"Contributions to a Theory of the Capillary Electrometer. II.—On an Improved Form of Instrument." By GEORGE J. BURCH, M.A. Oxon., F.R.S., Lecturer in Physics, University College, Reading. Received September 26,—Read November 20, 1902.

During the sixteen years that I have worked with the capillary electrometer I have had occasion to make between 150 and 200 instruments, and have therefore given naturally a good deal of thought to the problem of its construction. I have used eleven different forms, three of which are figured in my little book on the 'Capillary Electrometer in Theory and Practice,' reprinted from 'The Electrician,' 1896. A fourth is in use in the Physiological Laboratory, Oxford, for the research on nerve in which Professor Gotch and I have been engaged, and is in fact the improved form referred to on page 9 of my book.

It may be of interest to indicate briefly the points that must be observed in the design of the instrument.

It must be simple, easy to adjust and to clean, and with reasonable care not liable to be broken. Above all it must be suitable for use with objectives of short focus and wide-angle condensers. For this reason I adopted in my first projection-electrometers the plan of placing the capillary within a piece of thick-walled burette tubing of 1 mm. bore, half ground away so as to form a trough of semi-circular section. A piece of thin cover-glass serves as a front to this trough, the lower end of which dips into the dilute sulphuric acid, the liquid rising in it by capillary attraction to a sufficient height above the level of the U-tube to enable the microscope to be focussed on the capillary within.

In the first instrument of this type the trough was ground to fit the mouth of the U-tube like a stopper, and rested loosely in it. It was found, however, that as the acid loses or absorbs water with the changes of weather, the variations of level in the U-tube affect the adjustment of the trough, bringing the capillary sometimes too far from the cover-glass for good definition and sometimes dangerously near it.

Hence in the later improved type I fused the upper end of the glass trough on to a glass rod which was fixed firmly with adjusting screws to the brass support that held the capillary, the U-tube containing the acid being independently supported so that the end of the trough dipped into it. The short limb of the U-tube was made wide in order that the trough should not be likely to touch against it in the event of any accidental pressure on the instrument, and also because experi-

ence has shown that capillaries are less liable to become sticky with much acid than with very little. The only objection to this type is the difficulty of adjusting the capillary in so small a trough. The operation has to be effected under the microscope and is both delicate and tedious. When it has been completed the definition is perfect, and the instrument not unduly fragile. But in order to clean it the same process has to be gone through again.

I therefore determined to try an entirely different plan, on which the safety of the capillary should depend not on the rigidity of the supports by which the trough was fixed, but on their perfect flexibility and on the use of a trough so light that its entire weight might even be borne by the capillary.

Fig. 1 is a perspective diagram of the instrument in its final form, and figs. 2, *a*, *b*, *c*, and *d*, show the details of the trough which is the essential part. The support A is cut from a solid block of ebonite 9 cm. long, 5 cm. wide, and 2 cm. thick. It is first cut to shape, holes drilled for the binding screws E and F, and the piece B then separated from it by two saw-cuts.

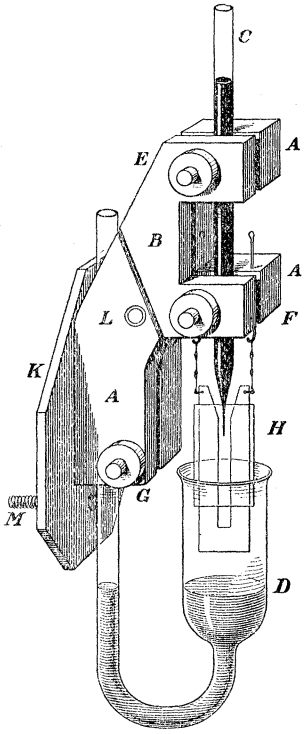

FIG. 1.—Half full size.

V-shaped grooves are cut to receive the capillary C, which is firmly clamped under B by E and F. The longer limb of the U-tube D passes through a hole drilled lengthways through the lower end of A, which is slit about half way up with a wide saw-cut, so that it may be pinched together by the screw G. Adjustments for setting the capillary at right angles to the optic axis and parallel to the slit of the photographic recording apparatus, are provided for by the stout brass plate K, bent at right angles, one end of which is fastened by a binding-screw at L to the back of A, and the other by a similar screw M to the adjustible stand of the projection microscope. The brass plate K is so shaped that there is a space of about 3 mm. between it and the left-hand side of the ebonite support A, in order to leave room for the adjustment of the latter about L as a centre.

