PRACTICAL

OBSERVATIONS

ON

Telescopes.

NE DAMNENT, QUÆ NON INTELLIGUNT.

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NOTWITHSTANDING so much has been written on the theoretical part of Astronomy, and so many treatises have appeared on that subject, I believe none of these astronomical grammars contain any rules for the management of the Telescope; the application of which, to the greatest possible advantage, together with that of the respective magnifying powers, and their proportions to the size of the instrument, and the circumstances of the object to be observed, seem to me to have been less considered than the general appendages to the other instruments of the observatory. The intention of this work is, to afford such information, and to present the amateurs of Astronomy with a few hints, which, I hope, will prove instructive and useful to them.

The following remarks, the result of some years' observations, were originally written at the request of a particular friend; and though in a circle of partial friends they have received much commendation, and I have been repeatedly solicited to give them to the public, I certainly never should have consented to the publication, but that constant observation has convinced me, such a practical and unprejudiced treatise would be acceptable to astronomers.

In the course of the last fifteen years I have been in possession of every sort of Telescope, and have seized every opportunity of ascertaining, experimentally, the peculiar powers of every description of reflecting as well as of refracting Telescopes; and have purchased, not without a very considerable expense of both time and money, the knowledge of the facts herein related.

And should the perusal of this little treatise, the fruit of these pursuits, afford any satisfactory intelligence, or be useful to the novice in Optics and Astronomy, by directing him in the choice, and assisting him in the use, of his instruments; the sacrifices I have made to obtain it, will, undoubtedly, become a source of much satisfaction to me, and my labours will be overpaid.

Many errors and defects, (which, no doubt, may be easily enough found in a first attempt to elucidate a subject of art in a more simple manner,) will meet indulgence from the candid and enlightened, who know that faults and omissions will sometimes escape the most persevering industry and unremitted attention.

I have (as far as I know) simply spoken the truth, unbiassed by prejudice or partiality to any opticians, or any interested motives whatever.

I hope it will be as generally acknowledged as it is universally lamented, that almost all arts and sciences are more or less encumbered with vulgar errors and prejudices, which avarice and ignorance have unfortunately sufficient influence to preserve, by help (or hindrance) of mysterious, undefinable, and not seldom *unintelligible*, technical terms — Anglice, *nicknames* — which, instead of enlightening the subject it is *professedly* pretended they were invented to illuminate, serve but to shroud it in almost impenetrable obscurity: and, in general, so extravagantly fond are the professors of an art of keeping up all the pomp, circumstance, and mystery of it, and of preserving the accumulated prejudices of ages past undiminished, one might fairly suppose those who have had the courage and perseverance to overcome these obstacles, and penetrate the veil of science, were delighted with placing difficulties in the way of those who may attempt to follow them, on purpose to deter them from the pursuit, and that they cannot bear that others should climb the hill of knowledge by a readier road than they themselves did: and such is *l'esprit du corps,* that as their predecessors supported themselves by serving it out *gradatim et stillatim,* and retailing with a sparing hand the information they so hardly obtained, they find it convenient to follow their example; and, willing to do as they have been done by, leave and bequeath the inheritance undiminished to those who may succeed them.

I heartily lament, that from these most determined and formidable enemies, the lovers of Astronomy have as many impediments to contend with as need be; very many more than sufficient to suspend their curiosity on the subject.

The principal prejudice which has confined the study of the minutiæ of Astronomy to the Observatories of the State, and of a few opulent individuals, is, that an immense apparatus of unwieldy magnitude, extremely costly to purchase, difficult to procure, and troublesome to use, is indispensably necessary to discern what has been described by various astronomers.

I hope I shall succeed in my endeavours to extinguish this *vulgar error*, and be able to prove, that neither such enormous instruments, nor monstrous magnifying powers, are either necessarily required or commonly used; and thereby the contemplation of the wonderful and beautiful celestial bodies may become more general, the science simplified and made easy, and the study of it rendered universally attractive, and no longer confined to the happy few whose good fortunes will furnish them with such expensive instruments* and I hope I shall clearly convince the amateurs of Astronomy, that all the principal and most interesting phenomena are visible with glasses which are easy to procure, and handy to use; and

* Truly these are entertainments so noble and glorious, as well as ravishing and transporting, that it is to be wondered how persons whose parts and fortunes qualify them for them, are able to temperate themselves from them.—Vide *Astronomy's Advancement*, London, 1684.

that the rationale of Telescopes has this in common with other sciences, that what is most worth learning is easiest learned ; and is, like all other sciences, reduced to *a few clear points:* there are not *many certain truths* in this world.

The principal modern discoveries in Astronomy have been made by Dr. Herschell, which have not arisen from the wonderful magnitude of his optical machineries, but from his indefatigable and matchless perseverance as an observer : and the astronomical world is greatly indebted to him for the time and labour that he has sacrificed in making experiments to ascertain the powers of reflecting telescopes, which it is presumed he has carried to the " ne plus ultra," both in perfection and magnitude, having built one stupendous telescope of the prodigious length of forty feet — with an aperture of four feet. Of the performance of this enormous engine I cannot speak, never having seen through it : however, this I may say with great truth, that his perseverance in constructing such a gigantic optical instrument, is beyond all praise; and his name will be ever remembered with gratitude by every optician and astronomer.

Dr. Herschell's first catalogue of double stars was made with a Newtonian telescope of not quite seven feet focus, and with only four inches and a half aperture, charged with a power of 222. The second catalogue was likewise made with a telescope of similar construction, but with an object metal of six inches and a quarter diameter, and magnifying 227 times. The third was composed with the same instrument, excepting the eye-glass, which was changed for one which gave the telescope a magnifying power of 460. This, the Doctor says, was much superior to that of 227 in detecting excessively small stars, and those which are very near to large ones. He says, he used a gradual variety of magnifying powers from 460 to 6000, with which many a night, in the course of eleven or twelve hours' observation, he has carefully, and singly, examined not less than 400 celestial objects, sometimes viewing a particular star for half an hour together with all the various powers of the telescope. And here let me pay the just tribute of well-deserved praise to the unparalleled perseverance this ingenious astronomer has manifested in composing these catalogues, which must for ever remain an indelible memorial of the determined ardour with which he has so successfully pursued his favourite study. Dr. Herschell's catalogue comprehends the names of the stars, and the number in Flamstead's catalogue, or such a description of those that are contained in it, as will be found sufficient to distinguish them; also the comparative size of the stars; their colours as they appeared to his view; their distances determined in several different ways; their angle of position with regard to the parallel of declination; and the dates when he first perceived them to be double, treble, &c. These catalogues have opened a new, most interesting, and extensive source of research and contemplation for astronomers, and may probably lead to the discovery of the motion of our system through infinite space. Dr. Herschell has expressed a wish, (that as they are some of the finest, most minute, and most delicate objects of vision he ever beheld,) to hear that his observations have been verified by other persons; and offers the following caution, as to the adjustment of the focus of our telescopes, and advises those who wish to examine the closest of these curious double stars, to previously adjust the focus of their glass with the utmost delicacy on a star known to be single, of as nearly as possible of the same altitude, magnitude, and colour, as the star which is to be examined, carefully observing the circumstances of the star you adjust by, whether it be round and well-defined, or surrounded by little flitting appendages which keep playing about the image of the star, varying in their appearance as it passes through the field, or remaining fixed to it uniformly the same.

