The Ritchey-Chretien Reflecting Telescope.

THE reflecting telescope possesses one obvious advantage over the refractor, in that the position of the focus is independent of the colour of the light used. But as an offset to this all types of reflectors which have been used by astronomers suffer from the fact that the field of good definition is comparatively small. It is true that, provided the mirrors be correctly figured, rays of light parallel to the principal axis of a Newtonian or Cassegrain reflector converge accurately to a focus, but a beam of parallel rays coming in in any other direction does not do this, and appreciable coma sets in at a comparatively small distance from the centre of the field of view.

It is in consequence of this defect that reflectors have so far not been used extensively for accurate positional work involving the precise measurement of good images, although they have been invaluable in colour photometry. As an exception to this general rule, however, it should be remarked that Dr. van Maanen has used the 60-inch reflector at Mount Wilson for the purpose of the photographic determination of stellar parallax—a research involving the most delicate and careful measures of position. Dr. van Maanen has usually chosen his comparison stars at a distance not exceeding eight minutes of arc from the centre of the field, and we have it on the authority of Prof. Ritchey that with this instrument really accurate measurements cannot be made at a distance greater than fifteen minutes from the centre.

The development of large reflectors, culminating thus far in the 100-inch mirror at Mount Wilson, has brought the astronomer up against another difficulty. The mirror is figured on a single large disc of glass, and for the largest mirrors the figure is apt to be spoilt by the flexure of the disc and by distortions introduced by temperature changes. In the case of the 100-inch the mirror had to be cast in three pourings, with the result that the bottom layer has, through de-vitrification, lost its rigidity, thereby impairing the general strength of the composite disc. In recent years Prof. G. W. Ritchey, with the co-operation of Prof. H. Chrétien, has devoted himself to the overcoming of the present defects in large mirrors and of the mechanical difficulties which threaten to bar the road to further progress. An account of these researches and of the designs to which they have led has been given by Prof. Ritchey himself in recent numbers of *L'Astronomie*, and also in a series of articles at present appearing in the *Journal of the Royal Astronomical Society of Canada*.

In 1905, Schwarzchild had shown by detailed calculation that it was possible to design a reflector which would give a large field of good definition. His plan consisted of allowing the light after reflection at the large concave mirror to impinge on a smaller concave mirror placed *inside* the focus of the large one. The beam then came to focus at a point on the optical axis *between* the two mirrors. The curves of the mirrors were not paraboloidal and ellipsoidal but departed from these forms, and Schwarzchild showed that they could be figured so as to secure good images at large angular distances from the centre of the field without at the same time spoiling the axial images. With such an arrangement, ratios of focal length to aperture as low as 2·5 to 1 could be secured. Schwarzchild probably regarded his design as giving a special type of telescope for a special purpose—a small focal ratio with a large field of view—but it could not be generally useful on account of certain defects. As designed, the diameter of the small mirror was half that of the large one, thereby cutting off a large proportion of the incident light. The photographic plate had to be situated between the two mirrors, thereby cutting off more light apart from the obvious awkwardness of such a position. Furthermore, the tube had to be inordinately long and consequently unwieldy.

Prof. Chrétien has continued the mathematical investigations thus begun by Schwarzchild, and has designed a telescope in which the usual Cassegrain form is adhered to, that is, in which the light after reflection at the large concave mirror is again reflected by a small *convex* mirror, placed inside the focus of the large one, and then passes through a hole in the centre of the large mirror and comes to a focus beyond. Following Schwarzchild's lead, the mirrors are not figured exactly to the paraboloidal and hyperboloidal forms, but are designed so as to give a wide field of good definition. One such design gives a focal ratio of 6·8 to 1, and the instrument as designed is compact and workable. The field is slightly curved, and in order to make the best use of it a spherically curved photographic plate is necessary. Alternatively, a correcting lens can be placed nearly in contact with a flat photographic plate.

Turning to the actual construction of mirrors, Prof. Ritchey has carried out careful researches in this direction. It will be remembered that he was intimately connected with the making of the 60-inch and 100-inch mirrors at Mount Wilson, and his experience of the various difficulties attending their construction and use has led him to concentrate his talent on new and improved designs. He has now designed a type of mirror in which, instead of figuring a single disc of glass, the mirror is a honeycomb structure composed of *cells* built up from thin plates of glass with their edges ground and cemented together. A thin spherical shell of plate glass is fitted on to the upper surface of the cellular structure to which it is then cemented, and a sheet of plane glass is similarly cemented to the lower surface. The upper surface is then figured to the required form.

The cellular mirrors constructed in this way are very light in comparison with other mirrors of the same aperture, and Prof. Ritchey anticipates that it will be quite practicable to construct a mirror of 10 metres aperture. Furthermore, they can be ventilated by circulating air through the cells, and in this way distortions arising from temperature inequalities can, it is claimed, be eliminated.

