verance accomplished by their aid. The reflecting telescope became the only available tool of the astronomer when great light grasp was requisite, as the difficulty of procuring disks of glass (especially of flint glass) of suitable purity and homogeneity limited the dimensions of the achro­matic telescope. It was in vain that the French Academy of Sciences offered prizes for perfect disks of optical flint glass. Some of the best chemists and most enterprising glass-manufacturers exerted their utmost efforts without succeeding in producing perfect disks of more than 3½ inches in diameter. All the larger disks were crossed by striæ, or were otherwise deficient in the necessary homo­geneity and purity.

Pierre Louis Guinand, a humble watchmaker living near Chaux de Fond in Neuchâtel, Switzerland, was the first who succeeded in making marked progress in the manufacture of optical flint glass. After making pre­liminary experiments extending over seven years (1784- 90), and nothing daunted by their comparative want of success, he erected a furnace near Les Brenets, and devoted most of his slender earnings (then derived from making the bells, or rather gongs, of repeating watches) to the fulfilment of his ambition. His persistency, courage, and self-denial recall forcibly the story of Palissy. In 1805 he joined the optical establishment of Fraunhofer and Utz- schneider and remained with them about nine years. During this period extensive experiments were instituted with remarkable success. It is said that the disks for the Dorpat refractor (9∙6 inches aperture, with which the observations of Wilhelm Struve were made) were manufac­tured during this period, though the complete instrument was not delivered till 1823. Fraunhofer had, however, profited so fully by the suggestions of Guinand, and had probably also so far improved on the original methods, that he afterwards succeeded in producing still larger object- glasses. After Fraunhofer’s death in 1826 his successors Merz and Mahler carried out successfully the methods handed down to them by Guinand and Fraunhofer, and produced some large and excellent telescopes, which are hereafter mentioned. Meanwhile Guinand, having re­turned to his native country in 1814, resumed there the manufacture of disks of optical glass, discovered a method of removing striæ by breaking and reuniting the portions by heat, when the glass was in a plastic state, and event­ually produced perfect disks up to 18 inches in diameter. Most of these he disposed of to Lerebours and Secretan, opticians in Paris, by both of whom some fine object-glasses were made.@@1 Guinand communicated his secrets to his sons before his death in 1823. About 1829 Bontemps entered into partnership with one of the sons, and another son carried on his father’s manufacture in partnership with his mother. The latter firm was succeeded by Dauget of Soleure, whose exhibits of optical glass excited so much attention at the London exhibition of 1851. About 1848 Bontemps joined the firm of Chance Brothers of Birming­ham, and thus carried the secret of Guinand’s methods to England. It is not a little remarkable that the only firms in the world by whom large disks of optical glass have been produced trace their success to information derived more or less directly from Guinand. MM. Feil of Paris, who are direct descendants of Guinand, and Messrs Chance Brothers of Birmingham are at the present time the only makers of optical glass in disks of larger diameter than 20 inches.

Instruments, &c.

We now proceed to give an account of the methods and principles of construction of the various kinds of telescopes,

and to describe in detail special typical instruments, which, owing to the work accomplished by their aid or the practi­cal advances exemplified in their construction, appear most worthy of record or study.

*Refracting Telescope.*

In its simplest form the telescope consists of a convex object­lens capable of forming an image of a distant object and of an eye­lens, concave or convex, by which the image so formed is magnified. When the axis of the eye-lens coin­cides with that of the ob­ject-glass, and the focal point of the eye-lens is co­incident with the principal focus of the object-lens, parallel rays incident upon the object-glass will emerge from the eye-piece as parallel rays. These, falling in turn on the lens of the human eye, are converged by it and form an image on the retina.@@2 Fig. 1 shows the course of the rays when the eye-lens is convex (or positive), fig. 2 when the eye­lens is concave (or negative) The former represents Kepler’s, the latter Lippershey’s or the Galilean telescope. The magnifying power obviously depends on the proportion of the focal length of the object-lens to that of the eye-lens, that is,

magnifying power=F∕*e*,

where F is the focal length of the object-lens and *e* that of the eye-lens. Also the diameter of the pencil of parallel rays emerging from the eye-lens is to the diameter of the object-lens inversely as the magnifying power of the telescope. Hence one of the best methods of determining the magnifying power of a telescope is to measure the diameter of the emergent pencil of rays, after the tele­scope has been adjusted to focus upon a star, and to divide the diameter of the object-glass by the diameter of the emergent pencil. If we desire to utilize all the parallel rays which fall upon an object­glass it is necessary that the full pencil of emerging rays should enter the observer’s eye. Assuming with Sir William Herschel that the normal pupil of the eye distends to one-fifth of an inch in diameter when viewing faint objects, we obtain the rule that the minimum magnifying power which can be efficiently employed is five times the diameter of the object-glass expressed in inches. The defects of the Galilean and Kepler telescopes are due to the chromatic and spherical aberration of the simple lenses of which they are composed (see Optics, vol. xvii. p. 802 *sq.}.* The substitution of a positive or negative eye-piece for the simple convex or concave eye-lens, and of an achromatic object-glass for the simple object-lens, transforms these early forms into the modem achro­matic telescope. The Galilean telescope with a concave eye-lens instead of an eye-piece still survives as the modern opera-glass, on account of its shorter length, but the object-glass and eye-lens are achromatic combinations.

The principles of an achromatic combination of prisms or lenses have been explained in Light (vol. xiv. pp. 592, 595) and further developed in Optics (vol. xvii. p. 804 *sq.*)*.* As a lens may be re­garded as built up of a series of thin slices of prisms, divided from each other by planes parallel to the axis of the lens, it will be seen that, if a prism perfectly achromatic for rays of two definite wave­lengths, and approximately achromatic for all rays, can be con­structed by combining two prisms of different kinds of glass, all that is required to produce an object-glass with similar small chromatic errors is to combine a convex lens of crown glass and a concave one of flint glass as in fig. 3, their surfaces being of such curvatures as to form a series of imaginary prisms (such as we have supposed an object-glass to consist of) through any one of which all kinds of light falling on the object-glass parallel to its axis will be refracted very nearly to a common focus F. Accordingly any pro-

@@@1 See Wolf, *Biographien,* vol. ii. p. 301, and Clerke, *History of Astronomy,* pp. 146-147.

@@@2 In the case of short-sighted persons the image for very distant ob­jects (that is, for parallel rays) is formed in front of the retina ; there­fore, to enable such persons to see distinctly, the rays emerging from the eye-piece must be slightly divergent ; that is, they must enter the eye as if they proceeded from a comparatively near object. For normal eyes the natural adaptation is not to focus for quite parallel rays, but on objects at a moderate distance, and practically, therefore, most persons do adjust the focus of a telescope, for most distinct and easy vision, so that the rays emerge from the eye-piece very slightly diver­gent. Abnormally short-sighted persons require to push in the eye-lens nearer to the object-glass, and long-sighted persons to withdraw it from the adjustment employed by those of normal sight. It is usual, how­ever, in computations of the magnifying power of telescopes, for the rays emerging from the eye-piece when adjusted for distinct vision to be parallel.