These imperfections of the object-glass, or object-metal, or eye-piece, may be detected by unscrewing, or turning them about in their cells. Dr. H. mentions an instance of the advantage of this method of adjustment to the late Mr. Aubert*, who could not discern that γ *Leonis* was a double star when his telescope was adjusted at γ *Leonis* itself, but soon perceived it when he had adjusted his telescope at *Regulus:* but, even then, Dr. Herschell says, although the glass was one of Mr. Dollond's best three and a half feet achromatics †, it exhibited the two stars of γ *Leonis* in close conjunction, or rather one partly hid behind the other. The Doctor then proceeds to praise his own telescopes, and concludes with the following observation on the inferiority of achromatics:—" A good three " and a half feet achromatic, of a large " aperture, when *Rigel* is on the meridian, " may, perhaps, also show the small star, " although I have not been able to see it " with a very good instrument of that sort,

* Vide *Philosophical Transactions*, part 1st, 1785.

† Those in which the errors arising from colorific refraction, are corrected by the figure, position, and different refractive power of the lenses employed.

" which shows the small star that accom-
" panies the pole star; but the evening
" was not very favourable."

I have seen the small star which attends the pole star with a two and a half feet achromatic *, with a triple object-glass of only one inch and three quarters aperture, and the small star which accompanies *Rigel* also. This is much more difficult to see on account of *Rigel's* excessive brightness; which, if the telescope be not exquisitely perfect, will efface the small star by its false light. But there is no difficulty in accounting for Mr. Aubert's three and a half feet achromatic showing the two stars of γ *Leonis* in close conjunction, or rather one partly hid behind the other; for be it remembered, until Dr. Herschell published his catalogues of double stars, the amateurs in Astronomy confined their ob-

* When I mentioned this to Mr. G. Dollond as a proof of the extraordinary excellence of this telescope, he informed me, that he had often seen the small star near the pole star, in the two and a half feet astronomical telescopes he makes of two inches aperture.

servations to the moon and the planets: to show which, Mr. Dollond knew an actual power of 180 was full as much as ordinary observers could manage, and therefore seldom fitted up his three and a half feet telescopes with a higher power, and very often not more than 120. This being the fact, it surely ceases to be a wonder, that the separation between the two stars forming γ *Leonis* could not be discerned in the refractor; when even in Dr. Herschell's own seven feet reflector, with a power of 460, he says, they appeared to him only one-sixth of the diameter of the star apart; and ε *Bootes,* with 460, was one and one-fourth diameter of the large star separate from the small one.

The following very interesting observations of Dr. Herschell, are from his account of the changes that have happened during the last twenty-five years, in the relative situations of double stars, &c.—2d Part of *Phil. Trans.* for 1803. So much and so universally it is lamented that Dr. Herschell's papers are not collected together, and printed separately from the "Philosophical Transactions," that it is hoped the astronomical world will not be long without a complete edition of his observations, &c.

"The distance of the stars γ and χ, as I
" shall again call the small one, has under-
" gone a visible alteration in the last
" twenty-one years. The result of a great
" number of observations on the vacancy
" between the two stars, made with the
" magnifying powers of 278, 460, 657, 840,
" 932, 1504, 2010, 2589, 3168, 4294, 5489,
" and 6652, is, that with the standard
" power and aperture of the seven feet
" telescope, the interval in 1782 was $\frac{1}{4}$ of a
" diameter of the small star, and is now $\frac{3}{4}$.
" With the same telescopes and a power of
" 2010, it was formerly $\frac{1}{2}$ of a diameter of
" the small star, and is now full 1 diameter.
" In the years 1795, 1796, and 1798, the
" interval was found to have gradually
" increased; and all observations conspire
" to prove, that the stars are now $\frac{1}{2}$ a
" diameter of the small one farther asunder
" than they were formerly. The propor-

" tion of the diameter of γ to that of χ, I
" have, by many observations, estimated
" as 5 to 4.

" The first measured angle in 1782, is
" 7° 37′ north following*; and the last,
" which has been lately taken, is 6° 21′
" south following. The sum of these angles
" gives 13° 58′, for the change that has
" taken place in twenty-one years and
" thirty-eight days. To account for this,
" we are to have recourse, as before, to the
" various motions of the three bodies."

" ε *Bootes.*

" This beautiful double star, on account
" of the different colours of the stars of
" which it is composed, has much the ap-
" pearance of a planet and its satellite,
" both shining with innate but differently
" coloured light.

" There has been a very gradual change
" in the distance of the two stars; and the

* Vide second Catalogue of Double Stars, *Phil. Trans.* for 1785.

" result of more than one hundred and " twenty observations, with different pow- " ers, is, that with the standard magnifier, " 460, and the aperture of 6,3 inches, the " vacancy between the two stars in the " year 1781, was 1½ diameter of the large " star, and that it now is 1¾. By some " earlier observations, the vacancy was " found to be considerably less in 1779 and " 1780; but the seven-feet mirror then in " use was not so perfect as it should have " been, for the purpose of such delicate " observations. By many estimations of " the apparent size of the stars, I have " fixed the proportion of the diameter of " ε to that of χ, as 3 to 2. August 31, " 1780, the first angle of the position mea- " sured 32° 19′ north preceding; and, " March 16, 1803, I found it 44° 52′, also " north preceding: the motion, therefore, " in twenty-two years and two hundred " and seven days, is 12° 33′. It should " also be noticed, that while the apparent " motion of α *Geminorum*, and of γ *Leonis*, " is retrograde, that of ε *Bootes* is direct."

The following are my reckonings on this subject with a forty-six inch treble object-glass achromatic, with an aperture of three inches and three-quarters, which was purchased at Mr. Aubert's sale. With 180, the blue star which accompanies the large star of ε *Bootes,* appears at least one diameter of the small star separate from the large one: with 250, the separation is about one diameter of the larger one. γ *Leonis* I easily discern to be double with 180; with 350, full one-half diameter of the star apart. The following observations I made with the same telescope, with a magnifying power of 180.

