XV. *Experiments relative to the effect of temperature on the refractive index and dispersive power of expansible fluids, and on the influence of these changes in a telescope with a fluid lens.* *By* Peter Barlow, *Esq. F.R.S. &c.*

Read May 15, 1828.

In a paper I had the honour to present to the Royal Society in January last, relative to the construction of achromatic telescopes with fluid lenses, I have stated that between the temperatures of 31° and 84° I had not been able to detect any very sensible change in the index denoting the focal length of the telescope: these observations however being made at intervals of some months, I was doubtful whether there might not be some minute variation which had escaped my notice; and I have since, by means of temperature artificially produced, ascertained that there is a certain small change, and the amount of that change, which is $\frac{134}{1000}$ths of an inch in the length of the telescope employed, between each of these extremes and the mean temperature of 57°. That is, the eye-piece of the telescope and the fluid lens being fixed, as was the case in this instrument, the plate lens required an adjustment of 0.134 of an inch, between the temperature of 57° and each of the above extremes, to produce the brightest and most perfect image.

Before I proceed, however, to detail the results of my inquiry on these subjects, it will be proper to define a few terms which appear in one or two instances to have been misunderstood.

1. The length or focal length of the telescope, is the distance from the front lens to the focus.

2. The fluid focus or fluid focal length, is the distance from the fluid lens to the focus.

3. The focal power of the telescope, or the equivalent focal length, is the focal length of a telescope of the usual construction, which gives the same convergency to the rays or the same sized image as the telescope in question.

In what follows:

l will denote the length of the telescope.
f the focal length of the plate lens.
f' the focal length of the fluid lens.
f'' the fluid focal length.
f''' the equivalent focal length.
d the distance of the lenses.

Under the particular form of construction to which we are now referring, f and f'' remain fixed or constant, but the rest are variable under different temperatures, in consequence of the effect which temperature produces in the value of f'.

If we knew the change in the value of f', or in the refractive index of the fluid under different temperatures, we might proceed immediately to compute its effects on the focal power of the telescope; but as this may be considered doubtful, I have endeavoured to determine the effect on the power of the telescope by direct observations, and have thence computed the corresponding change in the refractive index of the fluid.

In order to determine the change in the position of the front lens due to a certain range of the thermometer, I placed the telescope in a small room about twelve feet square in my garden, and having adjusted it very carefully to a dial-plate of a watch, at the distance of 150 feet, when the thermometer was at 40°, I had a fire lighted, the room shut up, and the temperature gradually raised to 75°, re-adjusting and registering the focus for every change of 5°.

As, however, the intermediate changes were very small, it will be sufficient to state, that between the two extremes, viz. 40° and 75°, the whole change was 0.177 of an inch; and hence, supposing the change uniform for equal variations of temperature, we find for the difference between the mean temperature of 57° and each extreme before mentioned, viz. 31° and 84°, an alteration in the length of the telescope of .134 of an inch, as stated in the beginning of this paper.

In the instrument on which these observations were made, the following are the values of the different quantities at the mean temperature 57°; viz. $f = 32.5$, $f' = 32.65$, $f'' = 40.5$, $l = 54.92$, $d = 14.42$, $f''' = \frac{ff''}{f-d} = 72.8$.

And since by the observations above referred to, the value of d varied 0.134 of an inch between the mean temperature and each of the extremes, we have in one case $d = 14.554$, and in the other $d = 14.286$. Whence the focal power of the telescope was

$$\text{at } 31°, \; f''' = \frac{ff''}{f-d} = 73.34$$

$$\text{at } 84°, \; f''' = \frac{ff''}{f-d} = 72.28$$

So that the instrument being adjusted at the mean temperature 57°, and fitted with a micrometer, it will require a correction of about $\frac{1}{3600}$th part of the angular measure for every change of 1° in the thermometer; that is, a 60th part of a second for every minute in the angle, a quantity too small to require any notice, except in cases of extreme delicacy.

In order to find the actual change in the focus of the fluid lens which rendered the foregoing adjustments of the plate lens necessary, we have

$$\frac{1}{f-d} - \frac{1}{f'} = \frac{1}{f''} \quad \text{or} \quad \frac{1}{f-d} - \frac{1}{f''} = \frac{1}{f'}.$$

In this expression, $f'' = 40.5$, $f - d$ at $31° = 17.946$

$f - d$ at $57° = 18.080$

$f - d$ at $84° = 18.214$

And substituting these values successively for $f-d$ in the above expression, we find

f' at $31° = 32.222$

f' at $57° = 32.650$

f' at $84° = 33.090$

And since it has been shown, Phil. Trans. 1827, Art. XV. that $\frac{\overline{f-d}|^2}{ff'}$ = dispersive ratio, we have at 31° dispersion = .3067

57° dispersion = .3075

84° dispersion = .3084

a difference sufficiently small to baffle the most acute and experienced eye. The change therefore in the power and colour of the telescope is so small, and the correction due to it (in any case where such correction is thought necessary) so easily made, that an instrument on this construction may I trust be considered just as applicable to all the nice purposes of modern astronomy, as one of the usual refractors of the same power.

The very inconsiderable change in the focal power of the telescope led me to conclude, in the early part of my experiments, that no optical change took place in the fluid between the above limits, or at least that the change was extremely small. It appears however from the preceding experiments and investigation, that the permanency of the telescopic effect is attributable to the peculiar construction of the instrument, and that the change in the refractive index of the fluid is much more considerable than I had imagined; for we have seen that the focal length of the fluid lens was at 31° = 32.22

at 57° = 32.65

at 84° = 33.03

And since the focal length is cæteris paribus inversely as the index, and the index at 57° being 0.634, we find 32.22 : 32.65 : : 0.634 : 0.642

33.09 : 32.65 : : 0.634 : 0.626

Hence the mean index of the sulphuret of carbon is at 31° = 0.642

at 57° = 0.634

at 84° = 0.625

That is, with a variation of temperature of 53°; the change of index amounts to $\frac{.017}{.634} = \frac{1}{37}$th part nearly of the whole index at 57°.

Which, supposing the change to be uniformly proportional in greater thermometrical ranges, gives a change in the refractive index of nearly $\frac{1}{10}$th between 32° and 212°. Now it has been stated on the result of experiment (Dr. Ure's Chemical Dictionary), that the expansion of sulphuret of carbon amounts to $\frac{1}{9}$th between the above limits. We have therefore strong reasons to conclude that in this, and all other expansible fluids, the index of refraction varies directly as the density; the trifling difference in the two results being attributable, in all probability, to slight errors of observation in one or other of the two processes, so different from each other, from which these results are deduced.

With respect to the dispersive ratio, it is probably the same at all temperatures; for, supposing $1 : 1 + a$ $1 : 1 + a'$, $1 : 1 + a''$ to be the ratio of the sines of incidence and refraction of the extreme and mean rays of the spectrum at any given temperature, the dispersive power is expressed by $\frac{a-a''}{a'}$. And as we have seen that the mean index a' varies as the density of the fluid, we

have strong reason to suppose that a and a'' vary also in the same proportion; and if so, the dispersive power will of course remain constant; and this deduction is verified, as far as the eye can judge of colour in the telescope, by the preceding experiments, which certainly indicated no perceptible change in the colour of the image. This, however, is a subject I intend to examine more particularly when my large telescope is completed.

It may be proper to observe, that the form of the instrument here employed differs a little from that described in my former paper: in the latter, the plate lens is a fixture, and the adjustment is made by a slight motion of the fluid lens. In this I can move either lens at pleasure; and I have chosen to fix the fluid, and to adjust the plate lens, merely for the sake of simplifying the investigation.