The construction of the trough is shown in the full-size diagrams, figs. 2, *a*, *b*, *c*. A piece of mica, such as is used for lamp-shades, is cut to the shape *a*, with a pair of scissors. Two or three thicknesses may

be taken if one is not enough. Four holes are drilled with a needle in the positions shown. A thin piece of the best clear mica is then laid on a pad of blotting paper, the piece *a* placed on it, and four corresponding holes pricked through with the needle, the piece being after-

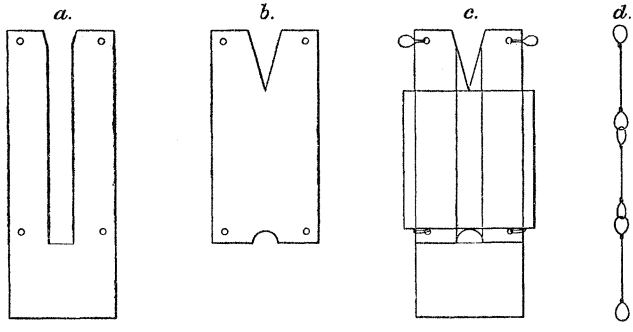

FIG. 2.—*a*, *b*, and *c*, full size; *d*, about twice full size.

wards cut to the shape *b*. Finally, *a* and *b* are fastened together by four little loops of No. 30 platinum wire, and the whole trimmed to shape with the scissors. The trough is then hung by two platinum chains (made of No. 30 wire with long links as shown enlarged at *d* (fig. 2), so that the acid may not creep up them) from the hooks shown in fig. 1. These hooks are best made of half-round wire, doubled like a linch-pin, sliding easily but firmly in holes on each side of the capillary, as in fig. 1.

The operation of putting in a capillary is as follows: The instrument is fixed to any convenient support by the screw M. The milled head G is loosened, and the U-tube D drawn down and turned aside. The whole instrument is then tilted backwards to an angle of 45° from the vertical. In this position the trough H hangs clear of the capillary. If the capillary has been already filled and connected with the pressure tube, the nuts E and F must be unscrewed far enough for the tube to pass sideways into the clamps, but a new capillary may be easily and safely inserted from below after merely loosening E and F. It must then be filled to within 2 cm.—not nearer—of the top, with recently distilled mercury from a perfectly clean pipette, connected with the pressure apparatus,* and some mercury forced through.

The screw M is then slightly loosened, and the instrument raised cautiously to a nearly vertical position. The trough H is adjusted by sliding the hooks from which it hangs up or down, or bending them, until the capillary rests against the centre of it—the apparatus being

* Full details of the pressure apparatus, the cleaning of the tubes, and the method of drawing capillaries were given in my book.

tilted back during each alteration. When these adjustments have been made, the inside of the trough is wetted by touching it with a glass rod dipped in dilute sulphuric acid of 25 per cent., and the apparatus is tilted forwards until the wet trough swings against the capillary, and sticks to it. A piece of thin cover-glass—or of mica if very high powers are to be used—slighly wider than the trough, is picked up with a pair of fine forceps, wetted on one side with the acid, and placed carefully against the trough, to which it adheres, holding it firmly against the capillary, the lower edge of the glass resting against the platinum loops with which the trough is fastened together (see fig. 2, *c*).

The U-tube is then turned back into position, cautiously raised until the lower edge of the glass just dips into the acid, and clamped by the screw G. Finally the trough is gently shaken or pushed to and fro in the plane of the mica, until the acid rises in it to the required height and all bubbles are expelled.

The trough is held together so firmly by surface-tension that it seems at first sight a difficult matter to take off the cover-glass without breaking the capillary. It may, however, be done with the greatest ease as follows: The screw G is loosened, and the U-tube D drawn down and turned aside. A small beaker filled with water is held in its place and raised until the trough H is completely immersed, when the slightest movement causes the glass to fall off. The apparatus is then tilted back so that the trough swings clear of the capillary, which may be washed or even wiped, and the trough dried, replaced, and a new cover-glass put on, in less than three minutes.

