V.—*On the Measurement of the Angular Apertures of Object-glasses.* By JABEZ HOGG, Surgeon to the Royal Westminster Ophthalmic Hospital, F.R.M.S., &c.

I AM led to infer from what has recently transpired that considerable misapprehension prevails with regard to the measurement of the angular aperture of object-glasses. An article contributed by Mr. Ingpen to the Journal of the Quekett Club, and quoted in the 'M. M. J.,' * though of some interest, only very briefly alludes to the various methods employed during the last quarter of a century, and does not touch upon any method that would be considered valid in the determination of the apertures of immersion lenses. Mr. Ingpen makes particular mention of Professor Robinson's method, and though he speaks of it as "a very elegant method, and likely to be valuable, in certain disputed cases, as to the true angle of immersion lenses," it would appear that he thinks immersion apertures can be measured by this method without any modification. It is, however, quite evident that Professor Robinson had solely in view the measuring of the apertures of dry lenses—such as have a true air-focus; and Mr. Ingpen offers no evidence whatever that he realizes what modification is necessary in Professor Robinson's method to render it applicable to immersion lenses.

In the Journal,† Mr. Wenham unhesitatingly affirms that Professor Robinson's method is by far the best. These are his words: "I consider that the most correct of all [methods of measuring apertures] is that proposed by Professor Robinson, which consists in passing the parallel rays of the sun through the back of the objective, and then by means of a white screen in a dark room intercepting the rays as a disk of light. The angle taken from the diameter of this to the focal point will give the true aperture." Mr. Wenham also appears to think that the aperture of immersion lenses can be accurately determined by the same method, and without modification of any kind. On the other hand, it is held by competent authorities who have given the subject special attention, that the only possible way of measuring immersion apertures with accuracy is to measure the angle of the cone of rays while they are in the condition of immersion. This view is entertained by Dr. Woodward, Professor Keith, Professor Abbe, Messrs. Hartnack and Prazmowski, Messrs. Powell and Lealand, Mr. Dallmeyer, Mr. Tolles, and Professor G. G. Stokes, whose authoritative utterances on the subject are of the highest importance.

The modification required in Professor Robinson's method to enable anyone to measure immersion apertures is an extremely simple one, and can be readily put into practice. In place of the white

* Page 236, May 1876.

† 'M. M. J.,' vol. viii., p. 233.

screen, a cube of glass greyed on the under surface should be so placed that the lens may be accurately adjusted and focussed on the upper surface in water contact, or still better, in glycerine. The angle can then be read off the luminous disk on the greyed surface, by applying a suitable tangent scale. I have some idea that Mr. Wenham first proposed a cube of glass for measuring apertures, but have been unable to verify this, although I feel sure that the lenses so measured were dry lenses only. No true aperture can be measured unless the lens is so adjusted as to give its best and finest definition; it is therefore utterly fallacious to attempt to measure the aperture of an immersion lens unless it is adjusted for and actually measured in immersion contact. It would be quite as fallacious to attempt to measure the aperture of a dry lens unless adjusted for and measured as a dry lens. If the lens is so contrived that it can be used either wet or dry, then the aperture will necessarily be greater when used wet than dry. I possess a Dallmeyer's $\frac{1}{4}$ th, which can, by suitable adjustment, be used either wet or dry. The angle when used wet is 70° measured in the cube of glass, and 55° when accurately adjusted and used dry.

It may give increased weight to what I have said to add that the modification of Professor Robinson's method spoken of has been submitted to Professor Stokes by Mr. J. Mayall, jun., and he admits its validity; and furthermore, Mr. Mayall has employed it in my presence for measuring the aperture of various immersion lenses; amongst others, Tolles' $\frac{1}{4}$ th, belonging to Mr. Crisp, and the measurements so made confirm Mr. Tolles', that is, the aperture of the lens in question was found to be nearly 100° in the cube of glass. It is but right I should state that the aperture of the same lens was measured by Mr. Wenham in my presence, by his semi-cylinder and turn-table method, and with a metal stop of $\frac{1}{80}$ of an inch in diameter fixed in the focal plane, and the measurement very nearly approached 100° .

I shall not enter upon the question of the utility of slits or metal stops for measuring immersion apertures, as I believe Professor Keith's criticism in the *Journal* for December last* effectually disposes of this part of the subject. I will, however, direct attention to the fact that Mr. Ingpen appears to think the slit is properly used when "separated to the exact diameter of any field of view, thus excluding all but 'image-forming rays.'" Those microscopists who have followed Mr. Wenham's more recent statements as to the right use of the slit will at once perceive that whilst he insists the slit should admit only the merest line of light, Mr. Ingpen thinks it should not encroach on the field of view. It is to be presumed that Mr. Ingpen has given the subject due consideration, and I hope he will at some future time favour the

* Page 284.

readers of the Journal with a more detailed exposition of his reasons for considering the slit "a valuable adjunct," while the method in which he would employ it is so entirely at variance with Mr. Wenham's. I am perfectly aware that when Mr. Wenham first brought forward his slit method he wrote, "it is preferable to open the slit till the edges appear in the margin of the field;"* but in a later paper vindicating his report on the aperture of Tolles' $\frac{1}{8}$ th, he appears to have abandoned this specific direction as to the size of the slit, and he now relies on some infinitesimally narrow slit, which he says should "cut off all lateral pencils"; however, with Professor Robinson's modified method no slit is required, and most conclusive and reliable results will be obtained.

* 'M. M. J.,' vol. xi., 1874, p. 118.