The Growth of the Telescope.¹

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IN the beginning of the year 1608, that is, 315 years ago, or about ten generations, telescopes did not exist. The main work of astronomers before the year 1608 was, therefore, concentrated upon observing and recording the positions of the heavenly bodies from day to day and from year to year. The early (1587) instruments for observations of position took the form of graduated quadrants mounted in a vertical plane capable of rotation about the centre of a horizontal divided circle. The direction of a heavenly body could be indicated only by pointing at it; so every quadrant was furnished with a pointer pivoted at the centre of the quadrant. The adjustments of the instruments were made by using a plumb line for the determination

surface, etc. The lens combination employed by Galileo underwent changes as time advanced. In 1620 Kepler suggested the use of two double convex lenses, and this was actually carried out by Scheiner in 1637. Astronomers had to wait nearly 100 years before Chester More Hall, in 1733, put forward the idea of making an object-glass of two different kinds of glass—crown and flint—placed close together, thus establishing the so-called achromatic lens. It was not, however, until another quarter of a century had passed that John Dollond in 1758 rendered this discovery effective, thus heralding the dawn of what may be termed modern astronomical observation.

In the year 1639 the discovery of another form of telescope was made, namely, the reflecting telescope; but it was not until the year 1663 that the principle was described in practical form by James Gregory. It was left, however, to Sir Isaac Newton in 1668 actually to construct an instrument of this nature, and the telescope he made, which is quite small, is to-day in the rooms of the Royal Society of London. Like the refracting telescope, the reflecting telescope underwent various changes in the optical train; thus we have the forms now known as the Newtonian, Gregorian, Cassegrainian, and Herschelian.

As soon as the refracting telescope became a practical instrument it was at once brought into commission for instruments employed in the measurements of the positions of the heavenly bodies. In fact, it at once replaced "pointers." Tycho Brahe's great quadrant was soon superseded by a type of instrument similar to that made in 1770 by Sisson for the Kew Observatory. This was an 8-foot quadrant, mounted in the meridian, with a finely divided scale and vernier. The quadrant

form developed later into a complete graduated circle read by several microscopes after the type of Gambey's mural circle, made in 1819 for the Paris Observatory.

The acme of perfection in accuracy is reached to-day by such an instrument as the present Cape Observatory transit circle. In this the telescope has an objective of 6 inches aperture of the finest construction, two very finely graduated circles are attached, and several micrometers are employed for reading each circle. Many other refinements, too numerous to mention here, are included to attain the highest accuracy.

In order to follow the developments of the two kinds of telescopes, namely the refractors and reflectors, it is best to deal with each kind separately. Returning to the epoch many years before John Dollond made the achromatic lens effective, it was found that an object glass, which then consisted of a single lens only, formed images at the focus which were highly coloured and spoilt definition. The only method of securing greater magnifying power, with increase of aperture or diameter of lens, was to make the lenses of great

FIG. 1.—Hevelius's aerial telescopes mounted by suspension from the roof of a tower which can be rotated by gearing.

of the vertical, and a level for placing the azimuth circle horizontal.

Tycho Brahe, the famous Danish astronomer (1546–1601), constructed many elaborate instruments of this nature for his observatory at Uraniberg, but his most important instrument was the large quadrant fixed in the meridian with which he observed transits of the heavenly bodies through a hole in the south wall. This instrument was the forerunner of the modern transit circle.

Galileo was the first to use the "optik tube" for the study of the heavenly bodies, and in consequence made a series of important discoveries. Thus, he found that the number of stars was enormously increased; the "wandering stars" were really planets; the moon displayed mountains; Jupiter possessed a family of satellites; Saturn exhibited curious features which were eventually identified as a ring system; Venus appeared as a crescent; spots were visible on the solar

¹ From a discourse delivered at the Royal Institution on Friday evening, April 20.

focal length; for experience had shown that the greater the focal length the less the colour.

Thus, about the year 1680 we come to the age of giant telescopes, when their lengths measured anything from 60 feet to 210 feet. These cumbersome instruments were generally suspended by their middle from tall masts or towers, and to reduce their weight diaphragms placed at stated intervals took the place of wooden tubes. Thus were the telescopes of Hevelius. Huyghens adopted the novel principle of only placing the object glass on the mast, the eyepiece being attached to it by a long cord which could be stretched tight, and so make the proper optical alignment.

An illustration of a giant observatory of Hevelius's time given here (Fig. 1) displays three of these long telescopes in use. Mechanism is shown by which not only can the telescopes be hoisted into position but the roof of the tower to which the telescopes are suspended can also be turned round to neutralise the earth's motion. The illustration shows that even in those days a considerable observatory staff was necessary.