α *Herculis*—small star, bluish, two diameters of large star separate; the blue about one-third the size of the other.

γ *Andromedæ*—small star, fine blue, four diameters of large star separate; blue star rather the least.

ϐ *Cygni*—small star blue, ten diameters separate.

Zeta Aquarii, one and a half diameter separate: the two stars are of equal size, and white.

Pole Star.—The accompanying star a very faint point.

Castor, one rather less than the other, two diameters of the largest star separate.

Rigel—the small star a mere point, four diameters of the large one from it.

Those who wish to examine these stars, will find them more readily by the use of Cary's twelve or twenty-one inch celestial globe, (on which is carefully laid down the whole of the double stars, clusters of stars, and nebulas, &c. contained in the astronomical catalogues of the Rev. Mr. Wollaston, compiled from the authorities of Flamstead, De la Caille, Hevelius, Mayer, Bradley, Herschell, and Maskelyne,) than by the aid of any astronomical atlas, &c. or other helps of that sort.

By the plain statement of these facts, and with the help of a few others, which will be narrated in their proper place, I trust I shall succeed in my endeavour to prove to the public, that these beautiful and minute objects are visible in refracting telescopes that are convenient to use and easy to obtain, and remove a ridiculous *vulgar error*, which has somehow or other obtained, that they could only be discerned with unwieldy reflectors of monstrous magnitude and enormous expense; which, instead of acting as a stimulus to astronomical pursuits, has had a very contrary effect, and operated as a sedative to further inquiry: but my own experience, and that of all the astronomers and most of the opticians I have conversed with on the subject, assure me, that for this department of Astronomy achromatic are superior to reflecting telescopes, which require to be made so much larger than refractors, and the machinery for directing their motions so much more ponderous and complicated, can only be used with advantage by those who have an Observatory on the ground.

In the appendix to the " Nautical Almanack" for 1787, Dr. Maskelyne informs us, that to produce an equal effect, the diameter of the aperture of a common reflecting telescope must be to that of an achromatic telescope as 8 to 5—but that, by a careful experiment, he found Mr. Edward's metal (which was composed of

Copper....	32 parts.
Tin	15
Brass	1
Silver	1
Arsenic ...	1

and of seventy-one mixtures, was by much the hardest, whitest, and most reflective,) showed objects as bright as a treble object-glass achromatic, both being put under equal circumstances of areas of the apertures of the object-metal and object-glass, and equal magnifying powers.

But the late Astronomer Royal, in the preface to the first volume of his Observations, has recorded the following comparisons, the result of many observations made with an excellent achromatic telescope of 46 inches focus, with a treble object-glass, the work of Mr. Dollond, and a six feet Newtonian reflector made by Mr. Short, and a two feet Gregorian reflector made by Mr. Edwards. The six feet reflector seemed to have the advantage over the achromatic telescope in observing the eclipses of *Jupiter's* first satellite by 13 seconds—and over the two feet reflector by 20 seconds; showing the immersions so much later, and the emersions so much sooner*. The diameter of the aperture of the six feet Newtonian reflector is 9,4 inches; that of the two feet Gregorian reflector is 4,36 inches; and that of the achromatic telescope is 3,6 inches. The preceding comparison of the achromatic, and the reflectors, does not go to support Dr. Maskelyne's assertion, that Mr. Edward's metals reflect as much light as the achromatic transmits, the immersions of *Jupiter's* moons being seen seven seconds later than with the Gre-

* This will, in a great measure, depend on the distinctness of the telescope, and the sharpness with which it defines the planet.

gorian reflector, whose aperture was nearly an inch larger in diameter. I have had many reflectors made for me by various artists, some of whom professed to make their metals after Mr. Edward's recipe; and others who used some compound of their own, which they thought still more brilliant and reflective.

The Doctor has (unfortunately for those who may wish to verify his experiments,) chosen such instruments for his comparisons, as I believe cannot very often be met with. I never heard of more than one reflector of eight inches aperture; and the only achromatic of five inches aperture is the ten feet one at the Greenwich Observatory.

However, though it is to be feared achromatics of five inches diameter will probably, from the lack of good glass, long remain in the catalogue of the astronomer's *desiderata*, Dr. Maskelyne's experiment may, perhaps, be equally well proved by charging a Gregorian and an achromatic glass of equal aperture, one with a power of 50, the other of 80 times: in proportion as the instruments then exhibit objects with the same degree of brightness, will be the accuracy of Dr. Maskelyne's position as to their respective illuminating power. One cause of Gregorians being complained of as being dark, and of the difficulty of finding an object with them, is, that they are generally made to magnify much more than achromatics; and from the tube being much shorter, it is comparatively more difficult (as every sportsman knows) to take aim with them.

I hope the reader will give me credit at least for the sincerity of my assertions, and that the opinions I offer on the illuminating powers of telescopes are founded on actual experiment; and, to the best of my knowledge and belief, are as near the truth as my eye has the faculty of judging: for, in whatever I have written, my only motive has been, a desire to communicate to others what I fancy I have by long and expensive experience gleaned from the many opticians and astronomers with whom I have conversed, and the fair result of my own observations; hoping this will save the reader the time and trouble it has cost the writer.

The highest magnifying power a Gregorian telescope will carry for day purposes, without overbalancing its illuminating power, will be given by multiplying the diameter of the large speculum by 20; for planetary observations, by 30 or 40; of an achromatic, by multiplying the diameter of the object-glass by 30; and for astronomical purposes, by 50: varying more or less, according to the goodness* of the object-glass, and the figure and reflective powers of the specula, and the condition they are in, especially the state of the small speculum. Of course, a fine new, bright, highly polished metal, of a perfect figure,

* Distinctness is frequently misnamed light and brilliance. A fine telescope, is said to be remarkably light, because all the rays, by the mirror being ground perfectly true, unite at one point; and this uniform action produces the same strong effect as the equal bearing of every fibre of Captain Huddart's cable, of which every thread pulls.

will reflect considerably more light*, and show objects much more brilliantly than an old tarnished speculum, of originally a bad composition and a bad figure. Illuminating power is most accurately estimated when it is most wanted, i. e. on very minute objects, and such as are badly lighted up: the advantage of a large telescope is most obvious if the comparison is made at the close of day: as darkness comes on, the superiority of illuminating power will become more easily visible.

