



# V. On the construction of the large refracting telescope just completed. Read at a meeting of the Royal Bavarian Academy of Science, the 10th of July 1824

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culminations, in the observations for 1822, any that had been fit for it. The volume for 1821 I have not yet seen; and to employ earlier ones I consider unadvisable, since it is probable that the instrument now gives quite different polar distances from what it used to do.

However, I am not of opinion that an imperfection in the meteorological instruments is absolutely necessary for the explanation of the difference between the two series of observations: on the contrary, I believe that this difference may be also explained from the supposition already made,—that the bend of the instruments is such as may be removed by the application of counterpoises invariable in all situations relative to the horizon. From this supposition follows the formula  $a \sin z + b \cos z$ . However, I have reason to think that this ground may be essentially erroneous, which I intend to explain in another paper.

For the present, the question respecting the difference between the Greenwich and Königsberg observations seems to me to stand thus :

1°. That there can be no doubt but that the mural circle at Greenwich (probably by the strengthening of the telescope undertaken in 1821) has now given larger polar distances than before; as is proved by the catalogues of 1813 and 1822.

2°. That the difference has been so far reduced from the perceptible magnitude, which it had according to the *standard* catalogue (partly by Mr. Pond's own subsequent catalogue, partly by M. Olufsen's calculation of the observations of 1822, made after my refractions), that the remaining part may be readily explained from very probable causes.

BESSEL.

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V. *On the Construction of the large Refracting Telescope just completed.* By M. FRAUNHOFER. Read at a Meeting of the Royal Bavarian Academy of Sciences, the 10th of July 1824 \*.

THE instrument, of which I have the honour of speaking, is destined for the Imperial Observatory at Dorpat. It is the largest of its kind, and new in various parts of its construction.

The largest telescopes hitherto used were those constructed with metal mirrors. But since even the most perfect of these mirrors reflect but a small portion of the light it receives (the larger portion of it being absorbed), the mirror telescopes must

\* From Schumacher's *Astron. Nachrichten*, Nos. 74 and 75.  
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be of an immense size to produce any effect; on which account the intensity of light that strikes the eye of the observer is still very small. Nor is it possible entirely to rectify the deviation of the rays occasioned by the spherical forms of the reflecting surfaces of these telescopes;—reasons which, with various others, have rendered the mirror telescopes of little value for mathematico-astronomical observations, and have caused their rejection as meridional instruments, &c.

The glass, on the other hand, allows all the rays to pass; and not only compensates in a telescope, made of flint- and crown-glass, for the deviation of the rays on account of the refrangibility of the colours, but this deviation may even be removed on account of the spherical forms of the glass surfaces; by which means the effect of achromatic telescopes is much more powerful than that of mirror telescopes. And it is for this reason, and on account of their construction rendering them fit for every species of observations, that at present almost all astronomical observations are performed with achromatic telescopes.

Although the largest achromatic telescopes hitherto used are small, compared with the largest mirror-telescopes, they have in many respects produced more important results than the latter. The best trial of telescopes is, as every one knows, the observation of double stars; in which, the effect of the glass telescopes is decidedly greater than with the mirror telescopes. Thus, for instance, M. Bessel, of Königsberg, discovered with an achromatic telescope made at this place, the object-glass of which is but 48 lines, that the star  $\zeta$  *Bootis* (stated by Herschel to be a double star of the 4th class) belongs, at the same time, to the 1st class; since it has, besides the principal star, another star near it, which Herschel did not see. In the same manner several fixed stars observed before, have only been found lately to be double stars when observed through achromatic telescopes.

It is a fact well known, that the effect of the telescope lies, not in its length, but in the diameter of the object-glass; so that for instance, among telescopes of a proportionably equal perfection, that telescope whose object-glass is of twice the magnitude of another will also be of double its strength. The difficulties of making large achromatic telescopes proportionably good with small ones, do not increase so much in the proportion of the diameter of the object-glass, as they do in proportion of the cube. This difficulty not having been as yet conquered, the large achromatic telescopes, the object-glasses of which had more than 48 lines aperture, did not bear a proportionate perfection to the smaller ones; and if still larger,

larger, their power decreased. One of the difficulties was, that the glass used for the object-glass could not be obtained as perfect as such large instruments require. In fact, the English flint-glass has undular lines which disperse the light irregularly in its passage through it. These streaks being more numerous in a larger and thicker glass than in a small one (whilst, if the effect is to be increased, they ought to be less so), the power of the object-glass was diminished if the instruments were particularly large. The English crown-glass too, as in fact every other kind of glass hitherto used, has those undular streaks, which, although not always visible to the naked eye, will yet give a false direction to the rays by an irregular refraction. The Bavarian flint- and crown-glass, however, is free from these streaks, and equally compact throughout: the difference between the flint- and crown-glass being chiefly in the greater power of dispersing the colours, and the proportion of this power being in the English flint-glass, compared to the common glass, as 3 to 2, but in the Bavarian as 4 to 2: the latter is also preferable in this respect in the given proportion.