A telescope cannot be properly manipulated unless it is equatorially mounted, *i.e.* mounted on an axis inclined to the latitude in which it is used. One of the first, if not the first, telescope to be set up in this manner was that used by Scheiner in 1618 for observing the spots on the sun. Scheiner had only to direct the telescope to the sun, and fix it in declination, when the diurnal movement could be compensated by simply moving the telescope westward by hand. The form of mounting he adopted was the foundation of the German type of mounting telescopes, to which reference will be made later.

Not only is it imperative for a telescope to be equatorially mounted, but it must also be driven by some power, clockwork or otherwise, so that the object under observation will always remain in the centre of the field of view of the telescope. Hooke, so far as is known, was the first to adopt this principle in 1674. As is indicated in an old print of his instrument, he mounted his quadrant at the upper end of a long polar axis, and rotated this by means of gear wheels actuated by a falling weight. The speed was controlled by a conical pendulum governor, which could be shortened or lengthened at will. We had to wait, however, until the year 1823 before a really efficient driving clock was applied to a telescope. This was the work of Fraunhofer, and was adapted to the 9½-in. Dorpat refractor, the largest refractor of that period, made for the Czar Nicholas of Russia. The principle is the same as that used to-day; the clockwork, driven by weights and controlled by a governor, actuating a tangent screw which is in gear with the threads cut in the circumference of the driving circle to which the telescope can

be clamped. The Dorpat instrument may be said to be the first real modern refractor, as it embodied all the fundamental features of telescopes constructed afterwards.

There are three well-known recognised forms of mounting telescopes, illustrated in Fig. 2, and termed the "English," "German," and "Composite" types. In the English type the telescope tube is mounted directly on the polar axis midway between the supports of this axis, and being symmetrically placed balances itself both in Right Ascension and Declination. The composite type is rather similar to that of the English,

FIG. 2.—The three main methods of mounting telescopes.

only the tube is placed on one side of the polar axis and the counterpoise weights on the opposite side. In the German type, the tube with its counterpoise weights is fixed symmetrically to the prolongation of the upper end of the polar axis, that is, outside the supports of this axis. There is still a more modern modification of the German type, in which the polar axis is prolonged at its upper end, taking the shape of a fork. The telescope tube is placed symmetrically in this fork, thus obviating the necessity for counterpoise weights.

Coming now to the advance in telescope construction, mention only may be made of such instruments as the 15-inch Pulkowa (1839) by Merz and Mahler, the 15-inch Harvard (1847), also by Merz and Mahler, and the 18-inch Chicago University telescope (1862), by Alvan Clark.

The year 1868 saw the completion of the fine 25-inch

made by Cooke for Mr. R. S. Newall's observatory at Gateshead. This instrument, by far the largest of its day, was mounted after the German form. It had a focal length of 30 feet, so that the dome and observing chair had to be of great proportions. So satisfactory was the behaviour of this instrument, that, after a journey to this country to inspect this telescope, the representatives from the Washington Observatory ordered a 26-inch of 32-feet focal length from Alvan Clark, and it was completed in 1873.

In 1880, Grubb surpassed this size by making a 27-inch for the Vienna Observatory; but five years later (1885) Alvan Clark turned out a 30-inch objective of 42-feet focal length for the Pulkowa Observatory. The following year (1886) saw another objective of the same size constructed by the Brothers Henry for the Nice Observatory, but this was soon eclipsed by the completion in 1887, by Alvan Clark, of the Great Lick Refractor of 36-inch aperture and 57-feet focal length, erected on Mount Hamilton, in California. For this instrument an observing chair, as such, had to be abandoned, but the floor of the observatory was made capable of elevation and depression, thus avoiding many difficulties and adding great facilities.

Two large telescopes, though not records in size, followed the construction of the Lick instrument. The first was the 28-inch of 28 feet focal length by Grubb (1893) for the Greenwich Observatory, mounted after the English fashion; this is the largest refractor in Great Britain to-day. In the following year (1894) the Brothers Henry completed the 32-inch, 53 feet focal length telescope for the Astrophysical Observatory at Meudon, near Paris.

The largest refractor in the world to-day, namely the Yerkes telescope of the University of Chicago, was completed in 1895, the object glass by Alvan Clark being 40-inch in diameter and of 62-feet focal length. It is mounted very similarly to the Lick instrument and fitted with all the latest facilities for assisting the observer at the eye end, including a rising and falling floor.

