secretion of the suprarenal glands in animals as a result of strain or emotion in the manner postulated by W. B. Cannon.[14] This conclusion is of course speculative, but it is to be pointed out that the anterior lobe is supplied by sympathetic nerve fibres which are probably derived from the superior cervical ganglion.[15]

That the anterior lobe of the pituitary is functionally correlated with the sexual organs is now definitely established, but the precise sequence of events leading up to the phenomena associated with œstrus is yet to be determined. P. Zondek and S. Aschheim,[16] P. E. Smith and E. T. Engle,[17] A. S. Parkes [18] and others have shown that anterior lobe extracts injected into mammals exert a powerful stimulating action upon the gonads, increasing in the female the number of follicles available for ovulation eight or ten times, besides affecting the other ovarian functions in a marked degree. That such a correlation exists in the birds has been shown by Oscar Riddle,[19] who found that the grafting of anterior lobe tissue or the injection of extracts into immature ring-doves promoted the growth of the gonads in both sexes and accelerated the attainment of sexual maturity.

It is no less evident that the gonads are themselves responsible for the development of sexual change, as is indicated negatively by the familiar effects of castration and oöphorectomy. W. Rowan [20] has suggested that the periodic growth of the gonads provides the necessary stimulation for migration, and the non-existence of the migratory instinct in sterile birds is consistent with this view. Moreover, Rowan has shown experimentally in the Junco (*Junco hymenalis*) that a premature recrudescence of the gonads, brought about by the use of artificial light from powerful electric bulbs, induced the birds to fly away, although the season was inappropriate, being mid-winter, whereas control birds with undeveloped gonads did not migrate but remained close at hand.

As to whether the gonads react upon the anterior lobe of the pituitary, there is at present no evidence excepting that in mammals the gonads seem to control the sexual cycle. In reality there is probably a complicated cycle of processes in which the thyroid and other endocrine organs play their part. The most that can be said at present is that certain links in the chain of causation can be demonstrated and that Eliot Howard is probably right in his conclusion that mutual posturing in birds secures an effective synchronisation of the essential reproductive conditions of the male and female, and so promotes the successful fertilisation of the eggs, a conclusion which he has reached as a result of prolonged and intensive watching of birds in a state of Nature.

[14] Cannon, W. B., *Amer. Jour. of Psych.*, vol. 25, 1914; *Amer. Jour. of Physiol.*, vol. 33, 1914.

[15] Sharpey-Schafer, E., "The Endocrine Organs", vol. 2 (second edition, 1926).

[16] Zondek, Paul, and Aschheim, S., *Klin. Wochensch.*, vol. 6, 1927.

[17] Smith, P. E., and Engle, E. T., *Amer. Jour. of Anat.*, vol. 40, 1927.

[18] Parkes, A. S., *Proc. Roy. Soc.*, B, vol. 104, 1929.

[19] Riddle, O., and Flemion, F., *Amer. Jour. of Physiol.*, vol. 87, 1928.

[20] Rowan, W., *Proc. Boston Soc. of Nat. Hist.*, vol. 38, 1926; cf. F. H. A. Marshall, "The Physiology of Reproduction" (second edition, 1922).

Molecular Air-Pumps.[1]

By Prof. E. N. DA C. ANDRADE.

ACCORDING to the kinetic theory a gas consists of molecules, which may be considered as little spheres, or, more generally, as little bodies of a more or less marked degree of symmetry, about a hundred-millionth of an inch long, rushing about in all directions and frequently colliding with one another and with the walls of the vessel. The collisions with the walls produce the pressure. The molecules move with a very high velocity, some hundreds of yards per second for gases at ordinary temperature, and this high velocity deduced from elementary considerations, was a point of difficulty in the early days of the theory, critics objecting that such speeds would imply very rapid diffusion, so that, for example, the vapour of any odorous liquid should be detected by its smell at the furthest parts of a room as soon as the bottle is opened. Such criticism leaves out of account the frequent collisions, which make the path of an individual molecule a zigzag with frequent turns back on itself. The average distance between collisions is called the mean free path, and is an essential factor in all questions of diffusion and of viscous forces. It is about a hundred-thousandth of a centimetre for air at ordinary pressure, and is, to a first approximation, independent of the temperature. It varies, with a given gas, inversely as the pressure, so that at low pressures it becomes quite large: in air at a pressure of 1 microbar it is 10 cm., and at a pressure of 0·01 microbar, easily attained with modern technique, it is 10 metres.

