by six surfaces. After satisfying the conditions of focal length, the first power of the spherical aberration, and two conditions of achromatism, we have still two available arbitrary conditions, which may be that *r*2=*r*3 and *r*4=*r*5. If these lead to convenient forms, as seems likely in the case in point, the whole may constitute a cemented lens ; thus the loss of light at the interior surfaces may be eliminated, and the final perfecting of the spherical aberration be left to the figuring of the surfaces.

In some recent large double object-glasses, especially those of Alvan Clark, it has been usual to leave a space between the crown and the flint lens sufficient to afford access, through apertures in the cell, for cleaning the inner crown and flint surfaces, without risk of disturbing the lenses and their centring.@@1 If in fig. 3 we imagine the lenses to be considerably separated and through both lenses trace a ray entering the crown lens parallel to and at some distance from the axis, we shall find that the effect of the separa­tion is to diminish the power of the flint lens, and therefore to change the character of the chromatic aberration. Thus an object­glass over-corrected for colour can be improved in this respect by increasing the distance between the lenses. It has been suggested that a telescope can be made suitable for both eye observation and photographic purposes if means are provided for increasing the distance between the lenses without risk of deranging the centring when the telescope is to be employed for photography. But the great change that would be necessary in such a case cannot be brought about consistently with preservation of the perfection of the corrections for spherical aberration.@@2

Any account of the achromatic object-glass would be incomplete without reference to the labours of the Rev. W. Vernon Harcourt and Prof. Stokes. Experiments in the production of optical glass were instituted by the former in 1834 ; and specimens, exhibited at the meeting of the British Association at Cambridge in 1862, were placed in the hands of Prof. Stokes, who determined the opti­cal constants of the numerous specimens of glass which Harcourt produced, and indicated from these results the direction in which fresh experiments should be undertaken. It was discovered that titanic acid extends the blue end of the spectrum more than corre­sponds to the dispersive power of the glass, whilst boracic acid has the opposite effect (*Report Brit. Assoc.,* 1871, p. 38). At a meeting of the British Association at Belfast in 1874 a telescope was exhibited whose object-glass was constructed from Harcourt’s glass by Sir Howard Grubb of Dublin. The following is Prof. Stokes’s complete and concise account of it.

“ The original intention was to construct the objective of a phosphatic glass containing a suitable percentage of titanic acid, achromatized by a glass of terborate of lead. (The percentage of titanic acid was so chosen that there should be no irrationality of dispersion between the titanic glass and the terborate.) As the curvature of the convex lens would be rather severe if the whole convex power were thrown into a single lens, it was intended to use two lenses of this glass, one in front and one behind, with the concave terborate of lead placed between them. It was found that, provided not more than about one-third of the convex power were thrown behind, the adjacent surfaces might be made to fit, consistently with the condition of destroying the spherical as well as the chromatic aberration. This would render it possible to cement the glasses, and thereby protect the terborate, which was rather liable to tarnish. At the time of Mr Harcourt’s death two disks of the titanic glass had been prepared whieh it was hoped would be good enough for employment, as also two disks of terborate. These were placed in Mr Grubb’s hands. On polishing, one of the titanic disks was found to be too badly striated to be employed ; the other was pretty fair. As it would have required a rather severe curvature of the first surface and an unusual convexity of the last to throw the whole convex power into the first lens, using a mere shell of glass to protect the terborate, Professor Stokes thought it more prudent to throw about one-sixth of the whole convex power into the third or crown glass lens, though at the sacrifice of an *absolute* destruction of secondary dis­persion, which by this change from the original design might be expected to be just barely perceptible. Of the terborate disks, the less striated happened to be slightly muddy, from some accident in the preparation ; but, as this signified less than the striæ, Mr Grubb deemed it better to employ this disk. The tele­scope exhibited to the meeting was of about 2½-inches aperture and 28-inches focal length, and was provided with an object-glass of the ordinary kind, by which the other could be replaced, for contrasting the performance. When the telescope was turned on to a chimney seen against the sky or other suitable object, and half the object-glass covered by a screen with its edge parallel to the edges of the object, in the case of the ordinary objective vivid green and purple were seen about the two edges, whereas with the Harcourt objective there was barely any perceptible colour. It was not of course to be expected that the performance of the telescope should be good, on account of the diffi­culty of preparing glass free from striæ, but it was quite sufficient to show the possibility of destroying the secondary colour.”

An experiment to determine whether the substitution of titanic acid for a portion of the silica in ordinary crown glass would have an effect similar to that which had been observed in the phosphatic series of glasses (viz., whilst somewhat raising the dispersive power, to produce a separation of the colours at the blue as compared with the red end of the spectrum, to an extent ordinarily belonging only to glass of much higher dispersive power) was carried out by Mr Hopkinson at the glass works of Messrs Chance of Birmingham ; but it proved unfortunately in this combination that, whilst the

dispersive power was increased, as in the phosphatic glasses, the blue end of the spectrum, as compared with the red end, was not spread out more than in ordinary glass of like dispersive power (*Report Brit. Assoc.,* 1875, p. 26). It is to be hoped, however, that makers of optical glass will not relax their efforts till astronomers shall be able to obtain refracting telescopes in which the secondary spectrum is nearly if not quite eliminated. Abbe’s new optical glass@@3 leads one to believe that this hope will soon be realized.

