lines, such as C and F, yet the flint glass prism will show a relative drawing out of the blue end and a crowding together of the red end of the spectrum, while the crown prism shows an opposite tendency. This want of proportion in the dis­persion for different regions of the spectrum is called the “ irrationality of dispersion and it is as a direct consequence of this irrationality, that there exists a secondary spectrum or residual colour dispersion, showing itself at the focus of all such telescopes, and roughly in proportion to their size. These glasses, however, still hold the field, although glasses are now produced whose irrationality of dispersion has been reduced to a very slight amount. The primary reason for this retention is that nothing approaching the difference in dispersive power between ordinary crown glass and ordinary dense flint glass (a difference of 1 to 1⅔) has yet been obtained between any pair of the newer glasses. Consequently, for a certain focal length, much deeper curves must be resorted to if the new glasses are to be employed; this means not only greater diffi­culties in workmanship, but also greater thickness of glass, which militates against the chance of obtaining large disks quite free from striae and perfect in their state of annealing. In fact, superfine disks of over 15 in. aperture are scarcely possible in most of the newer telescope glasses. Moreover the greater depths of the curves (or “ curvature powers ”) in itself neutralize more or less the advantages obtained from the reduced irrationality of dispersion. When all is taken into consideration it is scarcely possible to reduce the secondary colour aberration at the focus of such a double object-glass to less than a fourth part of that prevailing at the focus of a double objective of the same aperture and focus, but made of the ordinary crown and flint glasses.

The only way in which the secondary spectrum can be reduced still further is by the employment of *three* lenses of three different sorts of glass, by which arrangement the secondary spectrum has been reduced in the case of the Cooke photo visual ob­jective to about 1/20th part of the usual amount, if the whole region of the visible spectrum is taken into account. It is possible to construct a triple objective of two positive lenses enclosing between them one negative lens, the two former being made of the same glass. For relatively short focal lengths a triple construction such as this is almost necessary in order to obtain an objective free from aberration of the 3rd order, and it might be thought at first that, given the closest attainable degree of rationality between the colour dispersions of the two glasses employed, which we will call crown and flint, it would be impossible to devise another form of triple objective, by retaining the same flint glass, but adopting two sorts of crown instead of only one, which would have its secondary spectrum very much further reduced. Yet such is the rather surprising fact. But it can be well illustrated in the case of the older glasses, as the following case will show.

The figures given are the partial dispersions for ordinary crown and ordinary extra dense flint glasses, styled in Messrs Schott’s catalogue of optical glasses as 0∙60 and 0∙102 re­spectively, having refractive indices of 1∙5179 and 1·6489 for the D ray respectively, and (μD-1)∕(μF-μc) =60∙2 and 33∙8 respectively to indicate their dispersive powers (inverted), *=v.*

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | C to F | | A to | D | D to | F | F to | G |
| 0∙60 | ·00860 | \*  1·000 | ·00533 | \*  ·643 | •00605 | ·703 | •00487 | ·566 |
| 0∙102 | ∙01919 | 1·000 | ·01152 | ·600 | ·01372 | ·714 | ·01180 | ·615 |
|  | ·02779 | 1·000 | ·01685 | ·613 | ·01977 | ·711 | •01667 | ·600 |

The ∆μ from C to F being taken as unity in each case, then the ∆μ,s for the other regions of the spectrum are expressed in fractions ∆μ (C to F) and are given under the asterisks. Let it be supposed that two positive lenses of equal curvature powers are made out of these two glasses, then in order to represent the combined dispersion of the two together the two ∆μ's for each spectral region may be added together to form ∆'μ as in the line below, and then, on again expressing the partial ∆'μ

in terms of ∆'μ (C to F) we get the new figures in the bottom row beneath the asterisks. We find that we have now got a course of dispersion or degree of rationality which very closely corresponds to that of an ordinary light flint glass, styled 0∙569 in Schott’s catalogue, and having µD 1∙5738 and (μD-1)∕(μr-μc) =41∙4 = *v*, the figures of whose course of dis­persion are as below:—

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *Light Flint Glass* 0∙569. | | | | | | |
| C to F | | A' to D | | D to F | | F to G |
| ·01385 | 1·000 | ·00583 | ·615. | •00987 | ·713 | ·00831 ∙600 |

Hence it is clear that if the two positive lenses of equal curvature power of 0∙60 and 0∙102 respectively are combined with a negative lens of light flint 0·569, then a triple objective, having no secondary spectrum (at any rate with respect to the blue rays), may be obtained.

But while an achromatic combination of 0∙60 and 0∙102 alone will yield an objective whose focal length is only 1∙28 times the focal length of the negative or extra dense flint lens, the triple combination will be found to yield an objective whose focal length is 73 times as great as the focal length of the negative light flint lens. Hence impossibly deep curvatures would be required for such a triple objective of any normal focal length. This case well illustrates the much closer approach to strict rationality of dispersion which is obtainable by using two different sorts of glass for the two positive lenses, even when one of them has a higher dispersive power than the glass used for the negative lens.

It is largely to this principle that the Cooke photo visual ob­jective of three lenses (fig. 3) owes its high degree of achromatism. This form of objective has been successfully made up to 12½ in. clear aperture. The front lens is made of baryta light flint glass

(0∙543 of Schott’s catalogue) and the back lens of a crown glass, styled 0∙374 in Schott’s older lists.

The table gives their partial dispersions for six different regions of the spectrum also expressed (in brackets below) as fractional parts of the dispersion from C to F.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | C to F | A to C | D to F | EtoF | F to G' | F to H |
| 0∙543  Md — I∙564 x =5o∙7 | ∙01115  (1∙0000) | •00374  (•3354) | ∙∞790  (■7085) | •00369  (•3309) | •00650  (•5830) | ■01322  (1-1857) |
| o∙374  μn= ∣∙5∏  *v* =6o∙8 | •00844  (ι∙oooo) | •00296  (•3507) | •00593  (•7026) | •00274  (•3247) | •00470  (•5675) | •00976  (l∙1564) |

Since the curvature powers of the positive lenses are equal, the partial dispersions of the two glasses may be simply added together, and we then have :—

[o∙543 +o∙3741

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| CtoF | A to C | D to F | | E to F | | F to G' | F to II |
| •01950  (ι∙oooo) | •00670  (•3420) | •0138.  (•7059, | i | ■0064,  (■3282, | i | •01129  (•5763) | •02298  (ι∙1730) |

The proportions given on the lower line may now be compared with the corresponding proportional dispersions for borosilicate flint glass 0∙658, closely resembling the type 0∙164 of Schott’s list, viz.:—

Io∙658 (μn = ι∙546) v = 5o∙l]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| C to F | A to C | D to F | E to F | F to G' | F to H |
| l’OOOO | •3425 | •7052 | •3278 | •5767 | ι∙i745 |