If we consider the passage of a gas through a tube of any kind, a change in the laws governing the movement begins to manifest itself when the pressure becomes low enough for the mean free path to be about equal to the linear dimension of the cross section of the tube. The physical reason of this is clear: at higher pressures most of the collisions are between molecules, collisions with the walls being comparatively infrequent; at very low pressure collisions with the walls are common compared with those between molecules, and dictate the nature of the bulk movement of the gas. Knudsen, who studied the flow of gases through tubes at very low pressure, found that his results could be explained on the supposition that the molecules which struck the walls did not bounce off at the reflecting angle, like tennis balls from a smooth floor, but came off in random directions, like tennis balls thrown into a crowd, where they are caught and thrown up again at hazard. The gas behaves as if momentarily condensed on the wall, and then re-evaporated. He worked out the consequences of such behaviour, and deduced laws

[1] From a discourse delivered at the Royal Institution on Friday, May 31.

which he found to agree closely with experiment. If the quantity Q of gas issuing be measured by the volume multiplied by the pressure at which it issues, then

$$Q = pv = \frac{4}{3} \sqrt{2\pi} \ (p_2 - p_1) \ \frac{r^3}{l} \ \frac{1}{\sqrt{\rho}} \ t,$$

where ρ is the density of the gas *at unit pressure*; p_1 and p_2 are the pressures at the two ends of the tube respectively; r is the radius and l the length of the tube; t is the time. This formula shows that a gas at low pressure will take a surprisingly long time to pass through quite a wide tube into a perfectly exhausted vessel. For example, suppose a volume of 2 litres, containing air at 15° and at a pressure of 10 microbars, connected by a tube 50 centimetres long and 5 millimetres in diameter to a second vessel in which a pump maintains a pressure of only 0·01 microbar. It will take 5 minutes for the pressure in the first vessel to fall to 0·2 microbar. Many physicists who are familiar with this speak, however, as if the resistance to flow at low pressure were *greater* than that which we should anticipate if the ordinary law of flow which holds for higher pressure, namely,

$$Q = pv = \frac{\eta \, (p_2 - p_1)}{8 \, \eta \, l} \, p \, r^4,$$

with constant coefficient of viscosity η, held down to very low pressures. This is, however, incorrect, the resistance at such low pressures being less than if the normal laws of viscosity were valid. For example, if we take oxygen at such a pressure that the mean free path equals the radius r of the tube, we find that Knudsen's formula indicates rather more than four times as much gas passing through under a given pressure difference as would issue if the ordinary viscosity formula were applicable. The reason that, even so, wide tubes offer such a large resistance to the flow of gases at low pressure, is that the driving difference of pressure is very small. It is therefore necessary with all modern vacuum pumps to have very wide connecting tubes, made as short as possible, and very wide bore taps, if exhaustion is to proceed efficiently.

Considerations of the behaviour of gases at low pressure led Gaede in 1912 to design a new type of pump, termed by him a molecular pump. Since the molecules behave as if condensed on the surface and then quickly re-evaporated, if we move the surface rapidly we communicate a common velocity component to all molecules. If, then, part of the walls of a tube could by some means be kept in steady motion in the direction of the length of the tube a difference of pressure would be maintained between the two ends of the tube, the tendency of the gas to flow under the difference of pressure being counteracted by the drift imposed on the molecules. Calculation shows that with a given gas the *ratio* of the pressures at the two ends is fixed by the speed of the walls and the length of the tube. If the ordinary laws of viscosity were valid at these low pressures the *difference* of pressure would be fixed in this way. Clearly the ratio of pressure also depends upon the ratio of the speed of the gas molecule to the speed with which the walls move, so that at a given temperature this pressure ratio is much less for hydrogen than for a heavier gas.

In Gaede's pump the walls of the supposititious tube, which has just been discussed, are constituted by grooves cut in a drum which can be set in very rapid rotation. The drum fits closely into a housing from which a tongue protrudes into each groove, dividing the groove into a low-pressure side, where the walls are running from the tongue, and a high-pressure side, where the walls are approaching the tongue. The high-pressure side of one groove is connected to the low-pressure side of the next groove, so that we have virtually several pumps in series. A preliminary pressure of a fraction of a millimetre of mercury (say 0·1 mm.) is necessary to ensure the efficient working of this type of pump, but with such conditions a very low vacuum can be rapidly attained. A great advantage of pumps of this type is that they deal with condensable vapour as readily as with gases.

Another form of molecular pump has been recently designed by Holweck. In this pump a spiral groove is cut in the casing, and the drum has an unbroken cylindrical surface. The depth of the groove is tapered so as to allow for the decrease of mean free path with increasing pressure.

We now turn to another type of pump which has come into great general use in the last few years. As a preliminary let us consider the influence of a volatile liquid on a vacuum, in particular the question of obtaining a high vacuum in a vessel connected to which by a wide tube is a second vessel containing a liquid.

A celebrated German text-book of physics, published in 1906, says, for example, "If a receiver containing a little gas is in connection with a pump that contains mercury, the pressure of the gas cannot be less than 0·0013 mm. (the vapour pressure of mercury), and if there is mercury vapour in the receiver the total pressure cannot be less than 0·0013 mm. of mercury". This sounds reasonable, and is indeed true so long as everything is at rest and the problem is a statical one. It need not be true, however, if the vapours are streaming. We can, for example, actually connect a receiver to another vessel containing boiling mercury, and yet have a very low pressure in it. To do this we put a liquid air trap in between; the pressure in the trap is very low indeed, and there is a continuous stream of mercury vapour into it; the vapour condenses and the pressure in the receiver remains exceedingly low.