The variation of the comparative brightness of achromatic and of Gregorian telescopes, when employed in the day time,

* The kind of glass most proper for the eye-glasses of reflecting telescopes is *crown* glass, which is the most pure glass made in this country, and also transmits more light than even flint glass: objects may be seen through a much thicker piece of crown, than of flint glass. The combination of the colour of the crown glass and of the light reflected from the metals will always show objects of their true natural colour, and totally free from all dingy or yellowish tinge. An eye accustomed to use a crown glass eye-piece will never bear any other, the vision is so decidedly superior.

and when directed to a luminous celestial object, arises, in a great measure, from the different construction of the day and the night eye-tubes. The achromatic day eye-piece does not contain less than four glasses; the astronomical, not more than one or two: and the increase of illuminating power is the natural consequence of the pencil being more penetrating and vivid when conveyed to the eye through only one or two glasses, than through four. The eye-tubes of Gregorians are generally formed of two glasses, and the only cause which enables them to carry more magnifying power for astronomical purposes, is the vividness of the objects augmenting the brightness of the pencil: it being not the mere diameter of the pencil, but the quality of it, that stimulates the optic nerve, which is as much excited, and as perfect an impression is made on the retina by a vivid pencil of light of 1-50th of an inch diameter, as by one of inferior brightness of 1-25th of an inch diameter. The hole in the large mirror of the Gregorian telescope, when its diameter does not exceed three inches at least, is so great a deduction, compared to its aperture, that it is not fair to compare the respective illuminating powers of this, and other telescopes, with a metal of less size.

For all Gregorian telescopes under this size, perhaps an eye-tube containing only one eye-glass would be the best, from its transmitting more light. Dr. Herschell, in one of his observations, speaks of the decided superiority of the single eye-glass, when applied to his Newtonian. "I have "tried both the single and double eye-"glass of equal powers, and have always "found that the single eye-glass had much "the superiority in point of light and "distinctness. With the double eye-glass "I could not see the belts in *Saturn*, which "I very plainly saw with the single one: "I would, however, except all those cases, "where a large field is absolutely neces-"sary, and where power, joined to distinct-"ness, is not the sole object of view."—*Phil. Trans.* vol. lxxii. p. 95. Reflectors of

Newton's * construction are certainly more brilliant than Gregory's, as more light is transmitted to the eye by the plain small speculum of the Newtonian, than is reflected by the concave small speculum of the Gregorian; and in the Newtonian, if the large metal be worked truly spherical, and the small one a perfect plane, all the magnifying powers being produced by changing the eye-pieces, they may easily be made

* For the following observations on the Newtonian and Gregorian telescope, I am indebted to Mr. Butt, of the Paragon, in the Kent Road.

A Newtonian telescope has an advantage, on account of admitting a greater focal length of the great speculum, and also on account of the conveniency of viewing the object, over the Gregorian construction: but, in other respects, I think the Gregorian telescope, when the lengths of focus are the same, has an advantage over the Newtonian, as the errors of the great speculum are frequently corrected by the small one, which is not the case of a plain metal. The plain metal also is liable to represent a circular figure, not circular, but oval or irregular.

The magnifying power in the Gregorian, as well as in the Newtonian, should be effected principally by the eye-piece, and not by the small metal.

equally good, and they admit of the application of almost an endless variety of eye-glasses, which need not any apparatus of small eye-holes before them.

As a Gregorian or cassegrain telescope cannot be made equally perfect with the extremely low and extremely high powers, owing to the change of magnifying being produced by changing the small specula*; it would much improve these instruments, as well as render them more convenient for use, if eye-pieces were employed as in the Newtonian: still the latter would be incalculably superior for astronomical purposes, from the pleasant position in which we observe, especially for viewing objects in high altitudes; for which purpose, and its being much more steady, from the

* I have heard the superiority of Short's reflectors attributed to the very great care he bestowed in adapting the small speculum to the large one, which he called marrying of them: for this purpose, he made a great many small specula of the same focus, and tried them one after the other, till he made a good match.

construction of the stand supporting the telescope at the two ends, higher magnifiers may be used, as the tremors are very trifling compared to those of the Gregorian. The Newtonian stand, as now made, (which ingenious piece of mechanism was contrived by Dr. Herschell,) perhaps still admits of improvement, by being placed on three feet, two behind, and one before. I have seen an old stand of this make, which I thought appeared more steady than any of the new ones with four feet.

The invention of the Reflecting Telescope may be considered the epoch when astronomy began to become general: for the great length of dioptric telescopes, adapted to any important astronomical purpose, rendered them so extremely inconvenient, that it required the utmost dexterity to use them, as it is necessary to increase their length in no less a proportion than the duplicate of their magnifying power: so that, in order to magnify twice as much with the same light and distinctness, the telescope required to be lengthened four times, and to magnify thrice as much, nine times the length.

This unwieldiness of the refracting telescopes possessing considerable magnifying power, caused the attention of astronomers, &c. to be directed to the discovery and construction of reflectors; and, early in 1672, Sir Isaac Newton completed his two small reflecting telescopes, which were but six inches long, and were held in the hand for viewing objects, and in power were equal to a six feet refractor.

Mr. John Hadley, in 1723, presented to the Royal Society a telescope, which he had constructed on Newton's plan: and in *Philosophical Transactions Abridged*, vol. vi. p. 133, may be seen a drawing and description of this instrument, and also of a very ingenious, but complex apparatus by which it was managed.

The focal length of its large speculum was not quite five feet and a quarter, the diameter of the aperture five inches, and magnifying 208 times: it was compared with the celebrated Hughgenian refractor of 123 feet focus, and magnified the object as much as the refractor with its due charge: it represented objects as distinctly, though not so bright. With this reflector was seen whatever had been hitherto discovered with the Hughgenian, particularly the transits of *Jupiter's* satellites, and their shadows on the disk of *Jupiter*; the black list in *Saturn's* ring, and the edge of the shade of *Saturn* on the ring: five of *Saturn's* satellites were also observed with this telescope.—Speaking of the satellites of *Saturn*, Dr. Herschell observes, that the visibility of these minute and extremely faint objects, depends more on the penetrating * than on the magnifying power of our

* I would rather call this illuminating power, and believe it will be most perfect, when the diameter of the pencil of light transmitted to the eye, is nearly, if not quite, equal to that of the aperture of the pupil. Thus the magnifying power should be to the diameter of the object-speculum, or object-glass, as seven to one: this will be governed, in a great measure, by the brightness of the object; and we may, perhaps, fix the

telescopes: and with a ten feet Newtonian, charged with a magnifying power of only sixty, Dr. H. saw all the five old satellites; but the sixth and seventh, which he informs us were easily seen in his forty feet telescope, were not discernible in the seven or the ten feet, though all that magnifying power can do, may be done as well with the seven feet as with any longer instrument.

