IV. *On the concentric adjustment of a triple Object-glass.* By

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HAVING in my possession a telescope with a triple object-glass of forty-five inches focus, made by DOLLOND in 1771, I have had a good opportunity of examining the central adjustment of the lenses, and have made trial of a method of correcting that adjustment, which appears not to have been used for that purpose.

When I ventured to take to pieces an instrument that had stood the test of fifty years trial, with uniform approbation of its performance, those who knew the telescope, and who know the difficulty of centering, seemed to consider it an act of rashness which I was likely to regret; but, by the test which I am about to describe, I felt confident that my object-glass was capable of improvement, and I rested my hopes of success on principles that seemed indisputable.

When any bright object is viewed through a glass of this construction, without an eye-glass, there may be observed, at the same time with the refracted image, a series of fainter images, that are formed by two reflections from the different surfaces; and, as the position of each of these images is dependent on the curvatures of that pair of surfaces by which it is formed, they appear at different distances from the object-glass.

Since the number of surfaces is six, the number of binary combinations of these surfaces is fifteen; and just so many images formed by reflection may be discerned.

It is manifest, that if the glasses be duly adjusted to each other, so that their axes are correctly coincident, then this series of images must be all situated in the same straight line; and conversely, that any defective position may be immediately detected by a derangement of the line of images.

A very distinct view of a part of these appearances, fig. 1. (Pl. I.) is seen by placing the eye close to the object end of the telescope, so as to view the eye-hole illuminated by the flame of a candle set near it. In this position only ten of them are perceived; two beyond the refracted image; four in regular succession nearer to the eye; and four very small ones close together, at a short distance from the object-glass within the tube.

The remaining five images being some inches exterior to the object-glass, cannot be seen till the eye is withdrawn to a greater distance, and are best observed with the assistance of a lens, fig. 2.

Each of the two first named images is formed by a pair of surfaces that are curved in the same direction, fig. 3, of which that which reflects from its concave side is most curved. The next four are also formed by surfaces that are curved in the same direction; but in this case, the convex reflecting surface is more curved than the concave, fig. 4. The four small images arise from pairs of surfaces, that have their convexities opposed to each other, fig. 5; and the five exterior images are owing to those pairs of surfaces which present their concave sides to each other.

In order to explain distinctly the origin of each of these images, I have, in fig. 7, marked those surfaces which have their concavities toward the tube with large letters, A, B, C, and those curved in the opposite direction with the small letters, *d*, *e*, *f*; by which means, in fig. 8, where the origin of each image is indicated, similarity of source in the several groups will be seen from similarity of notation. The concurrence of a pair of large letters, or a pair of small letters, as BC, or *de*, shows combination of curvatures in the same direction as in figures 3 and 4; unequal letters in the order *d*C, show opposite curvatures, as of fig. 5, giving a negative focus; and the unequal letters, B*f*, in the opposite order, represent the opposite concavities of fig. 6, forming a positive focus beyond the glasses.

The origin of these images was ascertained by giving a small motion to one or the other of the convex glasses. When the outer glass is inclined, fig. 9, all the images dependent on A or *d* are inclined together in the same line *gh*; but it may be remarked, that the image A*d* is not displaced by this motion, as the relative position of the two surfaces A and *d* to each other remains unaltered.

In fig. 10, the inner glass is represented with a similar inclination; and with it all images dependent on C or *f* for their formation, assume an inclined position in the line *ik*.

By lateral motion of the outer glass, it is only the images dependent on A, that are moved; for since the motion takes place in the direction of the curve *d*, which remains in contact with the middle glass, the position of this surface is not altered, fig. 11.

By similar motion of the inner glass, fig. 12, those images only that are owing to *f* are moved, while those from C retain their position.

Any lateral motion given to the central concave has the same effect as moving both the convex glasses together in the opposite direction, and of course the effect is most discernible in the position of an image that is similarly affected by the lateral motion of both. For instance; downward motion of the concave, fig. 13, has the effect of placing a wedge between the two convex glasses from above, so that though each of their inner surfaces still remains in contact with the adjacent concave, their exterior surfaces, A and *f*, are parted from above, and the image A*f*, dependent on them both, is doubly elevated. Hence, the position of A*f* becomes a delicate test of the due centering of the concave glass, and is the best guide in making the final adjustment. In my object-glass, which has been the principal subject of my experiments, this image is very happily situated for this purpose, being so near to the outmost image, A*d*, that the smallest error in their relative position is with the greatest facility detected.

In order that I might have full command of each part, I had a cell constructed of larger dimensions than ordinary, with two pair of adjusting screws, at right angles to each other, applied to the edges of each glass, so that when the images had been first brought into the same vertical plane by means of one set of screws opposed to each other in the horizontal position, the series might next be adjusted to the same horizontal line by the screws placed above and below, at right angles to the former.

In performing these adjustments, there is another pair of images beside A*f*, A*d*, which deserve particular attention, as their motions are independent, and their contiguity renders any variation of their relative position very perceptible. In figures 11 and 12, the lines *lm*, *no*, mark the irregularities arising from defects in centering of the inner and outer convex glasses, as in fig. 13, the line *pq*, shows the error correspondent to a want of adjustment of the middle concave.

