MODERN PUMPS FOR HIGH VACUA.

THE widespread researches on the phenomena in electrical discharge tubes, which form so important a feature of modern physics, directed much attention to the question of obtaining high vacua. In 1888, as Lenard tells us,[1] an efficient vacuum pump was by no means an essential part of the equipment of a physical laboratory: at the present time it emphatically is so. In the following a brief account will be given of the modern forms of the different types of pumps, especial reference being made, however, to a pump recently invented by Dr. Gaede, as it depends on a principle never before applied, and seems from present information more efficient than any of its predecessors.

All vacuum pumps except this latest one of Gaede's make use of the principle employed by Otto von Guericke in the first air-pump—that is, the intermittent separation and discharge of a fraction of the gas from the reservoir to be exhausted by means of a piston, which in the mercury pumps takes a liquid form. We can, in reviewing the modern forms, divide these pumps into three classes: the solid piston pump, the hand mercury pump, and the automatic mercury pump.

The solid piston pump has preserved much of its original arrangement of valves, but has been modified in the Geryk pump, which may be taken as a modern example, by the use of layers of a particular oil in the place of packing. The valves are always covered by the oil, which takes up all clearance, and hence leakage is largely avoided, but the vapour pressure of the oil, though very small, prevents the highest vacuum being produced; however, 0·0002 mm. of mercury can be attained. In a still more recent pattern, the "Rose" pump manufactured by Messrs. Cosser, there is no piston rod, the piston being of iron and moved by electro-magnets oscillating outside the pump cylinder.

The forms of hand mercury pump now used are all modifications of the well-known Toepler pump. One of the simplest and most successful is that devised by Antropoff, in which the usual bulb is replaced by one of cylindrical form arranged obliquely instead of vertically.

The desire to reduce the time and labour attaching to the hand pump has led to the construction of a large number of mercury pumps which can be operated mechanically; in experiments such as those of Prof. Wien on canal rays such a continuously running pump is a necessity. The most convenient of these are the various rotary pumps, of which the first was devised by Schulze-Berge, and of which Kaufmann in 1905 brought out a pattern which has been considerably used. The essential of this is an inclined spiral tube which rotates continuously; a thread of mercury running in it cuts off and forces out a fraction of the air at every rotation. There are two such tubes; the pump, though efficient, is somewhat fragile and complicated.

The rotary mercury pump most in use at the present time is that of Dr. Gaede. It consists of an outer closed drum half filled with mercury, in which a second drum rotates. This drum is divided into chambers, which in turn become connected to the vessel to be exhausted; by the rotation they are filled alternately with gas and mercury, the gas being displaced into the outer space between the two drums and cut off from return by the mercury. The system is similar to the gas meter, only in this the moving gas effects the rotation, while in the Gaede pump the rotation sets the gas in motion. With this pump the pressure must first be reduced to a few millimetres of mercury by any rough preliminary pump, as otherwise the difference of pressure between the outside and inside of the rotating drum will become sufficient to drive the gas back into the drum again.

In the past year, however, Dr. Gaede described an air-pump depending on a new principle, which he calls the molecular air-pump. Maxwell assumed, and Knudsen has recently verified experimentally, that if a gas be in contact with a solid surface, the gas molecules are reflected from it in all directions independently of the angle of incidence, or "diffusely reflected." This is due to molecular irregularities of the surface. Gaede has shown that for pressures above 0·001 mm. of mercury the above assumption is not experimentally verified, and he attributes this to the formation of a film of adsorbed gas on the solid surface, which covers and conceals the molecular irregularities. The surface then presents only mechanical irregularities, and the result is that if a gas be travelling over a surface the molecules are preferentially thrown back in the direction from which they came, as they fall in general on small slopes of the irregularities facing their direction of drift. In both this case and that of diffuse reflection the new pump is effective, but the point is of interest in considering the theory of the pump, and it was considerations of this kind which led Gaede to its construction.

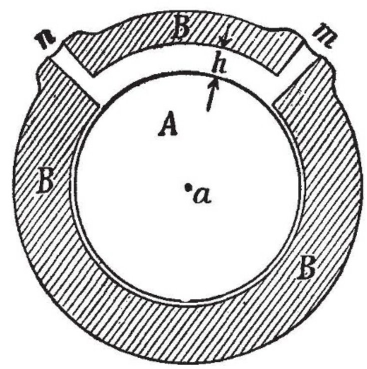

FIG. 1.—Principle of molecular air pump.

The new pump depends for its action on the dragging of the gas by a rapidly moving surface.[2] Consider a cylinder A rotating in a clockwise direction in a case B; in B there are two openings n and m connected by a slot (Fig. 1). The gas will be dragged by the cylinder from n to m, and in

[1] Nobel discourse, 1906, p. 3.