For the following Tables of the proportions of Gregorian and Newtonian reflecting telescopes, I am indebted to the *Nautical Almanack* of 1787, which now being out of print and become scarce, I have copied here, from the same motives Dr. Maskelyne inserted them in his book.

scale from seven to twenty: beyond this, magnifying power cannot be added without diminishing illuminating power: however, some objects require a predominancy of one, some of the other.

TABLE of the Apertures, Powers, and Prices of Reflecting Telescopes, constructed in the Gregorian form, by the late ingenious Mr. James Short.

Number.	Focal length in inches.	Diameter of Aperture in inches.	Magnifying Powers.	Prices. Guin.
1	3	1,1	1 Power of ——— 18 Times	3
2	$4\frac{1}{2}$	1,3	1 ——— ——— 25 ——	4
3	7	1,9	1 ——— ——— 40 ——	6
4	$9\frac{1}{2}$	2,5	2 ——— — 40 & 60 ——	8
5 }	12	3,0	2 ——— — 55 & 85 ——	10
6 }	12	3,0	4 ——35, 55, 85, & 110 ——	14
7	18	3,8	4 ——55, 95, 130, & 200——	20
8	24	4,5	4 ——90, 150, 230, & 300 —	35
9	36	6,3	4 ——100, 200, 300, & 400—	75
10	48	7,6	4 ——120, 260, 380, & 500—	100
11	72	12,2	4 ——200, 400, 600, & 800—	300
12	144	18,0	4 ——300, 600, 900, & 1200	800

Mr. Short, in the above table, *always* greatly over-rated the highest power of his telescopes. By *experiment* they were found to magnify much less than expressed in his paper. Mr. Short finished two or three telescopes of the Gregorian form, of eighteen inches focus, with 4,5 inches aperture, and power 170. He also made *one* telescope, of the cassegrain form, of twenty-four inches focus, with six inches aperture, and power 355. But it was very indistinct with that power. The greatest magnifier it bore, with sufficient distinctness, was 231 times*. He also made six telescopes of the same focus, of the Gregorian form, which bore the usual magnifying powers very well.

* For want of illuminating power. This telescope is well known in the optical world by the name of "Short's Dumpy," and was originally made for the Honourable Topham Beauclerc, at whose sale it was purchased by the late Mr. Aubert, who pointed it out to me, in his observatory, as a very curious and unique instrument.

TABLE of the Apertures, Powers, &c. of Telescopes of the Newtonian construction, in which the figure of the great metal is supposed to be truly spherical.

Foc. Dist. of concave metal.	Aperture of concave metal	Sir Isaac Newton's numbers.	Focal Distance of Single eye glass.	Magnifying Power.
Feet.	Inc. Dec.		Inch. Dec.	
½	0,86	100	0,167	36
1	1,44	168	0,199	60
2	2,45	283	0,236	102
3	3,31	383	0,261	138
4	4,10	476	0,281	171
5	4,85	562	0,297	202
6	5,57	645	0,311	232
7	6,24		0,323	260
8	6,89	800	0,334	287
9	7,54		0,344	314
10	8,16	946	0,353	340
11	8,76		0,362	365
12	9,36	1084	0,367	390
13	9,94		0,377	414
14	10,49		0,384	437
15	11,04		0,391	460
16	11,59	1345	0,397	483
17	12,14		0,403	506
18	12,67		0,409	528
19	13,20		0,414	550
20	13,71	1591	0,420	571
21	14,23		0,425	593
22	14,73		0,430	614
23	15,21		0,435	635
24	15,73	1824	0,439	656

Dr. Maskelyne then observes, that as telescopes of Sir Isaac Newton's construction are now found (particularly by the late exquisite observations of Mr. Herschell, of Bath,) to perform most excellently in the minutiæ of astronomy, especially if small apertures and long foci are made use of, I have added the foregoing table, chiefly taken from Dr. Smith's *Optics*, vol. i. p. 148. I have also annexed to it Sir Isaac Newton's numbers, by means of which the apertures of reflecting telescopes, of any construction, may be easily computed.—See Appendix to Gregory's *Optics*, p. 229; or *Philosophical Transactions*, No. lxxxi.

It may be necessary to mention, that the preceding table was constructed by using the dimensions of the middle aperture and power of Mr. Hadley's excellent Newtonian telescope as a standard; viz. focal distance of great mirror 62½ inches—aperture of the object-metal five inches, and power 208 times. Mr. Herschell chiefly makes use of a Newtonian reflector, the focal distance of whose great mirror is seven feet, its aperture 6,25 inches, and powers 227 and 460 times, though sometimes he uses a power of 6450 for the fixed stars.

Note: If the metals of a Newtonian telescope are worked as exquisitely as those in Mr. Herschell's seven feet reflector, the highest power that such a telescope should bear, with perfect distinctness, will be given by multiplying the diameter of the great speculum by 74*; and the focal distance of the single eye-glass may be found by dividing the focal distance of the great mirror by the magnifying power. Thus, $6,25 \times 74 = 462$, the magnifying power; and $\frac{7 \times 12}{462} = 0,182$ of an inch, the focal distance of the single eye-glass required.

* I have never seen a Newtonian that would, for planetary observations, bear, with any advantage, a higher magnifier than is given by multiplying the diameter of the large metal by forty, or fifty at the utmost, and that is granting that it reflects nearly as vivid a pencil as an achromatic transmits.

Notwithstanding this high authority for making Newtonian telescopes of long foci, I am far from being convinced it is absolutely necessary that, to insure their proper performance, they need be made so very long as thirteen diameters of their object speculum. One of the first opticians that ever existed, the celebrated Short, saw no necessity for their being so long ; and the focal length of the Newtonian he made for the Royal Observatory at Greenwich, is not quite seven diameters of its aperture ; i. e. it is six feet focus, and nine inches and a quarter diameter.

As it is confessedly more easy to produce a spherical than a parabolic curve, I think Newtonians might be made much shorter, and equally perfect ; i. e. five feet focus and seven inches aperture. This would be long enough to apply as great a magnifier as is of any use, and the metal large enough to reflect as much light as appears to be wanted.

TABLE of the Apertures, Powers, &c. of Gregorian Reflecting Telescopes, as they are now usually made, in which the figure of the large speculum is supposed to be truly parabolic.

Focal length in inches.	Diameter of aperture in inches.	Magnifying Powers.
12	3	55,100
18	4	55,90,150,200
24	5	75,130,200,300
28	7	75,130,200,300

The above are the usual proportions ; but if the purchaser is willing to pay an extra price for the additional trouble in working the metals of a shorter focus, he may have his telescope of any length, so that it be not shorter than two diameters of its aperture. I had a cassegrain reflector made by Mr. Watson, the well known and excellent telescope maker, of No. 4, Saville-Place, opposite Lambeth-Terrace, which was three inches aperture, and only six inches focus, and magnified from 75 to 400: it was an excellent little telescope, and, I believe, is now in the possession of Daniel Moore, F. R. S. of Lincoln's Inn. I had also a Newtonian reflector of seven inches aperture and seven feet focus, made by Mr. Watson, which was one of the finest instruments I ever saw.

