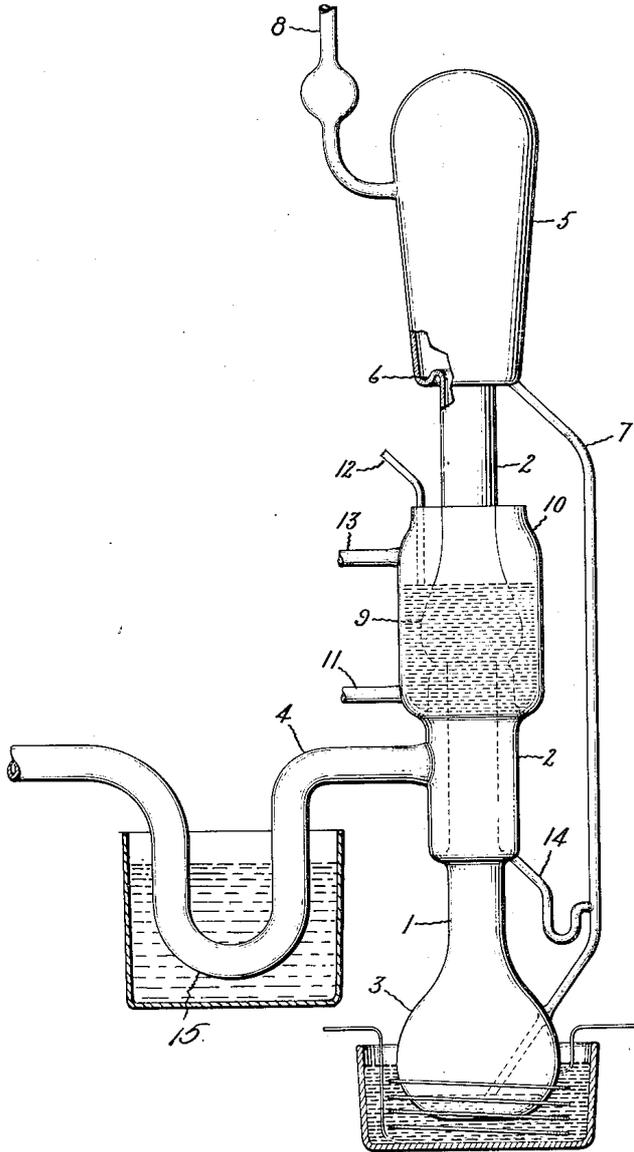


I. LANGMUIR.
METHOD OF AND MEANS FOR OBTAINING HIGH VACUA.
APPLICATION FILED FEB. 3, 1916.

1,393,550.

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Inventor:
Irving Langmuir,
by *Alfred H. Davis*
His Attorney.

UNITED STATES PATENT OFFICE.

IRVING LANGMUIR, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

METHOD OF AND MEANS FOR OBTAINING HIGH VACUA.

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Specification of Letters Patent.

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To all whom it may concern:

Be it known that I, IRVING LANGMUIR, a citizen of the United States, residing at Schenectady, in the county of Schenectady, State of New York, have invented certain new and useful Improvements in Method of and Means for Obtaining High Vacua, of which the following is a specification.

The object of my invention is to provide a simple and efficient means for obtaining high vacua in closed receptacles such as bulbs for incandescent lamps, mercury vapor rectifiers, X-ray tubes, electron discharge devices, etc. A further object of my invention is to provide an apparatus of this nature which will operate without mechanical movement of any of its parts and which will be quicker in its operation at low pressures than any exhaustion apparatus that has heretofore been employed.

In carrying my invention into effect I cause a high velocity stream of mercury vapor to flow through a tube toward a condensing chamber, and arrange the apparatus in such a way that a portion of the path of this stream communicates with the vessel which is to be exhausted. The gas or vapor which it is desired to remove is entrapped in the stream and carried along with it. I also provide means for preventing any of the mercury vapor from flowing away from the condensing chamber and toward the vessel which is being exhausted. As a result the gas or vapor which is to be removed will not at any point in its travel have to flow in an opposite direction to that of the stream of mercury vapor.

The features of my invention which I consider novel are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and what I consider its probable method of operation will best be understood by reference to the following description taken in connection with the accompanying drawing in which I have illustrated one way in which my invention may be carried into effect.