[2] For the illustrations which accompany this article, we are indebted to the makers of the new pump—E. Leybold's Nachfolger, Cöln.

consequence a difference of pressure will be established between n and m which is proportional to the speed of rotation and the internal friction of the gas; the latter being independent of the pressure, the difference of pressure produced should be independent of the pressure. This is true when the pressure is relatively high; if it continued to be true down to the lowest pressures we should be able to create an absolute vacuum by exhausting initially with another pump at n to a pressure lower than the (constant) difference of pressure between m and n. When, however, we come to pressures below 0·001 millimetre of mercury this is no longer the case; the molecules are then diffusely reflected, and fly from one wall to the other without meeting other molecules. If the surface of the cylinder moved with a velocity greater than the molecular velocity we would obtain an absolute vacuum; such speeds are impossible in practice. However, at these low pressures the ratio of the pressures at m and n remains constant independent of the pressure, and it has been found that attainable speeds of revolution (8000–12,000 revolutions per minute) are sufficient to give a vacuum better than any hitherto obtained.

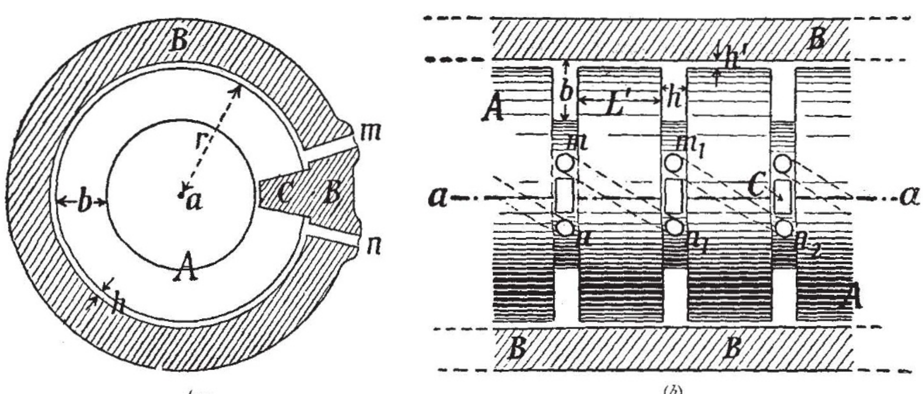

FIG. 2.—Construction of molecular air pump.

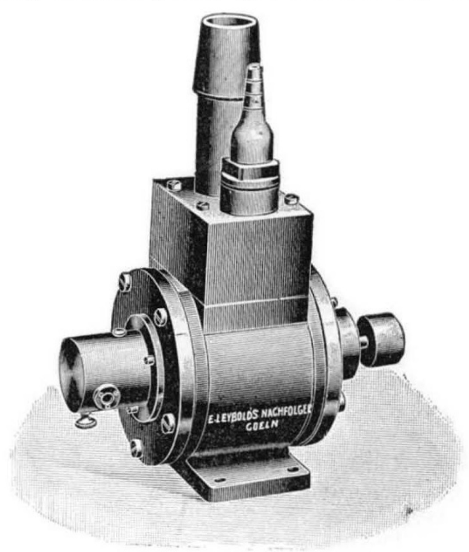

FIG. 3.—Molecular air pump.

In practice the pump is constructed as indicated in Fig. 2 (a) and (b). Instead of cutting the slot in the case, the cylinder is grooved, and a tongue C from the case projects into the groove; this is equivalent to a very long slot in the case. For increased efficiency several parallel grooves are cut, and connected with one another so that the low pressure side of one is the high pressure side of the next (Fig. 2, b). The complete pump is shown in Fig. 3. A preliminary pump is needed to reduce the pressure to a few millimetres of mercury initially.

A great advantage of this form of pump is that it deals with vapours as well as gases, as the low pressure part of the pump remains at low pressure. In other forms of pump the gases are compressed while being removed, and in consequence vapours condense which are afterwards brought back into the vacuum again. Without drying agents the new pump has produced a vacuum lower than any hitherto measured, 0·0000002 millimetre of mercury; this pressure was calculated by observing the ratio of the pressures in different grooves.

Very interesting are the measurements made by Gaede of the kinetic heat effect. Owing to the increased velocity of the molecules the temperature of the gas should be higher near the upper surface of the tongue C (Fig. 2) than near the lower surface, and by arranging a thermocouple in place of the tongue C Gaede has detected such an effect as soon as the pressure is low enough to allow the mean free path of the molecules to be larger than the dimensions of the groove.

A table of the exhaustion attainable with various selected pumps is appended.

Pump	Pressure in millimetres of mercury.
Water pump	10
Ordinary piston pump	1
*Older Geissler pump	0·1
*Newer Geissler pump	0·01
*Sprengel pump	0·001
*Modified Toepler pump	0.00001
*Kahlbaum's automatic mercury pump	0·000002
Geryk oil-filled pump	0·0002
Gaede rotary mercury pump	0·00001
Gaede molecular pump	0·0000002

* Taken from Winkelmann's "Handbuch der Physik," I. The numbers must only be taken as very rough; for instance, it is very doubtful whether Kahlbaum's pump can give a better vacuum than Gaede's mercury pump (the figure for which is given by the Physikalisch-Technische Reichsanstalt).

E. N. DA C. ANDRADE.