By these guides alone I have now so repeatedly restored my object-glass to correct performance after having removed it from its cell, that I may venture, with considerable confidence, to recommend trial of the method to those who wish to perfect glasses of this construction. The degree of accuracy to be attained will depend upon the smallness and brightness of the light employed.

For the purpose of merely seeing the series of images above described, the entire flame of a candle, not confined by an eye-tube, forms a set of very conspicuous images. To see that the images are not very irregular, an eye-hole of one-fourth or one-fifth of an inch may be used. When the intention is to commence adjustment by candle-light, a single eye-glass of one-tenth or one-fifteenth of an inch focus will be found to give a series of neat images very well suited to the purpose; but, for completing a very nice adjustment, I have found it necessary to employ the light of the sun, and a still smaller lens of one-twentieth or one-thirtieth of an inch focus. With this view, there is no occasion to point the telescope to the sun, for if his light falls even very obliquely on a small eye-glass, the exterior images A*d*, and A*f*, are mere luminous points, so that any error in their relative position is immediately detected.

With this test, as guide for final adjustment, and without farther revision, the telescope on which this method has been tried, is capable of either separating very small and nearly

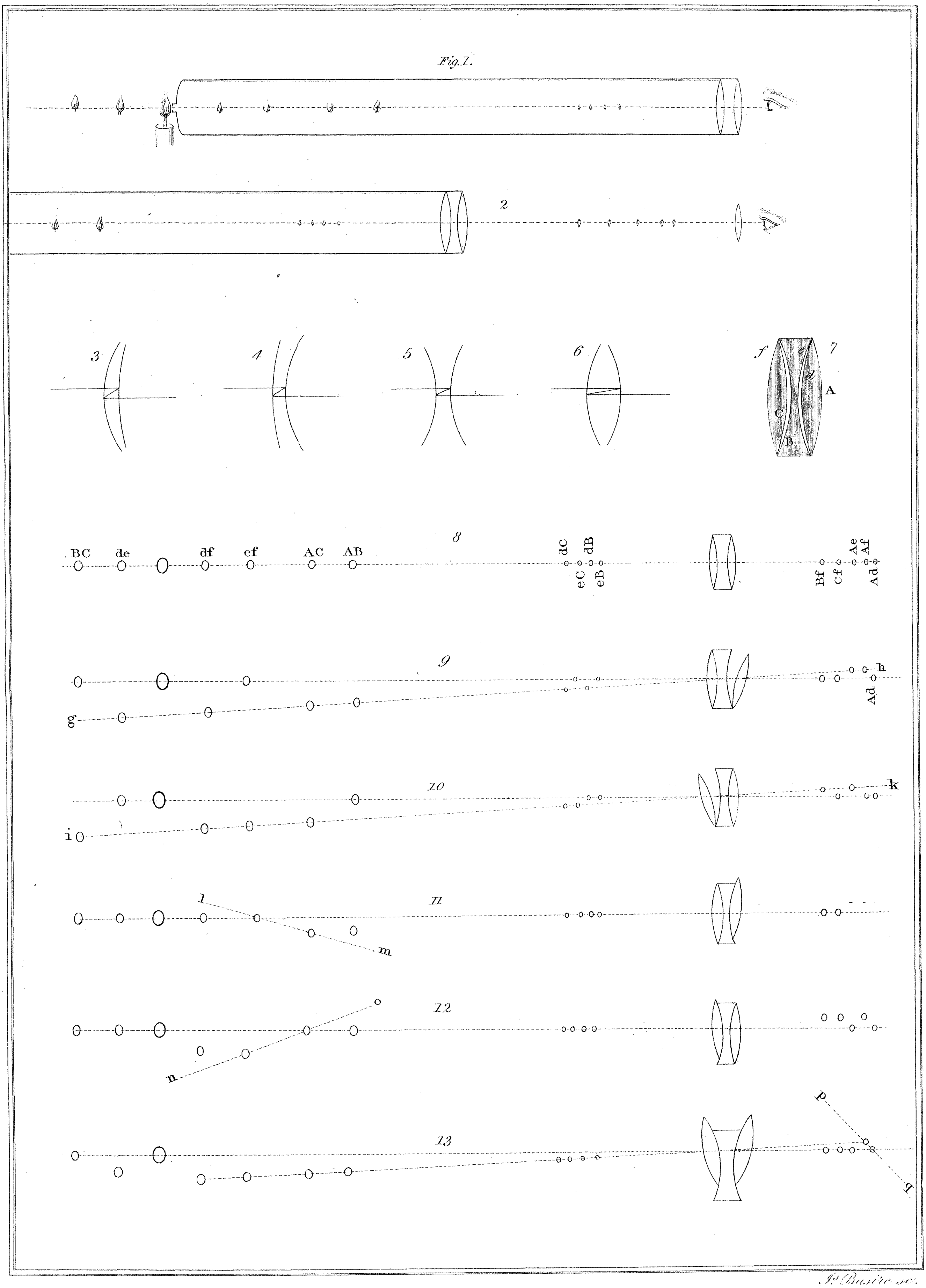
Fig. 1.
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J. Basire sc.

equal stars as those of 44 Bootis and σ Coronæ, or of exhibiting the minute secondaries of β Orionis and 24 Aquilæ, with as much distinctness as the state of the air will admit. The actual limit to its powers cannot be fully ascertained, excepting under such favourable conditions of the atmosphere as do but rarely occur.