As indicated in the drawing the conduit formed by the tubes 1 and 2 has at its lower end a bulb 3 which contains mercury. The desired stream of mercury vapor is obtained by heating this bulb in any convenient way. I have found that the degree of heat applied to the bulb may easily be regulated by placing the bulb in a bath of oil in which

an electric heating unit is immersed. By varying the current in the heating unit the temperature may be varied as desired to vary the pressure in the bulb and the amount of mercury which will be vaporized. The tube 2 surrounds the tube 1 at its upper portion and communicates through the side branch 4 with the vessel which is being exhausted, thus forming a second conduit for the passage of gas between the vessel and the first conduit. At the top of the first conduit is a condensing chamber 5. The mercury vapor which condenses in this chamber collects in the groove 6 around the bottom and returns by means of the tube 7 to the bulb 3. The gas or vapor which is carried to the condensing chamber from the vessel which is being exhausted may be removed through the tube 8 by means of any convenient form of exhaust pump which is capable of producing a vacuum lower than the vapor pressure of mercury at the temperature at which the bulb 3 is maintained. The stream of mercury vapor which is produced in the bulb 3 flows through the tubes 1 and 2 with a high velocity and the gas or vapor from the vessel which is being exhausted comes in contact with the stream of mercury vapor in the region around the end of tube 1 and is carried along with it to the condensing chamber 5. The velocity and density of the stream is such, however, that no gas can return against the stream. A portion of the vapor in the stream will strike the wall of the tube 2 and condense. If this tube were allowed to become hot some of the mercury would reëvaporate, flow toward tube 4, and oppose the flow of gas from the vessel which is being exhausted. To avoid this the tube 2 is kept cool by fluid circulating in the vessel 10 which surrounds it so that any vapor which strikes the wall is prevented from reëvaporating. The enlargement 9 of tube 2 is so shaped that there is a general tendency for any gas which comes in contact with the stream of mercury vapor to be deflected upward and into the condensing chamber. It will be apparent that with this arrangement the gas which is to be carried out does not at any point have to travel in opposition to the stream of mercury vapor. The cooling fluid is conducted into the vessel 10 by means of the pipe 11 and withdrawn by suction on the pipe 12 which may be adjusted to vary the height of the fluid in the

vessel. Pipe 13 serves as an overflow in case pipe 12 should become clogged or fail to operate to carry the fluid away. I prefer to use water for cooling purposes though other liquids or an air blast may be used if desired. The mercury vapor which condenses on the wall of the tube 2 falls to the bottom and returns to bulb 3 by means of the tube 14. If it is desired to obtain a vacuum higher than that corresponding to the vapor pressure of mercury at room temperature a trap 15 may be provided in the pipe 4 which may be cooled by any convenient medium, such as ice, a mixture of ice and salt, or liquid air.

A greater portion of the molecules of gas emerging from the end of tube 1 will be moving in directions substantially parallel to that in which the stream is flowing. All of those molecules which are moving in directions at an appreciable angle to that of the stream so as to effectively oppose the movement of gas from the vessel which is being exhausted will strike the cooled walls of the enlargement 9 of tube 2 and condense and thus be removed from the stream. Hence, substantially all of the molecules remaining in the stream will move in approximately parallel directions toward the condenser 5 and substantially none of the molecules will flow in opposition to the flow of the gas.

The following example of an actual test made with apparatus such as I have described will give an indication of the results which may be obtained: A vessel having a capacity of about eleven liters and containing air at a pressure of 1,100 microns was exhausted to a pressure of 9.6 microns in sixty seconds, that is, the pressure was reduced to less than one one-hundredth of the original pressure. During the next twenty seconds the pressure was reduced to .011 micron or to about one one-thousandth of the pressure at the beginning of the twenty-second period. The pressure in the condensing chamber during the first sixty seconds fell from 870 microns to 164 microns and during the next twenty-second period from 164 microns to 13.5 microns.

I have found that with apparatus constructed in accordance with my invention, as is indicated by the above example, the pressure in the vessel which is being exhausted decreases more rapidly at very low pressures than at higher pressures and that the lighter the gas which is being removed the greater the speed of exhaustion whereas with all exhaustion apparatus depending upon mechanically moving parts for its operation the pressure does not decrease any faster at very low pressures than at higher pressures, and a light gas is not removed any faster than a heavier gas.