Whoever desires to have a perfect and fine instrument, must have at least two sets of specula made: this alone will give the optician a fair chance of doing his best; for such is the extreme uncertainty of obtaining a perfect figure, that if their employers are not liberal enough to pay for the extra labour, they ought not to be surprised if the makers are willing to stop when the figure is tolerably good, rather than run the risk of destroying a week's work, by trying to make it a fine one. Get one metal as good as you can, then set to work at another, and when you have made one more perfect, try to mend the first: thus, by alternately working one after the other, you will at last obtain the "ne plus ultra" of perfection.

It is of the utmost consequence to the

perfection of reflecting telescopes, that the mirrors be truly parallel to each other, and also that the centres of them, together with the centres of the eye-glasses, be all in one direct line; viz. in the axis of the tube. Indeed, unless these particulars are attended to, the instrument will prove defective and faulty, even though the mirrors have the most exquisite figure possible given to them. That truly excellent artist, the late ingenious Mr. James Short, always took the greatest care to adjust and centre the metals of his telescopes. If the mirrors are truly centred and adjusted to their best position, a fixed star, when the telescope is put out of focus, should always appear, in reflecting telescopes, as a truly *round* circle of fire with a black spot exactly in its centre; and when the telescope is adjusted to distinct vision, the star should appear, if the telescope is excellent, and the state of the air favourable, exactly *round*, and totally free from all irradiations, or false rays and glare. Indeed I can assert, from experience, that no object is so proper to determine the excellence of telescopes as the fixed stars, as the least irregularity in the figure of the metals in reflecting telescopes, or of the object-glass in achromatics, is rendered by them exceedingly conspicuous by a false glare, and by their not appearing perfectly *round*.

One of the most curious reflecting telescopes I have ever seen, is a dumpy cassegrain, lately made by Mr. Butt, of the Paragon, in the Kent Road. It is eight inches aperture, and only sixteen inches focus. I saw *α Geminorum* with it very nicely defined as two points. The instrument was not then finished, and only one power was completely glassed, which magnified ninety-five times: with this it performed extremely well, and I thought it a very fine telescope. The great advantage of its uncommon shortness, the focal length being only twice two diameters of the object speculum, (they are usually made from four to six diameters,) is, that of being very conveniently portable, and proportionably more steady and more handy to use.

However, the difficulty of working an object-metal of so short a focus in proportion to its aperture, is so great, that I have never heard of its having been successfully accomplished on so large a scale before: but I hope, when opticians are informed of what has been produced by a private gentleman for his own amusement, it will induce them to have industry and perseverance enough to work their metals on the same improved plan; for as the tremors are diminished in proportion as the focal length is decreased, it will render these telescopes much more agreeable and effective.

I have a little dumpy Gregorian of two inches aperture and four inches focus, made by Mr. Cuthbert, optician, of St. Martin's Lane, which shews *Saturn* beautifully distinct with an actual power of ninety times. This is one of the most perfect and convenient portable reflectors I have ever seen, and has a set of magnifiers from thirty to two hundred times.

Achromatic telescopes have been heretofore charged with so low a power for terrestrial purposes, that they are more calculated for night glasses, than day telescopes; for which purpose they will carry one third more power than they are commonly charged with. When I made this remark to an optician, he observed, it was all right if the instrument was to be used by a person in the habit of adjusting a telescope, otherwise the absolute necessity of the positive focus being found, would be to common, untaught eyes, a labour they would not so easily overcome. The same observation was made when I suggested, that as the theatres were so large, the magnifying powers of opera glasses should be increased, the reply was, "It has been tried, and the "less they magnify the better people like "them, and those are most approved "which magnify so little they scarcely "want any adjusting. Charming opera-"glasses, that have no focus! and are "equally distinct, whether all the tube is "pulled out, or shut up! They don't like a "troublesome thing that requires half a "minute to set it in some particular form "before they can see through it!!!" The result of my own observations on opera-glasses, after many experiments of the achromatic, and the plano convex single object-glass, is a decided preference to the latter; and my favourite opera-glass is constructed with a single plano convex object-glass, of an inch and three quarters focus, the diameter about an inch, with which I use an eye-glass, about an inch double concave: the length, when in use, is about three inches: this magnifies full three times and a half, which is as much as can be used in a theatre, the vapour arising from the breath of a large assembly of persons, and the quantity of smoke from the numerous lamps, candles, &c. prevent our employing higher powers. An opera-glass on the scale I recommend is very conveniently portable, and will be found a delightful companion to those who frequent theatrical amusements. To the object-end of this opera may be attached a plane mirror, placed at an angle of 45 degrees, like the small speculum of a Newtonian telescope. If this be well made, and the lateral aperture of the same diameter as the object-glass, very little light will be lost by the reflection, and the diagonal will be as sharp, and almost quite as bright, as the direct vision. The *diagonal eye-glass* is another very pretty contrivance for a bashful beauty to watch her sweetheart with; and is an invaluable oracle for a fair lady to refer to, to repair her all-conquering charms, and adjust the irresistible artillery of her eyes and smiles.

With a hope the relation may be of some use to posterity, I will take this opportunity of offering a few observations on spectacles: and as I am fondest of discoursing on subjects which I fancy I understand, and writing from my own experience, being a short-sighted mortal myself, I will begin with some advice to those who are unfortunately what is commonly called near-sighted, and narrate the history of my own case of spectacles.

When I first discovered that I could not discern distant objects as distinctly as people who have common eyes usually do, I purchased a concave eye-glass, No. 2. After using it some little time, I accidentally looked through a concave No. 3, and found my vision much clearer and sharper with this, than with No. 2, and had my spectacles glassed with No. 3, which appeared to afford the eye as much assistance as it could receive: however, after using No. 3 a few months, I chanced to look through No. 4, and immediately found the same increase of sharpness, &c. I perceived before when I had been using No. 2, and first saw through No. 3: concluding I had not yet got glasses sufficiently concave, I procured No. 4, which soon became no more stimulus to the optic nerve than its predecessors, Nos. 2 and 3, had been. Thus it appears the visual organ is subjeet to the same laws which govern the other parts of the nervous system; and an increased stimulus, by repetition, soon loses its power to produce an increased effect, therefore I refused my eye any further assistance than it received from No. 2, which I have worn near twenty years, and it is as sufficient help to me now as it was when I first employed it, giving me a sight, as I find by comparison, about upon a par with common eyes, notwithstanding without my spectacles I am quite as short-sighted as some of my acquaintance who use No. 6 and 7 concave; i. e. we read at the same distance. I wish most earnestly to advise those who need the help of concave glasses, to be content with as shallow ones as possible; and for distant objects to use a small opera-glass, which, having an adjustable focus, if it only magnifies once, will be infinitely better than a single concave, because it can be exactly adapted to any distance.