There were not till the present time any fixed theoretic principles for the construction of achromatic object-glasses: and opticians were obliged, within a certain line, to rely on chance, which made them polish a greater number of glasses, and select those in which the faults were most compensated. As the probability of this chance is much less in large glasses than in small ones, even those of the middle size would have been seldom perfect; and even with the best flint-glass the construction of large achromatic object-glasses would have been impracticable. The more important causes which rendered this process necessary are as follows: The theory of achromatic object-glasses being as yet imperfect; the means formerly applied for ascertaining the powers of refraction and dispersion of colours in the different species of glass, which ought to rest on a firm basis, not being sufficiently established; and on account of the methods hitherto used for grinding and polishing the glasses not being calculated to follow the theory with that degree of exactness, as they ought, if a palpable indistinctness should be avoided.

All those impediments, however, together with many others, have now been successfully removed, partly by inventions and partly by discoveries, to which we were led in pursuing this object. I shall, however, perhaps find another opportunity for entering more largely upon this subject.

The object-glass of the great refractor, of which I am now speaking, has 108 Paris lines aperture, and 160 inches focus.

The power of a telescope may be best seen by a comparison with another directed on the same object. The great impediments in observing with large telescopes are the imperfection of the air, and especially an apparent undulation. These impediments are increased with large instruments, in proportion to the squares of the diameter of the object-glasses, but the effect increases only in proportion to the diameter; whence, although the sky may appear clear, and the air in that respect be but slightly imperfect, no observations can be made with large instruments. As the air is perfect in this respect but few days in the year, we chose for the purpose of ascertaining the proportionate effect of the large telescope, a terrestrial object, fixed for this purpose; as by this means the space of air which we had to look through being smaller, its imperfection would be less injurious. The trials made in this manner have shown that the effect of the great refractor increases, as it should, in proportion to the magnitude of the diameter of the object-glasses. It would lead us too far, were we to enumerate all the means which were employed, for instance, only for bringing the axes of the glasses perfectly into one line, to counteract the contraction and expansion of the metal rims of the object-glasses in different temperatures, &c.; circumstances which we had to attend to, in order to secure the greatest effect of the instrument.

One of the greatest impediments found hitherto in the observation of celestial objects, by means of large telescopes, is the apparent diurnal motion of the stars, which increases in proportion to the size of the instrument; so that the stars lying towards the equator remain but a very short time within the field of view of a strongly magnifying telescope, and traverse it very rapidly. However small the motion that may be given to the instrument by means of screws, and for the purpose of following them, it will receive oscillations which will be larger in proportion to the size of the telescope. Before the instrument has come to rest, the star will have crossed the field of view, so that the observer will see it perhaps only for a few moments, and as it were by accident, under favourable circumstances; circumstances which will be the more rare, as a star is seen to the greatest advantage only in the centre of the field. These difficulties could only be removed if the telescope could be made to follow the stars without the intervention of a human hand, whether their motion be apparently slow, as at the pole, or rapid, as at the equator.

For this reason the telescope has been mounted in a peculiar manner on a parallactic principle; *i. e.* one of the two principal axes, on which it is made to turn, is so inclined towards

wards the horizon, that its inclination may exactly correspond with the latitude of the place, and is consequently directed towards the pole. The second axis, called the axis of declination, is exactly vertical upon the first, or hour-axis. Thus, by directing the instrument upon a star, the hour-axis need only be moved with that degree of velocity, as to make it turn once within 24 hours, like the axis of the earth; by which means the star will always remain in the field as long as it stands above the horizon. This motion is imparted to that axis by means of clock-work, consisting of two distinct parts. The weight of the one part overcomes the friction and inertia of the mass of several hundred weight; the other part regulates the motion. But in order to prevent a concussional motion, and make the same regularly uniform, the clock-work was made without the usual pendulum, or balance. The regulator of this work is a centrifugal pendulum, which, being inclosed in a cone, constantly turns in one direction; and both the parts of the work may be wound up without the motion of the telescope being interrupted in any degree whatever. The telescope may also be stopped, and again set in motion, without any necessity of arresting the movement of the clock-work; and, if required, it may also be moved into any direction, either with the hand or by means of a screw. The motion of the clock may be at any moment accelerated or retarded, by simply moving a spiral disk to a different degree of its division. By this means a star may be moved to the centre of the field of view, which is peculiarly useful in micrometrical observations, and is not practicable in any other manner. By means of this disk we may give the telescope instantaneously the movement corresponding with that of the moon, or any of the planets.