In mounting large refractors the standard forms have occasionally been departed from in order to attain some special end. Four examples of these may be mentioned here. Thus at the Paris Observatory there was erected in 1890 a 23½-inch objective of 62-feet focal length in a tube mounted in the "Coudé" form after the design of Monsieur Loewy. This instrument is so constructed that the observer is housed in a comfortable room in which the eye end of the telescope is suitably fixed, and he can observe any object in the heavens, without moving from his chair, by means of reflections from two mirrors in the peculiar shaped tube after the light has passed through the object glass.

Another novel form was exhibited at the Paris Exhibition of 1900 to utilise an object glass of 49 inches aperture and 197 feet focal length made by Monsieur Gautier. In order to avoid the necessity of having to move such a heavy object-glass and tube, the principle adopted was to place the telescope horizontally in a true north and south position with the object-glass facing north. The light from any celestial object was then reflected into this tube by means of a large silver-on-glass mirror mounted as a siderostat and moved by clockwork. This particular telescope has never been

effectively used, so in spite of its great objective it has not been classed as the greatest telescope of to-day.

A curious mounting is that employed for the 27-inch telescope of 70 feet focal length of the Treptow Observatory, near Berlin, erected in 1909. The main object in the construction was to obviate the cost of a large dome and rising floor, and also to make the eyepiece of the instrument very easy of access for numerous visitors. To accomplish this, the tube was erected on the modified German type of mounting in such a way that the eye end of the tube should be situated just above the upper end of the polar axis. The tube was counterpoised in declination by two great weights placed at the extremities of two long arms extending northwards and symmetrically placed as regards the tube. Thus the eyepiece was in the centre of motion of the telescope and practically stationary for all positions of the tube: also by simply setting the tube near the position of horizontality it could be covered by a light wooden low structure.

The last novel form of mounting to be mentioned was erected in 1912, and is known as the 150-foot Tower Telescope of the Mount Wilson Observatory. Its origin developed from the fact that an objective of long focal length was required to be used in conjunction with a spectroscope also of long focal length.

Previous experience had shown that air currents near the ground affected the definition when such long instruments were used in a horizontal position. Dr. G. E. Hale conceived the idea of mounting the object lens high up on a metal girder tower and throwing the images of the celestial object to be studied vertically downwards on to the spectroscope placed vertically in a shaft in the ground, employing two plane mirrors above the object-glass to reflect the object downwards. The actual lens in use has an aperture of 12 inches and a focal length of 150 feet, while the focal length of the spectroscope is 75 feet. One of the chief peculiarities of the construction was that the girder work of the Tower was really in duplicate, one within the other and not touching at any place. While the dome at the top rested on the outer casing, the mirrors and lens were supported by the inner one; thus any wind pressure which might set up vibration in the outer casing did not affect the inner casing which supported the optical parts of the arrangement.

Reference has previously been made to the various forms of reflecting telescopes, such as the Newtonian, Gregorian, Cassegrainian, and Herschelian, and to the first reflector ever made, namely, that by Sir Isaac Newton in 1668. For a long time the progress of this type of telescope was slow, but impetus was given to it by Sir William Herschel, who was the first to make mirrors of really large dimensions. The mirrors themselves were composed of speculum metal—an alloy of copper and tin and highly polished. Herschel's largest reflector was four feet in diameter, with a focal length of forty feet. It was erected at Slough, near Windsor, in the year 1789. The tube was pivoted near the ground and mounted between high wooden trestles: while there was no restriction to its movement in the vertical direction it was only capable of a very small lateral motion east and west of the meridian. Just as Galileo, with his pigmy refractor, revolutionised ideas with his wonderful discoveries, so Herschel with the

giant reflector of his own construction made momentous additions to our astronomical knowledge.

Nearly sixty years later (1845) Lord Rosse ground, polished, and mounted a six-foot reflector at Parsons-town in Ireland. This leviathan of 54 feet focal length was mounted somewhat after the fashion of Herschel's, but solid masonry replaced the wooden-trestle structure. The movements of the tube were also similarly restricted.

While Lassell's reflectors, the largest of which was four foot and made in 1863, were not an advance in size, yet he instituted a great improvement by mounting the instrument equatorially after the modified German type. Grubb in 1870 completed a mirror of the same dimensions for the Melbourne Observatory, mounting it in the composite fashion. This was the last large reflector which employed a mirror of speculum metal, because glass mirrors were beginning to supersede them.

In the years 1856 and 1857 Steinheil and Foucault discovered a method of making mirrors by depositing silver on glass surfaces. This produced a highly efficient reflecting surface and soon came into common use. One of the first large reflectors with this type of mirror was that made by Foucault himself for the Paris Observatory. It was constructed on the Newtonian principle, mounted equatorially on a heavy wooden framework movable on castors and clock driven. In 1875 Martin made a four-foot mirror for the same observatory, and it was only owing to the thinness of the glass disc in relation to its diameter that it was not a success. The completed instrument was mounted in the composite form.

