red and Schroder’s to blue light. Also Grubb’s object-glass unites the red rays very closely with the brightest part of the spectrum, and leaves the blue and violet rays outstanding. Schroder, on the other hand, leaves the red rays outstanding in order to unite the rays between D and F more closely. The conclusion is that to Grubb’s eye the red rays would be obtrusively prominent in Schroder’s telescope, and that he would pronounce the object-glass under-corrected ; whilst Schroder’s eye would find the outstanding violet rays too prominent in Grubb’s telescope, and pronounce it over-corrected. The absolute amount of light in the secondary spectrum in viewing the same object depends, *cæteris paribus,* upon the square of the aperture ; therefore telescopes of large aperture have to be made of greater proportional focal length than those of small aperture, in order to diminish the secondary spectrum. Figs. *a, β, γ, δ* in the diagram give the form of the spectrum of a star in Schroder’s telescope for various adjustments of the focus ; figs. α' and γ' give the corresponding forms for Fraunhofer’s tele­scope. Fig. α represents the eye-piece focused for the brightest part of the spectrum ; fig. *β* when the red rays and those near Hα are simultaneously focused ; fig. *y* when the extreme red rays are in focus, the corresponding focus being a little below Hγ ; fig. δ when focused on Hγ.

When a telescope is to be constructed for photographic purposes the aim should be to unite, as perfectly as possible, the rays near that portion of the spectrum which act most powerfully on the photographic plate to be employed. This latter point has been de­termined for the various photographic processes by Captain Abney.@@1 The results are shown graphically in fig. 6 for the processes practi­

cally employed at present in astronomical photo­graphy.

To unite the rays near G or H the angle of the flint prism must be diminished ; that is, the focal length of the flint lens must be lengthened as compared with that of an object-glass of similar construction suited for eye observations ; and the rays of greatest photographic action can be united more perfectly than the visible rays.

If an object-glass is composed of three lenses of different kinds of glass it is theoretically possible to unite three instead of two points of the spectrum, besides improving the correction for spheri­cal aberration. The most important practical applications of such a system have been—(1) the triple object-glass of John Dollond ; (2) the application of a convex crown glass in front of an ordinary object-glass in order to alter its chromatic correction from that best suited for eye observations to that best suited for photographic observation. John Dollond’s object-glass is generally described as a concave flint lens between two crown lenses. If the crown lenses are of similar glass, there is no gain as to the correction of the secondary spectrum ; it becomes only possible to correct the spheri­cal aberration more perfectly. Very few telescopes with triple object-glasses have been made since the days of John Dollond. But the great and detrimental obtrusiveness of the secondary spectrum in the large object-glasses of the present day can be diminished in no other way, unless very extreme focal lengths are adopted, or some new kinds of glass that can be produced in large disks are discovered, in which the irrationality of their spectra is less, and in which also there is the necessary difference in the

relation between refractive index and dispersive power. The cost of a triple object-glass would of course be at least 50 per cent. greater than that of a double object-glass ; but, on the other hand, the extreme focal length necessary for large object-glasses might be considerably reduced. Thus the cost saved by a less heavy mount­ing and a smaller observatory and dome might counterbalance to some extent, if not entirely, the additional cost of the triple object­glass. Dr Schroder has constructed for the present writer an exquisite triple object-glass (three different kinds of glass) of 3¼-inches aperture and only 18-inches focal length. Its perform­ance with its highest eye-piece of ¼-inch focus (power 72) is most admirable. It would probably be impossible to construct large telescopes approaching such short focal length, but there is no doubt that a large triple object-glass of 10 or 12 apertures focus would have an enormous advantage in colour correction, and prob­ably in spherical aberration, over a double object-glass of the same aperture and much greater focal length. One peculiarity of such a triple object-glass is that three points in the spectrum can have the same focus, and therefore the point of minimum focus may for the best chromatic adjustment not quite correspond with the focal point for the brightest part of the spectrum ; but, obviously, the rays of the whole visible spectrum may thus be brought to intersect the axis much more nearly at the same point. There will probably be a far wider adoption of the triple object-glass in the future, especially as the greater intrinsic brilliancy of the image in short­focus telescopes is a matter of high importance in the spectroscopic and photographic processes of modern astronomy. On the subject of triple object-glasses the reader is referred to an admirable paper by Professor C. S. Hastings (*Amer. Journal of Science and Arts* for December 1879, p. 429), which exhibits the results to be got from combinations of different existing kinds of glass.