In order to render an uniform motion of the great telescope possible, it must be completely balanced with respect to its two principal axes, in whatever position it may be brought, without however this balancing being an impediment to its being directed towards any point of the sky that may be required. With respect to the axis of declination, the telescope, not being fixed in the centre, is balanced by two weights placed near the eye-glass and fastened to a conical brass tube, each having in the point of gravity two axes intersecting each other at right angles; so that in this respect the telescope is equally balanced in every direction. With respect to the hour-axis, the telescope is balanced by two weights, one of which is fixed immediately on the axis of declination. The second weight is fastened to a bar of a peculiar shape, forming

ing a ring towards the hour-axis. This ring touches (by means of two other axes placed opposite one another) a second and smaller ring; and this ring turns on the case containing the axis of declination; so that also with respect to the hour-axis the telescope is exactly balanced in every direction. In order to prevent the friction of the hour-axis and its pressing on its bed, another weight is added, operating on the bed of two friction-rollers. By all these dispositions the telescope, notwithstanding its immense size, may be moved with one finger.

The pedestal is of such a shape, that, although its position must never be altered, it cannot hinder the telescope from being turned towards any point of the heavens. It seems, indeed, that there may be situations of the telescope, in which the pedestal may be an obstacle against following the star; yet the instrument is so constructed that the telescope may be directed in two ways upon one and the same object, simply by turning the hour-axis  $180^\circ$ . Thus, if the pedestal should be an obstacle on one side, the turning of this axis will render the telescope free on the other.

As it is very difficult with a large telescope to find an object and bring it within the focus, it is usual to add to it a small one, the axis of which is perfectly parallel with that of the large one. The finder of the large refractor has 29 lines aperture, and 30 inches focus.

Each of the two principal axes has a graduated circle, called the hour and declination circles. These are fastened to their axis and turn with them. The division of the hour-circle shows 4 seconds of time, and that of the declination-circle 10 seconds of space. By this means those stars which are out of the meridian may also be found and observed in the daytime, which is particularly useful with fixed stars of the 1st magnitude, which cannot be observed so well in many particulars at night.

There are yet many other parts about this instrument, the use of which can however be illustrated only by a detailed description.

FRAUNHOFER.

*Postscript.*—The above description was not originally destined for the press, nor was it written for astronomers; it therefore contains much that is superfluous. A detailed description ought to be accompanied with designs of the several parts. I had only drawn the whole of the instrument in a perspective view, from the side on which the clock-work is fixed,

fixed, and a print of which accompanies the present description\*.

When the instrument was sent off to Dorpat, the micrometer, &c. belonging to it were not completed; but they will be there before the instrument can be entirely set up.

In the line micrometer belonging to the instrument, both threads may be separately moved by means of a screw; partly for the purpose of placing each thread where it may be required, partly for enabling the observer to make a kind of repetition in the observations with micrometers, which, with the use of the clock-work that moves the refractor, is much more practicable than it is in the common way of mounting. In the same sense the eye-glass is separately moveable, in order to make the two threads stand always equidistant from the centre of the field of view, which makes them both equally distinct. That part of the micrometer containing the threads, supports, besides the necessary correction-screws, &c., two verniers, in opposite positions, moving upon a graduated circle, made for the purpose of measuring the angles of position. The verniers read off to one minute. The micrometer may be gently moved with respect to the position-circle, with the hand or with a screw. The lines only are capable of being illuminated, so as to leave the rest of the field of view quite dark. As the position-circle must remain unalterable with respect to the position-axis, but the micrometer, together with the apparatus for lighting the threads, must be capable of being turned, I was obliged to make a disposition of it different from that which I had hitherto employed with micrometers without a position-circle. The whole field may also be lighted. This micrometer has four distinct eye-glasses.

The refractor will receive moreover a lamp circle-micrometer with four eye-glasses; a lamp net-micrometer with three eye-glasses; and finally, four ring-micrometers, two of which contain double rings.

As distinctness can only be properly obtained by the axis of the object-glass and that of the eye-glass being exactly in the same line, and a deviation in this respect being more injurious in large object-glasses than in small ones, a particular instrument will be added to the refractor, by which this deviation may be found and corrected.

FRAUNHOFER.

\* This plate is inserted in the *Astron. Nach.*, and it may also be seen in the 2d volume of the Memoirs of the Astron. Society of London; but it is too large for insertion in this work.