Gaede obtained some very interesting results by connecting a vessel containing a little air with a vessel of heated mercury, with an ice-cooled trap between the two vessels. If the total pressure of gas and mercury vapour were the same in both vessels, then, since there is only air in one, when the mercury is heated sufficiently to give this pressure, there should be no air in the other. However, it was found that air diffuses into the mercury vapour space against the current of vapour. The laws of diffusion are somewhat complicated, but Gaede worked out the case in detail, everything being at low pressure, and his results led him to devise his mercury vapour pump.

The principle is to let the gas diffuse into a rapid stream of mercury vapour which carries it away to a place where it can be removed by a rough pump. The vapour stream is produced by strongly heating liquid mercury; vapour which diffuses into the receiver space is condensed. Although the fore-vacuum is necessarily at a higher pressure than the receiver, gas cannot get back against the stream of mercury vapour. The pump will only work well at low pressure, for unless the mean free path is long the diffusion process does not become really operative. To render the diffusion effective Gaede used a slit, which diminishes the counter-current of mercury vapour. This case can be worked out mathematically, and it can be shown that diffusion is most effective when the width of the slit is equal to the mean free path of the gas. If the slit is too wide the density of the mercury vapour is too great, and the 'brush' action of the slit loses its sharpness; if it is too narrow not enough gas molecules diffuse through. Similarly, if the vapour pressure is too high the counter-current is too vigorous; if it is too low the stream is not fast enough.

A better arrangement of the vapour stream was devised by Langmuir. In his type of pump the vapour issues through a tube, which is surrounded by a wider tube, the walls of which are water-cooled. The tube to the receiver enters the outer tube at a point in the rear of the vapour jet. If the pressure is so low that the mean free path of the vapour is greater than the distance between the tubes, the molecules cannot diffuse back against the gas stream, but strike the wall and condense. It is true that a much lower temperature than the boiling point of mercury is needed for condensation at such low pressures, but with tap-water cooling the condensation is fairly effective. The importance of condensation is clear, and Langmuir called his pump a condensation pump, but the gas enters the vapour stream by diffusion just as in Gaede's pump. Both the original Gaede pump and Langmuir's pump are really diffusion-condensation pumps.

The different types of diffusion pump all need a good preliminary vacuum, as they cannot hold up against more than a slight difference of pressure without gas coming back against the vapour stream. A fore-pump producing something between a tenth and a hundredth of a millimetre of mercury should be employed. However, at higher pressures, where the diffusion effect is small, we can use the steam-injector principle, for in a jet of fast-moving comparatively dense vapour there will be a diminution of pressure corresponding to the kinetic energy of the accelerated vapour. The surrounding gas will flow in as a whole under the difference of total pressure, not partial pressure. This principle has been used for the creation of a fore vacuum by a vapour stream. In Gaede's three-stage steel mercury-vapour pump, for example, which has great speed of pumping, there is an injection stage working at comparatively high pressure, and a diffusion stage for the lowest pressure, while in between there is a stage of mixed action.

Mercury is not the only liquid which is suitable for use in a vapour pump. Quite recently Mr. Burch, by a process of distillation *in vacuo*, has obtained an oil the vapour pressure of which at ordinary room temperatures is extraordinarily low. This oil can be used effectively as the working fluid in pumps. Another liquid which can be used is normal butyl phthallate.

In addition to the types of vacuum pumps to which reference has been made, it must be remembered that other processes are widely used, especially in industrial laboratories, for producing high vacua. Solid surfaces in general exercise a marked condensing action on gases, and absorb on themselves thin layers of gases at temperatures and pressures under which the substance is gaseous in bulk. Consideration of these surface actions lie outside the scope of this discourse, as do the methods of combining the residual gases chemically with a substance which deposits on the walls of the glass, by the use of the so-called 'getters'. We may, however, with reference to the part which the walls of the vessel play in these processes, refer to these methods as *mural* methods. If we are allowed to do this we may alliteratively divide the methods of producing high vacua into *mechanical*, as exemplified not only by the Geryk pumps, and box-pumps, but by all pumps, such as the Gaede rotary pump, in which a portion of the gas is cut off and bodily expelled; *molecular*, including in this term both what is ordinarily called the molecular pump and also the vapour stream pumps, since they are based upon molecular theory; and *mural*. The action of the first is perfectly understood; the action of the second is largely understood, but more difficult; the third method, though widely applied, is theoretically still very obscure in many cases.

Finally, it may be mentioned that while pressures as low as a ten-thousand-millionth of atmospheric pressure can be certainly produced in the laboratory, even at this pressure more than a thousand million molecules are present in every cubic centimetre. We are still very far from being able to produce the kind of vacuum that exists in outer space.

Obituary.

Dr. C. Easton.

On June 3, 1929, Dr. Cornelis Easton died at the Hague at sixty-four years of age. Though he was not professionally engaged in science, his work attracted the attention both of astronomers and of meteorologists, and a short account of his life and work, abstracted from a contribution by Dr. J. Stein, S.J., to *Hemel en Dampkring*, July-September 1929, may interest readers of Nature.

Born at Dordrecht on June 10, 1864, Dr. Easton attended schools there and passed the entrance examination to the Polytechnicum at Delft in 1881. From early youth the stars had interested him, and one of his teachers encouraged observational