It must be emphasised at this point that the designs for the new telescope with a wide field of good definition, and for the new cellular type of mirror do not merely exist on paper. Prof. Ritchey has constructed in the optical laboratory of the Paris Observatory the mirrors for a model of this kind. Such instruments are to be known as Ritchey-Chrétien reflectors. In the model which has been constructed the aperture is 19·9 inches and the focal length of the combination 136 inches. The two mirrors are 41·73 inches apart, the convex being of 4·9 inches aperture. The focus is situated at a point 6·3 inches behind the vertex of the optical surface of the large mirror. The mirrors are of the cellular type described above, and are figured according to Prof. Chrétien's designs. The field is spherical and is concave towards the incident light, with a radius of 23·62 inches. Spherically-concave photographic plates have been constructed for use with the model. These are easily moulded to the required curvature. But it may be remarked here that, so far as astronomy of position is concerned, the precise measurement of images on a curved plate will present a difficulty to be overcome.

Optical tests with an artificial star have been carried out with this model, and also with a Newtonian model of the same aperture and focal length. These tests make interesting reading. Even at a distance of $2\frac{1}{2}$ minutes of arc from the centre of the field the images of the Newtonian reflector are distorted by appreciable coma. It is otherwise with the Ritchey-Chrétien model. Up to 20 minutes of arc from the centre of the field, the image is a diffraction disc of about 0·28 seconds of arc in diameter. Beyond this and up to 60 minutes from the centre they are approximately circular, the diameter of the image at 60 minutes being eight seconds of arc.

This much has been accomplished, and it is clear that the accomplishment represents something of the nature of a revolution in the design and construction of reflectors. There seems no reason why instruments of moderate size of the Ritchey-Chrétien type should not be constructed, and astronomers would welcome their obvious advantages. No doubt the constructional technique would develop in a normal manner and larger instruments would appear in the course of time.

Prof. Ritchey has, however, determined to go immediately to instruments of the largest kind, and he has already designed telescopes up to ten metres aperture. Space forbids a detailed description of his plans, but one such design provides for a fixed vertical telescope with cœlostat. The aperture is to be 10 metres and there are to be interchangeable mirrors, so that five combinations of focal ratios ranging from 2·75 to 20 will be available.

Prof. Ritchey has announced his intention of constructing such an instrument. Whilst sympathising with his desire for rapid progress, many astronomers will feel that it would perhaps be more desirable to consolidate the ground already occupied and to erect an instrument of moderate dimensions under practical working conditions in an observatory. At the same time, if Prof. Ritchey's great adventure is successful, they will be the first to rejoice with him: in the meanwhile they will wish him good luck.

W. M. H. G.

The States of Aggregation of Condensed Helium.[1]

By Prof. W. H. KEESOM, University of Leyden

IN virtue of the very low value of its interatomic forces, helium—discovered in the solar chromosphere in 1868 and obtained from terrestrial sources by Ramsay in 1895—represents the ideal gas more nearly than any other known substance, and is the thermometric gas *par excellence*, while its extremely low critical temperature and boiling-point furnish the means of descending the scale of temperature to the immediate neighbourhood of the absolute zero.

The first experimenters to attempt the liquefaction of helium were Dewar and Olszewski. The method they used—cooling the gas in liquid hydrogen and then allowing it to expand—proved ineffectual, but success attended the efforts of Kamerlingh Onnes, who, in 1908, resorted to the procedure employed ten years earlier by Dewar for the liquefaction of hydrogen. Fig. 1 shows diagrammatically the arrangement of the apparatus. The helium from the storage cylinders was compressed into the liquefying vessel, in which it was cooled, by means first of hydrogen vapour and afterwards of liquid hydrogen boiling under reduced pressure, to −258° C. The cooled helium then passed into the spiral regenerator and through the expansion valve, part undergoing liquefaction in virtue of the Joule-Kelvin phenomenon. The lower part of the liquefaction vessel has been since modified to allow of the transference of the liquid to a cryostat, in which it can be subjected to physical measurement. In a later experiment for obtaining the lowest possible temperature, Onnes made use of a battery of Langmuir mercury condensation pumps in conjunction with a preliminary series of powerful mechanical pumps. To judge whether helium at those extremely low temperatures would solidify, he introduced into the Dewar vessel containing the liquid helium a small metallic cylinder suspended from a rod and capable of being moved upwards or downwards.

The results of these experiments showed that, whereas hydrogen boils at 20° abs. and the temperature 10° is attainable by bringing the solid hydrogen under diminished pressure, a temperature little above 0·8° is brought within reach by the similar use of liquid helium, with boiling-point 4·2° abs. At this temperature, however, the helium, under its own very low saturated vapour pressure, retained its liquid state.

[1] From a lecture before the Fifth International Congress on Refrigeration, at Rome, delivered on April 13.