I am aware that apparatus similar in

form in some respects to that which I have shown has been used heretofore for pumping water and other fluids. For example, the well known steam injector utilizes a high velocity stream of steam to force water into a boiler. In this case, however, the operation depends upon the condensation of all of the steam by the water and the momentum of the steam is imparted to the water. A jet of steam moving at a high velocity has also been used to pump air from vacuum drying apparatus by means of a suction which is created thereby. Such a device, however, is operative only at pressures so high that there is no tendency for any of the steam to flow toward the receptacle from which the air is being exhausted.

The ordinary steam or air ejector depends for its operation upon a lowering of pressure caused by the high velocity of the jet in accordance with hydrodynamical principles. The gas which is being removed is thus sucked into the jet because the pressure in the jet is lower than that of the gas which is drawn into it. Since the pressure in the jet must always be considerable it is evident that the effect present in the ordinary ejector cannot be directly utilized to obtain a high vacuum. According to kinetic theory also the molecules in a jet of vapor passing out into a high vacuum must spread laterally so that there would be no tendency for gas at low pressures to be drawn into such a blast. On the other hand unless means is provided for preventing it there will be a tendency for vapor from the jet to flow toward the vessel which was being exhausted. This tendency is due to the reëvaporation of the laterally moving molecules of vapor which strike the side walls of the conduit into which the jet passes and are condensed. These reëvaporated particles, as they leave the heated walls, are just as likely to move toward the vessel which is being exhausted as in the opposite direction. As a result there will be formed a stream of vapor flowing toward the vessel which is being exhausted which will effectually prevent the entrance into the jet of gas at a low pressure. If, however, means is provided for preventing the formation of this stream of vapor flowing toward the vessel which is being exhausted the gas from that vessel will be able to come in contact with the vapor of the jet, will mix with it and be carried along with it to the condensing chamber. Hence a device constructed and operated in accordance with my invention does not depend upon the creation of a suction to draw the gas into the moving stream of vapor but upon the prevention of the formation of a stream of vapor which would flow toward the vessel which is to be exhausted and thus oppose the flow of gas or vapor away from that vessel.

By the term "pressure" as used in the above explanation and the claims which follow, reference is made to the internal, static or lateral pressure of the jet; that is, the pressure which the jet of vapor exerts in a direction at a right angle to the direction in which it flows.

A consideration of the known facts in regard to the flow of gases and vapors will show that the pressure in the jet must in all cases be greater than that which may be obtained in the receptacle which is to be exhausted. If it were possible to cause all of the molecules of the vapor stream to move in directions parallel to the direction of flow of the stream, and with equal velocities the lateral pressure of the stream might be reduced to substantially zero. Since it is possible with the device described to obtain a vacuum at least as low as one one-hundred millionth of a millimeter, it is apparent that if the device were to operate in the same manner as an ordinary ejector the lateral pressure of the stream must be reduced to substantially zero.

According to the kinetic theory of gases the molecules in a body of gas at rest are in constant motion in all directions. According to Maxwell's law of the distribution of velocities, some of the molecules will move at velocities greater than two or three times the average or mean velocity of the molecules. When the gas is given a mass motion the velocity of relative motion between the molecules will decrease. It is apparent, however, that this relative movement will not entirely disappear until the gas as a whole moves with the velocity equal to that of the fastest moving molecules. This would mean that with a jet of mercury vapor it would be necessary that the jet should be given a velocity of about 60,000 centimeters per second. Since the device described has been found to operate with jet velocities much less than this it is apparent that the condition necessary to obtain substantially zero pressure in the jet is not attained in practice.

In case it were possible to cause all of the molecules to move in the same direction at one point in the stream this condition would not exist for any appreciable time because of the collisions between the molecules due to the fact that they move at different velocities. Hence, some of the molecules will, as a result of these collisions, be caused to move in directions which are not parallel to the direction of the stream.

In considering the possible movements of molecules at pressures which are used in the vapor jet, account must also be taken of the viscosity of the vapor. The layer of vapor next to the wall of the conduit through which it flows will move at a lower velocity than the vapor at the center of the conduit.

On account of this viscosity effect it is apparent that it will be impossible to cause all of the molecules of the stream to move at the same velocity and hence for this reason the theoretical condition which is necessary to secure zero lateral pressure can never be attained.

