VI.—Mr. Tolles' "*Experiments on Angular Aperture.*"

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THE above essay would not have required any special notice from me, had not reference been made to my name. I consider that I have already said enough to settle the question in minds familiar with optical science, but there are others who might suppose, from the evidence of these experiments, that I have assumed things incorrectly, for there appears to be a lack of discrimination in this subject that quite justifies the remark made by the Rev. S. L. Brakey "as showing the incredibly low level at which the *scientific* knowledge of optics exists amongst microscopists."

Mr. Tolles' communication is set forth in an unassuming way, that does not provoke any hard strictures, but it enters within the lines of a controversy that has been long and hotly contested in reference to a subject which it would seem remains yet to be understood.

As shown by the figure, Mr. Tolles fixes before the front lens of an objective, a plano-convex lens nearly hemispherical, and then measures the aperture. "On testing the angle, only 80° (or at most, less than 82°) was obtainable. Were the plano-convex removed, the angle indicated would be 170° upwards. This was verified carefully." There is a simple honesty and truth in this experiment that is very pleasing. Half of 82° , or 41° , would be about the angle of total reflexion from the flat surface of the plano-lens, at which a veil of utter darkness would be thrown between the object-glass and the light, and none could pass beyond, so that after this the plano-convex had nothing whatever to do with apertures exceeding 82° .

We next come to the immersion question. I must compliment Mr. Tolles on the accuracy of his little diagram. The hemispherical lens is, I have no doubt, correct, and so is the front of the objective, both for diameter and thickness, as it should be, coming from a professional maker. Mr. Tolles says, "When the air in this interspace (*i. e.* between the lenses) is replaced by water, the angle becomes 100° , or a little more (an after-note states it as 110°). . . . It seems incontestable, at all events, that more than 82° of angular pencil *can* traverse the balsam-mounted object, and be transmitted by the immersion objective to the eye of the observer."

Though I saw at a glance why this assertion must be incorrect, and could explain the reason in a few words, yet as Mr. Tolles has given me facilities for doing so, I elucidate the point by the aid of a diagram, exactly copied, four times the size of his own figure. *a*, Fig. 1, is the front lens of the object-glass; *b, b*, rays; these, after being refracted by the convex and flat surfaces, would con-

verge in the dry lens at an angle of 170° , as shown by the dotted lines. Now let us introduce water between the lenses. Instantly a change takes place; no one, I think, will have the hardihood to maintain that the rays will hold their former position: on the contrary, they will converge at an angle of near 80° , and meet at a point in the body of the under lens. They cross and reach the lower hemispherical surface;* here they are refracted more outwards, and form an angle with each other of 108° , only two degrees short of the 110° given by the experiment. This

FIG 1

angle is obtained by careful projection of the rays, and is the one mistaken by Mr. Tolles for the representative of the extreme rays of the immersion objective. The microscope body is presumed to have been rotated on a sector as usual, but in order to make the thing more plain to those who do not perceive such matters very clearly, we will suppose the light itself to be traversed instead (which is very frequently done); it must be evident that this will have to be moved a *greater distance*, on account of the bending outwards of the rays by the lower surface of the hemispherical lens, and so give a false indication of increased aperture.

The loss of aperture on balsam-mounted objects was demonstrated by me on correct optical laws known ages ago, and I am astonished that in the nineteenth century anyone can dare to dispute it as a fact; but as it seems necessary to give an experiment to convince the sceptical that when the refraction of the front surface of an object-glass is partly neutralized by water contact, or destroyed by balsam, and the angle of aperture most woefully reduced on objects immersed therein, I have done this as follows:—

* A slight displacement of the ray, too small to be shown in the diagram, will be caused by the water-film; but this does not alter the angular direction in the hemispherical lens, though it may slightly increase the angle on finally leaving it.

a, Fig. 2, is a tank with a plate-glass bottom filled with water,*
b is the light some distance below on the floor; the sector for

measuring the apertures is set vertically, so that the nose of the object-glass *c*, may remain immersed in the water during the rotation. The following are some results:—
 A $\frac{1}{2}$ th of 170° (immersion front) showed an apparent aperture of 100° ; a $\frac{1}{3}$ th of $130^\circ = 87^\circ$, and a $\frac{1}{4}$ th of $90^\circ = 67^\circ$. If a higher refractive medium than water had been employed, the angles would have been still less, and with Canada balsam, or something of the same refractive power of the glass, the aperture from 170° could not exceed 80° . This experiment would have been more inconvenient to try, and I did not think it worth while to run the risk of injuring my object-glasses for demonstrating a simple fact in known optical laws quite incontrovertible. About 80° is the utmost aperture that we can expect to obtain for an object mounted in balsam; and the principle does not

differ, whether we employ an immersed front or not. The latter, of course, has the advantage in transmitting more light, and allows greater control over the aberrations. A tank might be used with a glass side, and the sector kept horizontal as usual, but this requiring an elastic water-tight connection from the object-glass, would be troublesome.

Messrs. Tolles and Stodder have girded on a convex front, and then ventured forth to make a stand against my unwelcome statements—that the aperture of object-glasses is reduced on balsam-mounted objects, and that there is no subsequent increase of this aperture by using an immersion lens. I had not the pleasure of shaking hands with them before the collision, but in the absence of this ceremony, I hope they may take the reception that they have met with in good part.

* The glass-bottomed metal pot, used by fastidious beer-drinkers, will answer the purpose, but I do not know whether our Transatlantic friends are familiar with this.