TWO SIMPLE APERTOMETERS FOR DRY LENSES.

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Figs. 5 and 6.

In dealing with questions of apertometry it is very important to inquire, in the first place, as to what order of accuracy it is desirable to work. No useful purpose would be served by giving a carpenter a foot-rule, divided to hundredths of an inch, with which to measure the length of a plank. The measurement, if made to such an order of accuracy, would be useless and meaningless.

Prof. Abbe, in "Some Remarks on the Apertometer" (*Journal of the Roy. Mic. Soc.* 1880, p. 20), after stating that the error of measurement in his well-known apertometer is limited to about ½ per cent., goes on to say that "an exactness of *reading* to this extent is evidently more than sufficient. An unavoidable amount of uncertainty resulting from the nature of the object, and many other sources of slight error, will always limit the real exactness of *observation* beyond 1 per cent. of the unit, different observers and different methods of equal reliability being supposed. In low powers slight variations in the length of the tube, in high powers slight alterations of the cover-adjustment, will admit of much greater difference than the error of reading will introduce. It should be observed that in high-angled objectives the aperture has not the same value for different colours, owing to the difference of focal length (or amplification), even in objectives, which are perfectly achromatic in the ordinary sense. In the case of very large angles, the aperture, angular or numerical, will be greater for the blue rays than for the red, generally by more than 1 per cent. Last, not least, there is no possible interest, either practical or scientific, appertaining to single degrees, or half

degrees, of aperture angles; for no microscopist in the world will be able to make out any difference in the performance of objectives as long as the numerical apertures do not differ by several per cent., other circumstances being equal."

"For these reasons I consider all attempts at very accurate measurements of this kind to be useless."

No one, probably, is likely to have the temerity to question the authority of Prof. Abbe on such a question as Apertometry, so that we can accept his limit of 1 per cent. with confidence.

Fig. 5 shows a plan of a form of apertometer for dry lenses which for simplicity in use and for the accuracy of its results probably leave nothing to be desired. A strip of vulcanite A * is so divided that the distance D of any line from the zero of the scale is given by the equation

$$D = 2 \Delta \tan (\sin^{-1} \text{N.A.})$$

set out in this Journal for April 1904 (Ser. 2, vol. ix. p. 1), in the article on "Abbe's Test of Aplanatism, etc." The graduations are marked with the corresponding N.A. values for a value of Δ equal to 25 mm. In use the apertometer is placed upon the stage and the object plane of the lens to be tested adjusted at a height of 25 mm. above the plane of the scale. The upper focal plane of the objective is then observed in any known way and the apertometer adjusted on the stage until the inner edge of the fixed white block B is seen on one edge of the objective opening. This adjustment effected, the sliding white block C is slid along the strip A until its inner edge is seen on the opposite edge of the objective opening to that on which the block B is just seen. The N.A. value found opposite to the inner edge of the block C on the scale is that of the lens tested.

The graduations from 0 to 0·9 N.A. proceed by steps of 0·02 and from 0·9 to 0·96 N.A. by steps of 0·01.

Fig. 6 shows a modification of the form of apertometer described in my original paper in 1904. I have substituted for the concentric circles there shown curved lines which project optically into the upper focal plane of the lens being tested as a number of equi-distant straight lines of equal thickness. The projected image of the apertometer scale is thus a simple linear

* The right-hand end is shown broken off.

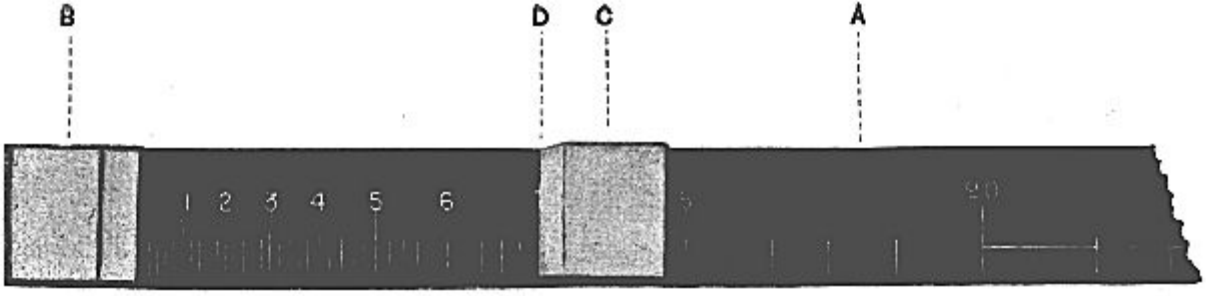

FIG. 5.

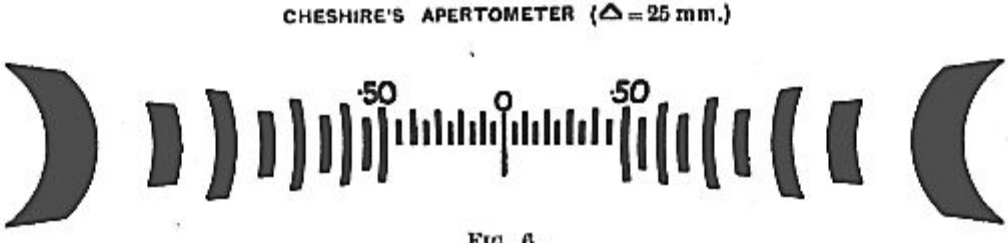

FIG. 6.

scale upon which N.A. values can be read directly. The scale runs from 0·0 to 0·9 N.A. by steps of 0·05, *i.e.* the divisions starting from the centre have the values 0, 0·05, 0·10, 0·15, 0·20, etc., of N.A.

The short curved lines of the scale should strictly be hyperbolas, but such curves are very difficult to draw accurately, and it was not until my son, Mr. R. W. Cheshire, suggested to me that they might be replaced by arcs of circles with curvatures equal to those of the corresponding hyperbolas at their vertices that the apertometer described became a practical construction.

I may, perhaps, be allowed to avail myself of this opportunity to say that in my opinion there are several objections to Mr. Nelson's form of the Apertometer which was introduced by me in 1904. These may be briefly indicated. In the first place, no advantage can result from the use of the outer edges of the lines, instead of the middles, as is usually done, as the part of the lines from which distances and therefore N.A.'s must be estimated by eye. Further, in Mr. Nelson's form the thickness of the lines varies in different parts of the diagram, and has no assigned or stated thickness in terms of N.A. This, I think, is a fatal defect, because when the thickness of a line has a N.A. value of 0·02, say, such thickness, especially when dealing with low-power lenses, provides an invaluable standard of reference when estimating by eye N.A. values intermediate to those represented on the scale.

In apertometers of the kind in question the further the subdivision of the scale is carried the greater must be the complexity of the image presented to the eye—the advantage of one is balanced by the disadvantage of the other. Possibly, however, most people would prefer the simplicity of a diagram with the larger divisions to the optical Hampton-Court-maze necessitated by the smaller ones.