THURSDAY, JUNE 18, 1874

PLATEAU ON SOAP-BUBBLES

Statique expérimentale et théorique des Liquides soumis aux seules Forces moléculaires. Par J. Plateau, Professeur à l'Université de Gand, &c. (Paris, Gauthier-Villars; London, Trübner & Co.; Gand et Leipzig, F. Clemm. 1873.)

ON an Etruscan vase in the Louvre figures of children are seen blowing bubbles. Those children probably enjoyed their occupation just as modern children do. Our admiration of the beautiful and delicate forms, growing and developing themselves, the feeling that it is *our* breath which is turning dirty soap-suds into spheres of splendour, the fear lest by an irreverent touch we may cause the gorgeous vision to vanish with a sputter of soapy water in our eyes, our wistful gaze as we watch the perfected bubble when it sails away from the pipe's mouth to join, somewhere in the sky, all the other beautiful things that have vanished before it, assure us that, whatever our nominal age may be—we are of the same family as those Etruscan children.

Here, for instance, we have a book, in two volumes, octavo, written by a distinguished man of science, and occupied for the most part with the theory and practice of bubble-blowing. Can the poetry of bubbles survive this? Will not the lovely visions which have floated before the eyes of untold generations collapse at the rude touch of Science, and "yield their place to cold material laws"? No, we need go no further than this book and its author to learn that the beauty and mystery of natural phenomena may make such an impression on a fresh and open mind that no physical obstacle can ever check the course of thought and study which it has once called forth.

M. Plateau in all his researches seems to have selected for his study those phenomena which exhibit some remarkable beauty of form or colour. In the zeal with which he devoted himself to the investigation of the laws of the subjective impressions of colour, he exposed his eyes to an excess of light, and has ever since been blind. But in spite of this great loss he has continued for many years to carry on experiments such as those described in this book, on the forms of liquid masses and films, which he himself can never either see or handle, but from which he gathers the materials of science as they are furnished to him by the hands, eyes, and minds of devoted friends.

So perfect has been the co-operation with which these experiments have been carried out, that there is hardly a single expression in the book to indicate that the measures which he took and the colours with which he was charmed were observed by him, not in the ordinary way, but through the mediation of other persons.

Which, now, is the more poetical idea—the Etruscan boy blowing bubbles for himself, or the blind man of science teaching his friends how to blow them, and making out by a tedious process of question and answer the conditions of the forms and tints which he can never see?

But we must now attempt to follow our author as he passes from phenomena to ideas, from experiment to theory.

The surface which forms the boundary between a liquid and its vapour is the seat of phenomena on the careful study of which depends much of our future progress in the knowledge of the constitution of bodies. To take the simplest case, that of a liquid, say water, placed in a vessel which it does not fill, but which contains nothing else. The water lies at the bottom of the vessel, and the upper part, originally empty, becomes rapidly filled with the vapour of water. The temperature and the pressure—the quantities on which the thermal and statical relations of any body to external bodies depend—are the same for the water and its vapour, but the energy of a milligramme of the vapour greatly exceeds that of a milligramme of the water. Hence the energy of a milligramme of water-substance is much greater when it happens to be in the upper part of the vessel in the state of vapour, than when it happens to be in the lower part of the vessel in the state of water.

Now we find by experiment that there is no difference between the phenomena in one part of the liquid and those in another part except in a region close to the surface and not more than a thousandth or perhaps a millionth of a millimetre thick. In the vapour also, everything is the same, except perhaps in a very thin stratum close to the surface. The change in the value of the energy takes place in the very narrow region between water and vapour. Hence the energy of a milligramme of water is the same all through the mass of the water except in a thin stratum close to the surface, where it is somewhat greater; and the energy of a milligramme of vapour is the same all through the mass of vapour except close to the surface, where it is probably less.

The whole energy of the water is therefore, in the first place, that due to so many milligrammes of water; but besides this, since the water close to the surface has an excess of energy, a correction, depending on this excess, must be added. Thus we have, besides the energy of the water reckoned per milligramme, an additional energy to be reckoned per square millimetre of surface.

The energy of the vapour may be calculated in the same way at so much per milligramme, with a deduction of so much per square millimetre of surface. The quantity of vapour, however, which lies within the region in which the energy is beginning to change its value is so small that this deduction per square millimetre is always much smaller than the addition which has to be made on account of the liquid. Hence the whole energy of the system may be divided into three parts, one proportional to the mass of liquid, one to the mass of vapour, and the third proportional to the area of the surface which separates the liquid from the vapour.

If the system is displaced by an external agent in such a way that the area of the surface of the liquid is increased, the energy of the system is increased, and the only source of this increase of energy is the work done by the external agent. There is therefore a resistance to any motion which causes the extension of the surface of a liquid.

On the other hand, if the liquid moves in such a way that its surface diminishes, the energy of the system diminishes, and the diminution of energy appears in the form of work done on the external agent which allows the surface to diminish. Now a surface which tends to diminish in area, and which thus tends to draw together any solid framework which forms its boundary, is said to have surface-tension. Surface-tension is measured by the force acting on one millimetre of the boundary edge. In the case of water at 20° C., the tension is, according to M. Quincke, a force of 8·253 milligrammes weight per millimetre.

