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NOTE ON A SIMPLE FORM OF LIPPMANN'S CAPILLARY ELECTROMETER USEFUL TO PHYSIOLOGISTS.[1] By Professor JOHN G. M'KENDRICK, M.D.

THE action of the substances set free on the electrodes in electrolytic decomposition, and the energy shown as motion in these circumstances, is strikingly manifested by the behaviour of a drop of mercury in dilute sulphuric acid, when the positive pole of a battery is put in connection with the mercury, and the negative pole dips into the acid. The mercury extends towards the negative electrode during the passage of the current, becoming covered with a film of sub-oxide, which dissolves in the acid, leaving a bright surface. By making and breaking the current a series of oscillations is set up. Movements in the mercurial electrode and adjacent acid have been observed by Henry, Gerboin, Erman, J. F. W. Herschel, Draper, Paalzow, Faraday, and Quincke,[2] and they received various explanations. Erman,[3] in 1809, was the first to observe that when a drop of mercury was placed on a grooved surface between the electrodes it moved towards the negative pole; and he also observed that "a drop of mercury in a horizontal tube, with dilute acid on both sides, moved at the passage of the electric current through the tube towards the negative electrode."[4]

This latter phenomenon was fully investigated by Lippmann,[5] and led, along with researches by Quincke, not only to a theoretical explanation of electro-capillary action, but also to the construction of the capillary electrometer. It is now known that these phenomena, both as seen in the experiment with the globule of

[1] Read before the Philosophical Society of Glasgow, January 17, 1883.

[2] For an historical account of this subject see Lippmann, *Annales de Chimie et de Physique*, 1875, p. 540. Also references in arts. "Capillary Action, by Professor Clerk Maxwell, *Encyclop. Britann.*, vol. v. p. 65; and "Electrolysis," by Mr. W. N. Shaw, vol. viii. p. 108. See also art. "Electricity," Watt's *Dict. of Chem.*, third suppl., vol. viii. part i. p. 714.

[3] Gilbert's *Annalen*, t. xxxii. p. 261, 1809.

[4] Art. "Electrolysis," *op. cit.*

[5] Lippmann, *Comptes Rendus*, 1873, p. 1407; *Annales de Chimie et de Physique*, 1875, p. 494; Poggendorff's *Annalen*, cxlix. p. 547; also translated in *Phil. Mag.* [4], xlvii. p. 281.

mercury and in the capillary tube, are due to a change in the surface tension produced by the electrical polarisation of the surface of the mercury.

Lippmann's form of the electrometer consists of a tube of ordinary glass, 1 metre long and 7 millimetres in diameter, open at both ends, and kept in the vertical position by a stout support. The lower end is drawn into a capillary point, until the diameter of the capillary is ·005 of a millimetre. The tube is filled with mercury, and the capillary point is immersed in dilute sulphuric acid (1 to 6 of water in volume), and in the bottom of the vessel containing the acid there is a little more mercury. A platinum wire is put into connection with the mercury in each tube, and, finally, arrangements are made by which the capillary point can be seen with a microscope magnifying 250 diameters. Such an instrument is very sensitive; and Lippmann states that it is possible to determine a difference of potential so small as that of the $\frac{1}{10080}$ of a Daniell. It is thus a very delicate means of observing and (as it can be graduated by a compensation-method) of measuring minute electro-motive forces.

As the sensitiveness of the instrument depends essentially on the smallness of the bore of the capillary, and on the constant electro-motive force between the mercury and the sulphuric acid (termed by Lippmann the *différence électrique*), it is important to have the tube as fine as possible, and also to prevent variations in the strength of the sulphuric acid by evaporation. These considerations led to improvements in the construction of the instrument, thus described by Burdon Sanderson:[1]—"Two important improvements have been recently made in the construction of this instrument by Professor Lovén,[2] of Stockholm. The first of these consists in constructing the tube which contains the dilute sulphuric acid of extremely thin glass, so that the capillary tube which is in contact with its internal surface can be observed with

[1] Burdon Sanderson "On the Electro-motive Properties of the Leaf of Dionæa in the Excited and Unexcited States," *Phil. Trans.*, part i., 1882. See also his lecture "On the Excitability of Plants," at the Royal Institution of Great Britain, 9th June 1882. In stating his opinion that "it is much better to measure the electro-motive value of each excursion with the aid of the compensator, than to deduce it, as has been done by Fleischl, from the 'compensation pressure,'" Dr. Burdon Sanderson refers to Fleischl's paper, *Archiv f. Anat. v. Physiol.*, 1879, p. 269.