The following table exhibits the excess of the focus for any ray over the true focus, the unit being 1/100000 of the focal length, in —I. the actual results of Dr Vogel’s observations on three existing object-glasses already quoted, but each reduced to comparison with its true or minimum focus ; II. the theoretically best possible results from a double object-glass consisting of Feil’s crown 1219 and Feil's flint 1237, as computed by Hastings ; III. the theoretical results of four different triple object-glasses, capable of practical construction, of which details are given by Hastings.

|  |  |  |
| --- | --- | --- |
|  | Double Object-Glass | es. Triple Object-Glasses. |
|  | I. | II. III. |
|  | Fraun- Grubb Schrö-  hofer. der. | Hast- Hastings Hastings Hastings Hastings ings.12 3 4 |
| A B C D  E F G | + 47 + ’ 64 + 106  + 36 +41 +78  0 +8 +23  + 27 + 29 0  + 64 + 56 + 33  + 171 + 226 + 243 | + 135 .. +2 .. - 3  + 66 + 1 - 53 - 22 - 35  + 41 0 +41 +91 +50  0 0 + 28 + 41 +2  + 13 + 25 - 10 - 67 - 10  + 73 0 - 14 - 60 - 4  + 287 0 + 2 + 21 - 3 |

Prof. Hastings’s first condition in these computations is that the radius of curvature of none of the surfaces shall exceed one-fifteenth of the focal length. He also neglects the thickness and distance apart of the lenses, since these affect chiefly the focal length, but do not very materially affect the difference of the foci for different rays. The expression for the focal length F is then *ϕ*=(*μ'* - 1)(1/*r*1 + 1/*r*2) + (*μ*'' - 1)(1/*r*3 + 1/*r*4) + (*μ'''* - 1)(1/*r*5 + 1/*r*6), where *Φ =* 1/F*, μ', μ", μ'"* are the indexes of refraction for the three kinds of glass, and *r1, r2, . . . r6* the radii of curvature for the six successive surfaces. Writing this in the form

*φ =* (*μ'* - 1)A + (*μ" -* 1)B + (*μ'''* - 1)C,

we may call A, B, and C the *curvature sums* of the first, second, and third lenses respectively. The problem then is to find, for existing specimens of glass, values of A, B, and C no one of which shall exceed 30 when *ϕ* = 1, and which shall make *φ* independent of the wave-length of the light transmitted. The resulting values of A, B, and C for the first combination (marked “ Hastings 1 ”) are A B C

3∙47026 7∙20827 -8∙35472;

the curvatures are therefore very moderate and perfectly practicable. The constants for the glass of the first and second lenses have been determined by the author with great accuracy (see *Amer. Jour.,* vol. XV. p. 273). The third glass is Fraunhofer’s flint 13 (Hastings *ι*, misprinted *v* in his table, in *Amer. Jour.,* vol. xviii. p. 131), for which the constants are given in Schumacher’s *Astron. Abhandlung für 1823.* If this glass can be reproduced in large disks, as no doubt it could be, we have the means of making an object-glass very superior to any in existence and equally available for eye and photographic observation. Such an object-glass could be made of much shorter proportional focus than is usual or possible in double object-glasses, not only because of the absence of secondary spectrum but also from the command afforded over the spherical aberration

@@@1 *Proc. Roy. Soc.,* vol. xxxiii. pp. 164-186.