An immense advance was made by Common, who in 1888 constructed and used a mirror of five feet diameter. The tube was mounted on the modified German plan, being placed in a fork bolted to the upper end of the polar axis. To minimise the great weight of the polar axis on its bearings the novel idea of floating it was adopted. It was not till the year 1908, that is, twenty years later, that a mirror of the same size was made. This was accomplished by Ritchey for the Mount Wilson Observatory: the style of mounting was rather similar to that adopted by Common.

Another ten years saw the completion (1918) of the six-foot reflector for the Dominion Observatory, Ottawa. This great glass, the work of Brashear, is equal in size to the speculum mirror of Lord Rosse and weighs two tons. The form of mounting of the tube is after the composite type, the moving parts weighing 35 tons. The telescope is capable of being used either as a Newtonian or as a Cassegrainian.

It should be noted that "rising floors" in an observatory cannot be employed for reflecting telescopes of the Newtonian form because the eye end of the telescope is situated at the upper end of the tube. The

staging to accommodate the observer is therefore of very complex construction, and the arrangements adopted vary very considerably from one instrument to another, no two forms being alike.

We come now to the largest reflector of the present time, namely the Hooker 100-inch erected at the Mount Wilson Observatory in 1919. This mirror of 13 inches thickness, and weighing four and one-half tons, has a focal length of 42 feet. Though the block of glass was cast in France, the figuring and silvering is due to the

FIG. 3.—The growth of telescopes during the century 1820 to 1920.

skill of Ritchey. The great tube carrying the mirror is mounted after the English type, and the moving parts of the telescope amount in all to fourteen and one-half tons. Either the Newtonian or Cassegrainian form of instrument can be utilised. Thus, after a lapse of two and a half centuries, the one-inch reflecting telescope of Sir Isaac Newton has grown into a monster of 100 inches.

Having thus separately surveyed the progress of the two types of telescopes, it is interesting to obtain a bird's-eye view of this growth. This is represented by

means of the accompanying diagram (Fig. 3). The period of time covered is the century beginning in 1820, and while the years are displayed down the centre of the diagram, the size (in inches) of the object glasses and mirrors are shown respectively on the left- and right-hand sides against the years of their erection. Many other large instruments of interest, apart from those that were records in size in their time, have been inserted.

No less interesting and important is the study of the geographical distribution of large telescopes. For this

at Cordoba. This instrument, although completed, has not yet been erected.

South Africa and Australia are both blank in this respect, except that a 26-inch refractor is nearing completion for the former, but it is hoped that in the near future both these countries will be better represented.

The limit of size of a telescope, whether it be refractor or reflector, for the accomplishment of useful work has by no means yet been reached, providing the instrument be placed in a specially selected locality high up on

FIG. 4.—Geographical distribution of large telescopes.

purpose the positions of the great telescopes have been indicated on a chart of the world (Fig. 4). On this diagram refractors from 30 to 40 inches aperture are represented by large black spots, and those between 20 and 29 inches by small black dots. On the other hand, reflectors from 60 to 100 inches in diameter are indicated by large circles, and those from 30 to 59 inches by small circles. It will be seen that the very large telescopes predominate in two main regions, namely Europe and the United States of America with Canada. Only one telescope of the very large type is situated in the southern hemisphere, and that is the five-foot reflector for the Argentine National Observatory

some extensive plateau, where the "seeing" is of a high-class nature during the greater part of the year.

This limit is at present only temporarily restricted by the maximum limit that can be reached by those whose work it is to cast the necessary glass blocks. The mounting of even the largest telescope is now only a mild engineering problem.

It must not be forgotten, however, that large telescopes are very expensive not only to construct but also to house; yet experience has shown, at any rate in the United States of America, that when occasion arises an enthusiastic private donor generally appears.

Obituary.

THE death is announced of Dr. Hermann Biggs, Commissioner of Health, New York State, at the age of sixty-three. After graduating at Bellevue Medical College, Dr. Biggs studied in Berlin and Greifswald, and returning to the United States in 1895, directed the production of the first diphtheria antitoxin in that country. In 1900 he became general medical officer of the New York City health department, and there established the first municipal bacteriological laboratory. This post he held until 1914, when he was

appointed Commissioner of Health to New York State. Under his administration the health of New York City and State changed markedly for the better. He organised a campaign against tuberculosis, and was responsible for a body of wise health legislation. He was a scientific director of the Rockefeller Institute, and, for a short time, medical director of the League of Red Cross Societies. He gave to his country and to the world distinguished services, and preventive medicine loses by his death an ardent disciple. R. T. H.