Let those who use convexes be content with as little assistance as will enable them to read a newspaper by candlelight, always using a reading candlestick with a shade, to shield the eye from the glare of the candle: this is of the greatest assistance to the sight, by preserving the sensibility of the optic pupil, which inevitably adjusts itself to the brightest object*.

I had long suspected that a judicious application of various eye-pieces to the

* Vide page 59.

achromatic telescope, would render it a much more universal and powerful instrument than it is, as fitted up in the usual way with only two or three powers. But I should never have discovered to what extent these sight-invigorating tubes can be agreeably and usefully varied, but for the assistance of an ingenious and liberal friend. Justice requires me to say, I have always found him equally able and willing to construct for me the various eye-pieces I unavoidably wanted, while making the numerous experiments which were absolutely necessary for ascertaining the precise limits of useful magnifying power, how best produced, and the most convenient mode of applying it to refracting telescopes. These, I am happy to find, may be made to carry as much power as the rapid diurnal motion and atmosphere of the earth will permit us to employ ; and, for examining double stars, I think are more agreeable instruments than the reflecting telescopes.

I had a Newtonian reflector made for me by Mr. Cary, optician and mathematical instrument maker, in the Strand, of seven feet focus, and the aperture six and a quarter inches; and two Gregorians made by Mr. Tulley, reflecting, and achromatic telescope maker, Territ's-Court, Upper-Street, Islington, of seven inches aperture, and twenty-seven inches focus, magnifying from 50 to 2000 times. As these are first-rate artists, and the instruments were got up at an unlimited expense, from the acknowledged ability and integrity of the makers there can be no doubt that an unusual degree of care was bestowed on them; and, indeed, they performed extremely well at any object in the day time, and exhibited *Jupiter* and *Saturn* in a most brilliant and beautiful manner; for, from the aperture of these telescopes being so much larger than the achromatics, they will show *Saturn* much better, especially the belts and the black list on the ring, as it was formerly called; or, as it is now called, the division or space between the rings. I saw this much easier with the Newtonian, than with any other telescope; and most easily with powers of between 200 and 300*. However, I could not always get these reflectors to perform so well as a fine refractor, when turned to fixed stars, which the reflectors sometimes showed with more or less of false light about them, when the same night I have seen them with my forty-six inch achromatic perfectly free from all accompaniments, round and sharply defined like little planets†. It is, I believe, generally allowed, that a fixed star of the first magnitude is the best criterion of the degree of perfection of such telescopes as are made for examining stars; as the least defect in the figure, or adjustment of the metals in a reflector, or of the object-glass in a refractor, is immediately seen by the star not appearing round, but surrounded by false lights and little flitting luminous accom-

* A lower power does not magnify enough to show the belts, and division in the ring, distinctly: higher magnifiers do not afford sufficient light.

† However, Mr. Beauclerc's forty-six inch is certainly a chef-d'œuvre; not one in fifty telescopes, of any construction, will do what it does.

paniments. They make their appearance in a periwig, instead of presenting themselves bald and clean shaved, or like round silver spangles on a bit of black cloth.

The following very valuable and accurate observations of Dr. Herschell I have copied from the second part of the *Philosophical Transactions* for 1803, as they are highly interesting to all observers of double stars.

" From a number of observations and
" experiments I have made on the subject,
" it is certain that the apparent diameter
" of a star, in a reflecting telescope, depends
" chiefly upon the four following circum-
" stances: the aperture of the mirror with
" respect to its focal length; the distinct-
" ness of the mirror; the magnifying
" power; and the state of the atmosphere
" at the time of observation. By a con-
" traction of the aperture, we can increase
" the apparent diameter of a star, so as to
" make it resemble a small planetary disk.
" If distinctness should be wanting, it is
" evident that the image of objects will not
" be sharp and well defined, and that they

" will consequently appear larger than they
" ought. The effect of magnifying power
" is, to occasion a relative increase of the
" vacancy between two stars that are very
" near each other; but the ratio of the in-
" crease of the distance is not proportional
" to that of the power, and sooner or later
" comes to a maximum. The state of the
" atmosphere is perhaps the most material
" of the four conditions, as we have it not
" in our power to alter it. The effects of
" moisture, damp air, and haziness, (which
" have been related in a paper where the
" causes that often prevent the proper
" action of mirrors were discussed,) show
" the reason why the apparent distance of
" a double star should be affected by a
" change in the atmosphere. The altera-
" tion in the diameter of *Arcturus*, extend-
" ing from the first to the last of the ten
" images of that star, in the plate accom-
" panying the above-mentioned paper *,
" shows a sufficient cause for an increase

* See *Phil. Trans.* for 1803, p. 232, plate III.

" of the distance of two stars, by a contraction of their apparent disks. A skilful observer, however, will soon know what state of the air is most proper for estimations of this kind. I have occasionally seen the two stars of *Castor*, from one and a half, to two, and two and a half diameters, asunder; but in a regular settled temperature and clear air their distance was always the same. The other three causes which affect these estimations, are at our own disposal: an instance of this will be seen in the following trial. I took ten different mirrors of seven feet focal length, each having an aperture of 6,3 inches, and being charged with an eye-glass which gave the telescope a magnifying power of 460. With these mirrors, one after another, the same evening, I viewed the two stars of our double star; and the result was, that with every one of them the stars were precisely at an equal distance from each other. These mirrors were all sufficiently good to show minute

" double stars well; and such a trial will " consequently furnish us with a proper " criterion, by which we may ascertain the " goodness of our telescope, and the clear- " ness of the atmosphere required for these " observations. To those who have not " been long in the habit of observing " double stars, it will be necessary to men- " tion, that, when first seen, they will " appear nearer together than after a cer- " tain time; nor is it so soon as might be " expected, that we see them at their " greatest distance. I have known it take " up two or three months before the eye " was sufficiently acquainted with the " object to judge with the requisite preci- " sion." Dr. Herschell observes, in a preceding paper, that to use the highest magnifying powers to the utmost advantage, " the air " must be very clear; the moon absent; " no twilight; no haziness; no violent " wind; no sudden change of temperature. " Under all these circumstances, a year " that will afford 100 hours must be called " a very productive one."