It may appear that the pressure relations described would result in the delivery of the molecules of vapor into the vacuous space in a quantity more than sufficient to compensate for the molecules drawn therefrom. One of the objects of the present invention however is to provide means for preventing such a condition of affairs. In the structure shown and described the molecules of gas which tend to flow toward the space which is being evacuated are condensed before they have an opportunity to reach that space.

As long as the number of laterally moving molecules is comparatively small and the depth of the fringe of the laterally moving molecules is less than the mean free path of the gas molecules the gas molecules will be able to enter the stream and be struck by molecules which are moving in a parallel direction and thus be carried along with the stream. As the number of laterally moving molecules increases and the thickness of the fringe increases the chance of a molecule of gas entering the stream far enough to be struck by a parallel moving molecule will decrease and a point will finally be reached at which all of the molecules of gas will be struck by laterally moving molecules before they have an opportunity to collide with a parallel moving molecule. In applicant's device it is probable that the depth of the fringe of laterally moving molecules at the point where the jet emerges from the conduit 1 will be greater than the mean free path of the gas molecules. Consequently it is possible that none of the gas molecules will reach the portion of the jet which is moving in a parallel direction at the point where it emerges from the conduit 1. The gas molecules will, however, be struck by laterally moving molecules and driven toward the wall of the enlargement 9. Some of them will then be struck by other laterally moving molecules and gradually driven upward and nearer the portion of the stream which is moving in a parallel direction. They will finally reach this stream and be entrained therein near the upper part of the enlargement—where substantially all of the molecules which are moving in lateral directions have been removed from the stream.

While I have shown and described only one embodiment of my invention I do not wish to be limited to the particular form shown as it will be apparent that many modifications therein may be made without departing from the scope of my invention

as set forth in the appended claims. The form which I have shown is constructed of glass but other materials may equally well be employed. I have described its operation with mercury vapor as I find that this is especially suitable for operation with very low pressures. Its operation, however, does not depend upon the use of mercury, as the necessary stream of vapor may be derived from other liquids than mercury.

I have shown the preferred method for preventing any of the vapor from flowing away from the condensing chamber toward the receptacle which is to be exhausted but I believe it to be possible to accomplish this result by other methods, as for example, it may be unnecessary to cool the portion of the tube 2 near the point where the two conduits join if the configuration of the enlargement 9 is varied in such a way that there will be no tendency for any of the mercury which strikes the wall to move in such a direction as to oppose the stream of gas from the vessel which is being exhausted.

Various modifications may also be made in the relative positions of the conduits, the means for preventing any of the vapor from flowing toward the receptacle which is to be exhausted and the condensing chamber without changing the principle of operation of my apparatus.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. The method of obtaining a high vacuum in a closed receptacle which consists in causing a stream of mercury vapor to flow at a high velocity toward a condensing chamber, in such a way that a portion of its path communicates with the receptacle which is to be exhausted, the pressure of said stream at all points being greater than that to be finally attained in the closed receptacle, and preventing mercury vapor from flowing toward the receptacle which is to be exhausted in opposition to the gas which is to be removed therefrom.

2. The method of exhausting a closed receptacle to obtain a high vacuum therein, which consists in causing a stream of vapor to flow toward a condensing chamber in such a way that a portion of its path communicates with the receptacle which is to be exhausted, the pressure of said stream at all points being greater than that to be finally attained in the closed receptacle, and preventing vapor from flowing toward the receptacle which is to be exhausted in opposition to the gas which is to be removed therefrom.

3. An apparatus for obtaining a high vacuum in a closed receptacle comprising means for producing a stream of mercury vapor, a condensing chamber, a conduit through which the stream of mercury vapor flows to the condensing chamber, a second

conduit communicating with the receptacle which is to be exhausted and with the first conduit and cooling means for preventing mercury vapor from flowing from the first conduit through the second conduit toward the receptacle which is to be exhausted.

4. An apparatus for obtaining a high vacuum in a closed receptacle comprising means for producing a stream of vapor, a condensing chamber, a conduit through which the stream of vapor flows to the condensing chamber, a second conduit communicating with the receptacle which is to be exhausted and with the first conduit, and cooling means for preventing vapor from flowing from the first conduit through the second conduit toward the receptacle which is to be exhausted.