The addition of a convex crown lens in front of the ordinary object-glass, to diminish the colour - correction and change the minimum focus from that for rays between D and E to that for rays near G, was first made by Rutherford of New York. In this way he altered his telescope from one suited for eye observations to one in the best chromatic adjustment for photographic work. The chromatic effect is the same as increasing the convexity of the crown lens, and by proper proportioning of the two radii of curvature it becomes possible also to conserve, and even to further perfect, the destruction of spherical aberration. The great object­glass of 36-inches aperture, now (1887) under construction for the Lick observatory by Messrs Clarke of Boston (Mass. ), is to be pro­vided with an additional crown lens for this purpose.@@4

The problem of making a perfectly achromatic object-glass has been solved by Dr Blair *{Edin. Trans.,* vol. iii. p. 53) by employ­ing fluid media, and he actually constructed an object-glass con­sisting of a plano-convex lens and a meniscus lens, both of crown glass with their convexities turned towards each other, the space between the lenses being filled with hydrochloric acid. Unfortu­nately such combinations are practically useless, not only on account of unavoidable leakage, but also because currents are set up in fluid lenses by changes of temperature, which correspond in effect with want of homogeneity in the flint lens in an ordinary object-glass.

*Eye-Pieces.*

The first substitute for the single lens of the Galilean and Kepler telescopes was the compound eye-piece invented by Rheita. Behind the convex eye-lens of the Kepler telescope he applied a second short telescope, consisting of two convex lenses, their distance being the sum of their focal lengths. The principal effect was to erect the inverted image, and thus to constitute the simplest form of the day eye-piece, or common terrestrial telescope. The next improve­ment was the Huygenian eye-piece, which consists of two convex lenses (see fig. 7),—the “field-lens,” that next the object-glass, having its focal length to that of the “ eye-lens ” as 3 to 1 ; the distance between them is twice the focal length of the latter, the combination being so placed as to form the visible image half-way between the two. This eye-piece is achromatic in the sense in which an eye-piece is said to be so : a colourless image seen through it does not appear bordered with coloured fringes, as is the case with a single lens or Rheita’s eye-piece. This is not because, as in the achromatic object-glass, all the central coloured rays are collected in one focus, which in the case of an eye-piece is a matter of compara­tively small consequence, but because it possesses the same magnify­ing power for rays of all colours on an object of sensible angular diameter, so as not to form overlapping coloured pictures of it on the retina. This condition it is which furnishes the “ equation of achromaticity ” of an eye-piece. An expression for the magnifying power of a telescope provided with a certain eye-piece is formed in general terms which involve the focal length of its lenses, their dis­tances from each other, and their refractive indexes ; and, this being made to vary by the variation of the last-mentioned elements only, the variation is equated to zero. The algebraic working, which even for a two-glass eye-piece is a little complex, is given in H. Lloyd’s *Treatise on Light and Vision* (London, 1831), and in an elaborate paper by Littrow in the fourth volume of the *Trans. Roy. Astron. Soc.* (p. 599). From the former we extract the following proposition : An eye-glass of two lenses of the same medium is achromatic when the interval between the lenses is an arithmetical mean between their focal length,—a condition which the Huygenian construction evidently satisfies. The rationale of this is obvious, independently of algebraic analysis, by inspection of the course of the rays in fig. 7, where AC, BD are the lenses, PQ the image which would be formed by the object-glass alone, *pq* that really formed by the action of the field-glass. The object-glass being supposed achromatic, a ray of white light, as OC, going to form the image of a point Q, will be refracted by the field-glass at C towards the corresponding point *q* of the new image, but not as a

@@@1 This arrangement also helps to equalize the temperatures of the lenses with each other and with the outer air.

@@@2 Quite recently Prof. Stokes has suggested that to adapt a telescope to either photographic or telescopic purposes at pleasure the crown lens should be reversible as well as changeable as to distance with respect to the flint. In this way doubtless the chromatic and spherical aberration could be pre­served for the two kinds of work.

@@@3 See *Nature,* vol. xxxiv. p. 622, 26th October 1886.

@@@4 For recent literature on the secondary spectrum in double and triple object­glasses, &c., see W. Schmidt, *Die Brechung des Lichtes in Gläsern, insbesondere d. achromat. und aplanat. Objectivlinse,* Leipsic, 1874; W. Harkness, “On the Colour Correction of Achromatic Telescopes,” in *Amer. Jour. of Science and Arts,* September 1879, pp. 189-196 ; C. S. Hastings, “ Triple Objectives with Complete Colour Correction,” *ib.,* December 1879, pp. 429-435; Perty, *Ueber die Grenzen der sichtbaren Schöpfung nach den jetzigen Leistungen der Mikroskope und Fernrohre,* Berlin, 1874 ; H. C. Vogel, *Ueber eine einfache Methode zur Bestim­mung der Brennpunkte und der Abweichungskreise eines Fernrohr-Objectivs für Strahlen von verschiedener Brechbarkeit·,* C. A. Young, “The Colour-Correction of Certain Achromatic Object-Glasses,” in *Amer. Jour. Sci.,* June 1880, pp. 454- 456 ; also a review of these papers by A. Safarik, *Vierteljahrschrift der astrono­mischen Gesellschaft,* 1882, pp. 13-39.