The definition, with these electrometers, is perfect. The capillary touches the cover-glass throughout its length, so that any dry objective can be used. The microscope should not, however, be left focussed on the capillary, lest the acid should chance to get between the objective and the cover-glass—an accident which I have known to happen in very damp weather.

My only fear in designing this instrument was lest contact with the mica should contaminate the acid and so spoil the tubes. There does not, however, seem to be any such effect. I have had some mica troughs in use for nearly three years, and have never once been troubled with a sticky capillary, and even with induction shocks they will stand more than the old type on account of the larger quantity of acid in the U-tube. They are easier to make than my old "normal type" on account of the straight capillary, and so far as I can judge they seem likely to supplant both it and my previous projection electrometer.

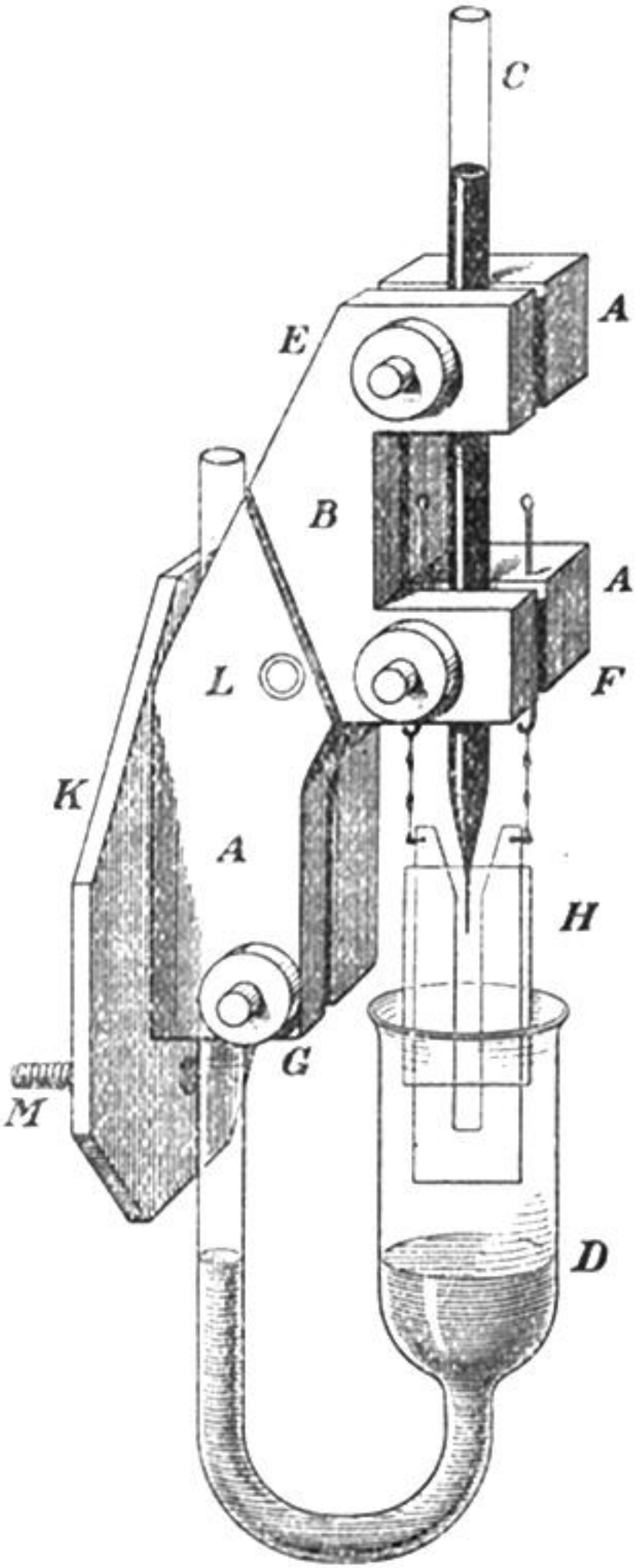

FIG. 1.—Half full size.