5. An apparatus for exhausting closed receptacles comprising means for producing a stream of vapor, a condensing chamber, a conduit through which the stream of vapor flows to the condensing chamber, a second conduit communicating with the receptacle which is to be exhausted and with the first conduit, and means for cooling the wall of the first conduit in a region near the junction of the two conduits.

6. An apparatus for exhausting closed receptacles comprising means for producing a stream of mercury vapor, a condensing chamber, a conduit through which the stream of mercury vapor flows to the condensing chamber, a second conduit communicating with the receptacle which is to be exhausted and with the first conduit, and means for cooling the wall of the first conduit in a region near the junction of the two conduits in such a way as to prevent mercury vapor from flowing from the first conduit into the second conduit.

7. An apparatus for removing gas or vapor from a receptacle comprising means for producing a stream of vapor, a condensing chamber, a conduit through which the stream of vapor flows to the condensing chamber, a second conduit communicating with the receptacle from which the gas or vapor is to be removed and with the first conduit, an enlargement in the first conduit immediately beyond the point where the two conduits communicate with each other, and means for cooling the wall of said enlargement.

8. An apparatus for removing gas or vapor from a receptacle comprising means for producing a stream of mercury vapor, a conduit through which the stream of mercury vapor flows, a second conduit communicating with the receptacle from which the gas or vapor is to be removed, and with the first conduit, an enlargement in the first conduit immediately beyond the point at which the two conduits communicate with each other, and means for cooling the wall

of said enlargement so as to prevent mercury vapor from flowing from the first conduit into the second conduit.

9. An apparatus for removing gas or vapor from a receptacle at comparatively low pressures comprising means for producing a stream of vapor, a conduit through which the stream of vapor flows, a second conduit communicating with the receptacle from which the gas or vapor is to be removed, and with the first conduit, and cooling means adjacent the junction of the two conduits for preventing vapor from flowing from the first conduit into the second conduit.

10. The method of obtaining a high vacuum in a closed receptacle which consists in causing a stream of vapor to flow toward a condensing chamber, bringing the gas from the receptacle into contact with the stream of vapor, preventing the re-evaporation of those particles of vapor which condense on the wall of the first conduit near the point where the gas from the receptacle meets the stream of vapor and thereby preventing the formation of a stream of vapor which would oppose the movement of the gas away from the receptacle.

11. An apparatus for removing gas or vapor from a closed receptacle to obtain a high vacuum therein, comprising means for producing a stream of vapor, a condensing chamber, a conduit through which the stream of vapor flows to the condensing chamber, a second conduit communicating with the receptacle from which the gas or vapor is to be removed and with the first conduit, and means for preventing the re-evaporation of particles of vapor which condense on the wall of the first conduit near the point where the two conduits meet and thereby preventing the formation of a stream of vapor which would tend to oppose the movement of the gas or vapor from the receptacle into the stream of vapor in the first conduit.

12. The method of exhausting a closed gas containing receptacle to obtain a high vacuum therein which consists in causing a stream of vapor to flow toward a condensing chamber, the pressure of said stream being at all points greater than that to be finally obtained in the receptacle which is being exhausted, causing the gas from the receptacle to come in contact with said stream and at the same time removing from the stream molecules moving in directions other than substantially parallel to the path of the stream and thereby preventing any appreciable flow of vapor toward the receptacle in opposition to the gas coming therefrom.

13. The method of exhausting a closed gas containing receptacle to obtain a high vacuum therein which consists in causing a stream of vapor to flow toward a condensing chamber, the pressure of said stream being at all points greater than that to be finally obtained in the receptacle which is being exhausted, causing the gas from the receptacle to come in contact with said stream and at the same time preventing any appreciable flow of vapor toward the receptacle in opposition to the gas coming therefrom.

14. An apparatus for exhausting closed receptacles comprising means for producing a stream of vapor, a condensing chamber, a conduit through which the stream of vapor flows to the condensing chamber the pressure of the vapor stream produced being at all points greater than that to be finally attained in the closed receptacle, a second conduit communicating with the receptacle which is to be exhausted and with the first conduit, and means for preventing vapor from flowing from the first conduit into the second conduit in opposition to the gas which is being removed from the receptacle.

In witness whereof, I have hereunto set my hand this 2nd day of February, 1916.

IRVING LANGMUIR.