M. Plateau hardly enters into the theoretical deduction of the surface-tension from hypotheses respecting the constitution of bodies. We have therefore thought it desirable to point out how the fact of surface-tension may be deduced from the known fact that there is a difference in energy between a liquid and its vapour, combined with the hypothesis, that as a milligramme of the substance passes from the state of a liquid within the liquid mass, to that of a vapour outside it, the change of its energy takes place, not instantaneously, but in a continuous manner.

M. van der Waals, whose academic thesis, "Over de Continuiteit van den Gas- en Vloeistoftoestand,"* is a most valuable contribution to molecular physics, has attempted to calculate approximately the thickness of the stratum within which this continuous change of energy is accomplished, and finds it for water about 0·0000003 millimetre.

Whatever we may think of these calculations, it is at least manifest that the only path in which we may hope to arrive at a knowledge of the size of the molecules of ordinary matter is to be traced among those phenomena which come into prominence when the dimensions of bodies are greatly reduced, as in the superficial layer of a liquid.

But it is in the experimental investigation of the effects of surface-tension on the form of the surface of a liquid that the value of M. Plateau's book is to be found. He uses two distinct methods. In the first he prepares a mixture of alcohol and water which has the same density as olive oil, then introducing some oil into the mixture and waiting till it has, by absorption of a small portion of alcohol into itself, become accommodated to its position, he obtains a mass of oil no longer under the action of gravity, but subject only to the surface-tension of its boundary. Its form is therefore, when undisturbed, spherical, but by means of rings, disks, &c., of iron, he draws out or compresses his mass of oil into a number of different figures, the equilibrium and stability of which are here investigated, both experimentally and theoretically.

The other method is the old one of blowing soap-bubbles. M. Plateau, however, has improved the art, first by finding out the best kind of soap and the best proportion of water, and then by mixing his soapy water with glycerine. Bubbles formed of this liquid will last for hours, and even days.

By forming a frame of iron wire and dipping it into this liquid he forms a film, the figure of which is that of the surface of minimum area which has the frame for its boundary. This is the case when the air is free on both sides of the film. If, however, the portions of air on the two sides of the film are not in continuous communication, the film is no longer the surface of absolute minimum area, but the surface which, with the given boundary, and inclosing a given volume, has a minimum area.

M. Plateau has gone at great length into the interesting but difficult question of the conditions of the persistence of liquid films. He shows that the surface of certain liquids has a species of viscosity distinct from the interior viscosity of the mass. This surface-viscosity is very remarkable in a solution of saponine. There can be no doubt that a property of this kind plays an important part in determining the persistence or collapse of liquid films. M. Plateau, however, considers that one of the agents of destruction is the surface-tension, and that the persistence mainly depends on the degree in which the surface-viscosity counteracts the surface-tension. It is plain, however, that it is rather the inequality of the surface-tension than the surface-tension itself which acts as a destroying force.

It has not yet been experimentally ascertained whether the tension varies according to the thickness of the film. The variation of tension is certainly insensible in those cases which have been observed.

If, as the theory seems to indicate, the tension diminishes when the thickness of the film diminishes, the film must be unstable, and its actual persistence would be unaccountable. On the other hand, the theory has not as yet been able to account for the tension increasing as the thickness diminishes.

One of the most remarkable phenomena of liquid films is undoubtedly the formation of the black spots, which were described in 1672 by Hooke, under the name of holes.

Fusinieri has given a very exact account of this phenomenon as he observed it in a vertical film protected from currents of air. As the film becomes thinner, owing to the gradual descent of the liquid of which it is formed, certain portions become thinner than the rest, and begin to show the colours of thin plates. These little spots of colour immediately begin to ascend, dragging after them a sort of train like the tail of a tadpole. These tadpoles, as Fusinieri calls them, soon begin to accumulate near the top of the film, and to range themselves in horizontal bands according to their colours, those which have the colour corresponding to the smallest thickness ascending highest.

In this way the colours become arranged in horizontal bands in beautiful gradation, exhibiting all the colours of Newton's scale. When the frame of the film is made to oscillate, these bands oscillate like the strata formed by a series of liquids of different densities. This shows that the film is subject to dynamical conditions similar to those of such a liquid system. The liquid is subject to the condition that the volume of each portion of it is invariable, and the motion arises from the fact that by the descent of the denser portions (which is necessarily accompanied by the rise of the rarer portions) the gravitational potential energy of the system is diminished. In the case of the film, the condition which determines that the descent of the thicker portions shall entail the rise of the thinner portions must be that each portion of the film offers a special resistance to an increase or diminution of area This resistance probably forms a large part of the superficial viscosity investigated by M. Plateau, which retards the motion of his magnetic needle, and evidently is far greater than the viscosity of figure, in virtue of which the film resists a shearing motion.

