

II.—*On the Measurement of the Angle of Aperture of Object-glasses.* By F. H. WENHAM.

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ALL methods hitherto employed for measuring the degrees of the angle of aperture of microscope object-glasses, have included rays from oblique pencils which constitute the entire field. These having greater divergence from the axis and being superadded to the angle proper, confuse angle of aperture with angle of field.

This remarkable source of error appears to have escaped notice, and is sometimes so considerable as to show an excess in the highest powers of nearly twice the amount of aperture attributed to them by opticians.

The angle of aperture in reality means, that the cone of rays should proceed from one approximate point in the field of view: for example, it cannot be doubted, that if the margin of a very minute diatom were to be enclosed by a screen impervious to light it would not only be seen with the full aperture, but also with improved definition on account of the exclusion of extraneous rays from the field of view.

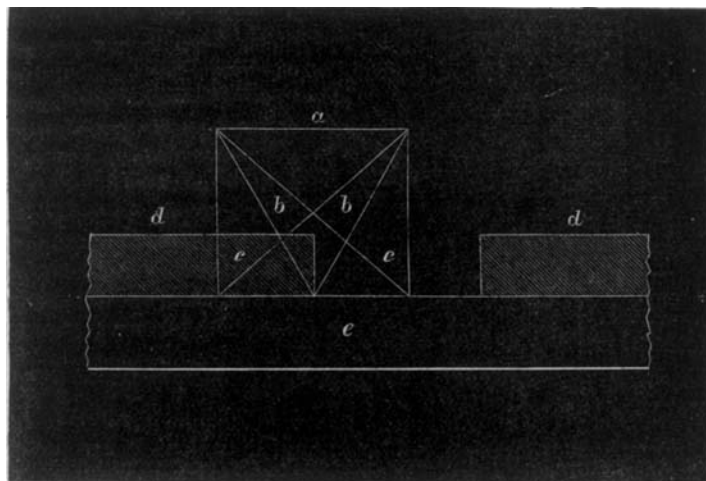
It is the admission of a portion of the rays from lateral pencils that gives an erroneous excess of aperture, by the usual methods of measurement, for the marginal rays of the lateral pencils having a greater obliquity than the outer rays of the central one, of course admit light beyond the true degree, and therefore they should be stopped off during the measurement.

In order to confine the cone of rays to an approximate point in the focus of the object-glass, I have proposed that the light should be admitted through a very narrow slit cut in an opaque film duly set in the focus. There are, however, several difficulties in the use of this slit. In the first place, the measurement depends on the effect of the disappearance of light. This is not altogether a definite indication, and may give rise to dispute, as it may be asked whether the index is to be stopped at the first movement in the slit, or continued till the last trace of light remains visible? Secondly, it may be objected that however thin the material through which the slit is cut, if the space is exceedingly narrow very oblique marginal rays from a large aperture may be cut off.

If the first objection is met by obtaining through a suitable eye-piece arrangement a telescopic image of the lamp flame, in order to see this distinctly the slit must be opened out to a width that will cause a considerable error in excess of spurious aperture, arising from the admission of some lateral rays.

I have stated that "the narrower the slit, the more accurate the result will be." This means strictly that for absolute accuracy, we

must approach to a line, and cut off all rays in the focal plane on either side, quite up to the axis of the object-glass. To ensure this condition I now adopt the following method of measuring apertures:— a is the working diameter of an object-glass; b , the central pencil, or true angle of aperture; c, c , oblique or lateral pencils enclosing the field of view; d, d is a slit of considerable width, with parallel edges attached to a glass slip, e . In order to measure



apertures, the object-glass is first adjusted and focussed on the upper surface of the glass slip. One edge of the slit is now brought forward so as exactly to bisect the field of view, half of which will appear quite dark. Over the eye-piece is now placed a cap containing a biconcave lens of about half an inch radii; by means of this and the movement of the sliding containing tube, a distinct telescopic image of a distant lamp, or other bright object, may be obtained through the open half of the object-glass. Turn the open end *away* from the lamp by rotating the microscope, and the flame will suddenly disappear at the point when it is obscured by the edge of the slit. Mark this as zero! Now remove the lens from over the eye-piece, bring back the slit till the opposite edge obscures the other half of the field, and again exactly bisects it, seeing that plane e is still in focus, replace the cap and turn the microscope, till the flame again vanishes, and the true aperture will be indicated.

It will readily be seen by the diagram how the rays, c, c , of the oblique pencils, which have hitherto given a false indication in excess of aperture, are cut off by the edges. The thickness of these by this method is of no consequence, as it is the bottom of

the edge only that intercepts the extraneous rays. The top might touch the object-glass without detriment to the result. However, it is more convenient to employ a film as thin as possible for the slit. This may be easily made as follows:—Take an ordinary 3×1 glass slip, pour upon it a drop of turpentine (which is best after being long kept), and drain it off; move the slide about over the open smoking flame of an ordinary coal oil lamp, till the black deposit is quite impervious to light. Again pour turpentine over the cooled slide, drain, and evaporate it dry by heat. The film may now be cut to a very clear edge with a sharp penknife, drawn along the edge of a small square. Make two cuts about one-twentieth of an inch asunder, and scrape away the intermediate black with a pointed wire, guided by the straightedge. Lay over the slit a thin glass cover, and let Canada balsam run under it by capillary attraction. The small particles left in the slit are excellent objects to adjust the object-glass by, the aperture of which is taken in the conditions of its actual use, and for an immersion lens water can be used between that and the cover.

It is not difficult to bisect the field by estimation, but if required a cross line may be inserted in the micrometer slit of the eye-piece.

The plan of obtaining an angle of aperture by measuring the working portion of the front lens by the diameter of the spot of light transmission, and distance of focus from the surface as the data for the angle, is only so far useful for demonstrating that certain stated angles are impossible, for the computed result may be excessively inaccurate. For example, an object-glass may have an extensive field with good definition with no focal distance, the plane of this being on the surface of the front lens. In this case, of course, the resulting angle will come out near to 180° , however small it may in reality be.

Finally, in order to show the fallacious value of pretended angles near to this extreme, I append a table of apertures: the relative value of the degrees is taken as the chord of the arc. The limit of 180° is indexed as 100, and the corresponding figures give the comparative percentage of value for each aperture.

Relative value of angular aperture taken as the Chord of the Arc.			Relative value of angular aperture taken as the Chord of the Arc.		
180°	=	100	130°	=	90.6
170°	=	99.6	120°	=	86.6
160°	=	98.4	110°	=	81.9
150°	=	96.5	100°	=	76.6
140°	=	93.9	50°	=	42.2

By this table it will be seen that there is but little to be gained by apertures exceeding 150° , while the last lines of the column show the great increase of value for a corresponding increase in degrees.