[2] Lovén, *Nordiskt Medic. Arkiv.*, vol. xi. No. 14.

a magnifying power of at least 300 to 400 diameters (No. 10 Hartnack). The other consists in cementing the sulphuric acid tube to the mercury tube, so that no evaporation takes place. By the first the instrument is rendered much more sensitive; by the second, variations in the strength of the sulphuric acid which arise from evaparation are avoided."

The instrument thus described is difficult to make, and requires delicate handling. Whilst studying the subject, and endeavouring to see the phenomena for myself, I resorted to the simple expedient of taking a bit of glass tubing, 60 millimetres in length, and 2·5 millimetres in internal diameter, bending one end at a right angle, 20 millimetres from the end, and the other end at a right angle, 6 millimetres from the end, and then drawing out the tube to a capillary in the blow-pipe flame. The diameter of the capillary tube varies from ·02 mm. to ·001 mm. I then slip a bit of thick-walled india-rubber tube on one end of the glass tube, and exhaust the other end of the india-rubber tube with a powerful syringe. Having some clean mercury in a beaker covered with a deep layer of dilute sulphuric acid (1 to 20 of water by volume), I first immerse the end of the glass tube into the mercury, and then exhaust by the syringe. When mercury appears in the upper portion of the tube, I raise it a little so as to cause it to dip for an instant into the dilute acid, and then I dip into the mercury a second time and draw a little more of it into the tube. Thus, with a little practice, I succeeded in filling tubes, so that there is a reservoir of mercury at each end, with a little sulphuric acid in the centre of the capillary. This is placed on a suitable platform on the stage of the microscope, and a thin platinum wire is dipped into the mercury at each end.

Such an instrument is very sensitive, showing the muscle-current, the negative variation, and the changes in potential in the injured heart of the frog whilst beating. As observed by Burdon Sanderson, it is striking to notice "that the movements of the mercurial column not only correspond closely in time to the actual changes which they represent, but express with very great accuracy the differences of a potential which actually exist in each successive phase of a variation."

It will be found that, in the instrument I have described, the column of mercury will not always return to zero when the electro-motive force pushing it in one direction has ceased to act. When it does return, the return is due to the pressure of the column of mercury against which the force acted. As a matter of fact, the most sensitive instruments are those which do not return to zero, but in which the movement of the mercurial column corresponds to each change in the direction of the electro-motive force, or to any increase or diminution of the electro-motive force even in one direction. Thus, if there be a negative oscillation, it will be at once seen, although it last for a fraction of a second. Sometimes the instrument is "sluggish" in its movements. This is caused by the mercury, or the acid, or the tube not being perfectly clean.

An electrometer such as this can have its deflections photographed[1] or exhibited on a screen, whilst its simplicity and cheapness makes it possible to place a sensitive instrument in the hands of every student—or, better still, a student may make it for himself.[2] For convenience in working, when it may be necessary to make observations with a galvanometer at the same time, the image of the capillary may be thrown on the plate of a camera, adjusted to a microscope, and thus the trouble of looking through the latter is got rid of.

[1] Marey obtained such a photograph in his research on the Electrical Discharge of the Torpedo (*Physiologie Expérimentale*, 1877, p. 33, fig. 19), and Burdon Sanderson has photographed the oscillations caused by the changes of potential in Dionæa, and in the frog's heart.—Royal Institution Lecture, fig. 10.

[2] Various forms of the instrument were shown, and the oscillations of the mercury were projected on a screen, the oscillations being magnified 300 diameters. There is nothing novel either in the theory or in the mechanism of this instrument, as it in no way differs in principle from one shown at the meeting of the British Association in Glasgow in 1876, by Professor Dewar of Cambridge, but I have shown an easy and convenient mode of making such an instrument of exquisite delicacy for physiological purposes. A figure of Professor Dewar's instrument is shown in Dr. S. P. Thompson's recent Manual on Electricity.