The coloured bands gradually descend from the top of the film, presenting at first a continuous gradation of

* Leiden, A. W. Sijthoff, 1873.

colour, but soon a remarkable black, or nearly black, band begins to form at the top of the film, and gradually to extend itself downwards. The lower boundary of this black band is sharply defined. There is not a continuous gradation of colour according to the arrangement in Newton's table, but the black appears in immediate contact with the white or even the yellow of the first order, and M. Fusinieri has even observed it in contact with bands of the third order.

Nothing can show more distinctly that there is some remarkable change in the physical properties of the film, when it is of a thickness somewhat greater than that of the black portion. And in fact the black part of the film is in many other respects different from the rest. It is easy, as Leidenfrost tells us, to pass a solid point through the thicker part of the film, and to withdraw it, without bursting the film, but if anything touches the black part, the film is shattered at once. The black portion does not appear to possess the mobility which is so apparent in the coloured parts. It behaves more like a brittle solid, such as a Prince Rupert's drop, than a fluid. Its edges are often very irregular, and when the curvature of the film is made to vary, the black portions sometimes seem to resist the change, so that their surface has no longer the same continuous curvature as the rest of the bubble. We have thus numerous indications of the great assistance which molecular science is likely to derive from the study of liquid films of extreme tenuity.

We have no time or inclination to discuss M. Plateau's work in a critical spirit. The directions for making the experiments are very precise, and if sometimes they appear tedious on account of repetitions, we must remember that it is by words, and words alone, that the author can learn the details of the experiment which he is performing by means of the hands of his friends, and that the repetition of phrases must in his case take the place of the ordinary routine of a careful experimenter. The description of the results of mathematical investigation, which is a most difficult but at the same time most useful species of literary composition, is a notable feature of this book, and could hardly be better done. The mathematical researches of Lindelöf, Lamarle, Scherk, Riemann, &c., on surfaces of minimum area, deserve to be known to others besides professed mathematicians, and M. Plateau deserves our thanks for giving us an intelligible account of them, and still more for showing us how to make them visible with his improved soap-suds.

In the speculative part of the book, where the author treats of the causes of the phenomena, there is of course more room for improvement, as there always must be when a physicist is pushing his way into the unknown regions of molecular science. In such matters everything human, at least in our century, must be very imperfect, but for the same reason any real progress, however small, is of the greater value.

J. CLERK MAXWELL

HINTON'S PRACTICAL PHYSIOLOGY

Physiology for Practical Use. By various writers. Edited by James Hinton. 2 vols. (Henry S. King & Co.)

THIS work consists of a series of independent essays by different writers, on points in physiology which are likely to prove interesting and instructive to the general public. No attempt is made to give more than the best known facts of the science, together with the most approved theories by which they are, at the present day, connected. The thoroughness of the knowledge of the authors, the largeness of the view they take of the subject, and the easiness of the style they adopt add greatly to the interest of the book.

Those who are accustomed to regard the living body as an arrangement of organs which is quite peculiar and whose mechanism is altogether inexplicable upon the ordinary principles of mechanics and chemistry, will, after having carefully studied this work, be convinced how subject it is to the same influences that affect the inanimate world, and that in fact it is nothing more than a very complex machine, with the detailed mechanism of which we are daily becoming more and more acquainted. There are peculiarities however in the living frame which fail to be represented in working out the analogy with the steam engine. "The latter, after being constructed, daily wastes. Every day it becomes worse, for each stroke of its piston, to say nothing of the motion of its other parts, implies a waste of the piston itself, and of the cylinder in which it is inclosed, and in which it works. Now when we get these out of order, the whole machine has to be stopped, that the engineer may repair the deteriorated portions." Such is not the case in the living body, which differs from any machine yet constructed in that it is "constantly working, constantly wasting, and *constantly repairing its own deficiencies*." This is a most important difference between the two engines; and it is almost certain, that as our knowledge of machine-construction increases, but little improvement will ever be made in this direction, on account of the nature of the materials employed, so that the difference will not be diminished. The cell of a Daniel's battery may be instanced as an example of an engine in which a partial repair of its structure is continually being effected, for by the gradual solution of the crystals of sulphate of copper that are always placed in one of the compartments, the power of the battery, and therefore the constancy of the current it developes is rendered more perfect.

There is an excellent chapter on alcohol, in which the principle of its action is most clearly explained. The author prefaces his subject by clearly stating his views on its social relations. For instance, he remarks:—"We are not in the ranks of those who would remove the tax on spirits, a tax whereby the poor as well as the rich are made to contribute to the expenses of Government, by paying a price above its production-cost for an article of luxury; and very far are we from siding with those who misinterpret the liberty of the subject—we mean the right of any man to wrong his neighbour, to sell him fictitious goods—poison, perchance for food." . . . "We are not abstainers ourselves, and we are not about to advocate teetotalism under the banner of physiological instruction."

There is a paragraph which quite represents the generally accepted doctrine of the relation of mental activity to work done, but to which we think all physiologists ought now-a-days to take exception. It is remarked that "energy, the manifestation of power, or the conversion of force into action, involves no expenditure of life or loss of power. Thinking or lifting a weight is but a function of