I dare say some of my readers will be surprised to hear, that I have seen telescopes show stars distinctly and neatly, which would not give a sharp and distinct image of any other object; and those instruments which have exhibited *Jupiter* and *Saturn* very beautifully, sometimes hardly define a close double star: moreover, those telescopes which, from their being a little over corrected *, and the purple rays predominating, are most brilliant and distinct in the day-time, and for day purposes decidedly superior to the finest astronomical telescopes, are proportionately inferior for celestial purposes. The most difficult object to define in the day-time, and the best test of the distinctness and correctness of our instruments, is the dial-plate of a watch when the sun shines upon it, placed about one hundred feet from the glass.

There is an extraordinary and curious fact, with which few people are acquainted,

* i. e. When the focal length of the convex lens is formed rather too long for the concave;

but is of the first importance every one should be aware of when choosing a telescope, or comparing instruments to ascertain their peculiar powers; that when trying astronomical glasses, we should not be satisfied with less than three evenings' observation: such is the capricious variation of the atmosphere of this country, that some evenings which appear extremely fine, and the stars look most brilliant and dazzling to the naked eye, are quite unfit for observation, and our best telescopes will not perform. Quiet, serene nights, when there is no moon, are the most favourable. When comparing telescopes, we should take very particular care that the eye-tubes be glassed with the same sort of glass, and that they are charged with precisely the same magnifying powers, otherwise the comparison will be in vain: a difference of even five or ten times in the magnifying power will sometimes, on some objects, give a different character to the glass: and whatever difference there may be in the size of the instruments, when we wish to become acquainted with their respective advantages, they should each be charged with the same magnifying power, which, if the telescopes are intended for astronomical use, should not be less than 100 times; if for terrestrial purposes, not less than fifty times.

It will very much assist the eye to wear a kind of goggle, big enough to go over the eye-piece, to defend the organ of vision from the intrusion of collateral rays, that distract and strain the sight, and prevent the perfect adjustment of the eye, by its receiving the stimulus of surrounding objects and light, at the time its whole attention should be confined to the pencil of rays from the telescope. A concave chamber, similar to an eye-bath, prefixed to the eye-piece, would, perhaps, answer this purpose best. I have seen a very ingenious contrivance applied by Mr. Adams, of Fleet Street, to the magnifiers of his microscopes, consisting of a spiral spring covered with black silk: and this first gave me the idea of the importance of such a screen, which helps the eye more than any one would imagine who has not tried it: the picture on the retina is neither confused nor disturbed by adventitious rays; the sensibility of the eye is much increased, and prevented from being employed on any other than the images presented to it through the telescope. The eye will be especially sensible of this assistance when observing on moonlight nights*. I have seen a cup-eye-head, at Messrs. Gilberts, opticians and telescope makers, in Leadenhall Street, which answers the purpose perfectly well, and is worthy the attention of those who wish their eyes to enjoy the utmost sensibility the visual organ is capable of being excited to.

Those who are acquainted with the laws of mechanics know, that all the productions of art are circumscribed by nature, and governed by certain laws and proportions. If these be overstepped, to render one part

* The end of the telescope should also be shaded with a dew-cap, or spray shade; i. e. a piece of tube projecting six inches from the object end.

of the machine more powerful, another part will in proportion become less perfect; so that when this line of perfection is broken, as much as is gained one way is commonly lost another, or the good of the whole is sacrificed for certain parts.

According to this general rule, I shall endeavour to prove that optical instruments have their proper limits, as well as every thing else which is made by the hands of man; and unless the apertures of our telescopes can be greatly increased, when a high magnifier is used the image of objects becomes too diluted to sufficiently stimulate the optic nerve: this increased diameter of object-metal, or object-glass, must bear a high proportion to the focus: enlarging the aperture and lengthening the focus do not appear to answer so well. The disproportion of the diameter of the object-glass, or object-metal, to its focal length, may be easily discerned by its not coming up to adjustment at a decided and positive point; as the adjusting screw always does in all good telescopes, which are of proper proportions.

Of the achromatic telescope, this has been sufficiently proved by the inventors of it, Messrs. Dollonds, who informed me, that between the years 1760 or 1765, they met with a pot of uncommonly fine pure flint glass, crown glass was also then to be had of much superior quality than they have been able to procure since the cessation of the glass-house at Ratcliffe; and these celebrated telescope-makers were then in the meridian of their age and experience, and equally indefatigable and ingenious in their endeavours to improve refracting telescopes: however, after numerous experiments, they found that for general sale they could not even then, with these confessedly superior materials, produce object-glasses of larger aperture than three inches and three-quarters; such was then, when it was much more plentiful than it is now, the extraordinary rarity of good glass of so large a diameter, and of the thickness required,—(added to the extreme difficulty of precisely ascertaining and working the figure of the curves with that perfect accuracy which is absolutely necessary to properly correct the aberration in such large apertures; for though the curve of the concave lens may be so proportioned as to aberrate exactly equal to the convex lenses, near the axis; nevertheless, as the refractions of the crown and flint glass are not equal, this equality of the aberrations cannot be continued to any great distance from the axis;)—they have not been able to extend the diameters even of the triple object-glasses any farther; nor have they made any larger, except only about a dozen of full four inches aperture, of six, seven, and ten feet focus, and the famous ten feet achromatic at the Royal Observatory at Greenwich, which has a double object-glass of five inches diameter, which, Mr. Peter Dollond told me, is the largest and only one of that size he ever made*.

* The difficulty of obtaining large object-glasses induced opticians to make binocular telescopes. Mr. Aubert had one made by Mr. Dollond, composed of two five feet achromatics, each having an aperture of three inches: yet, though an object seen with both eyes does appear a little brighter and more luminous

At the sale of Mr. Aubert's incomparable collection of astronomical instruments, I purchased the celebrated achromatic of forty-six inches focus, with a triple object-glass of three inches and three-quarters aperture, which was originally fitted up by Mr. Ramsden for the Honourable Topham Beauclerc, and Mr. Ramsden's name is engraven on the eye-end of the telescope: but Mr. Peter Dollond informed me that he made the object-glass, and, smiling at the time he gave me this information, said, "Yes, that object-glass is one of the things "which is to make me immortal;" and appeared much pleased with the permission I gave him to engrave his title to it on the tube of the telescope. To have composed such a perfect piece of art, is so honourable to the talents of an artist, that, to avoid all appearance of partiality or pre-

than when only one is used, the advantage to vision thereby is much less than we might expect. And Dr. Irwin has proved, by a variety of experiments, that it appears only one thirteenth part brighter than when seen with only one eye.

judice to either of these eminent opticians, I have been advised to call it by the name of the person it was made for, "Beau-clerc."

This telescope is, indeed, one of those miracles of perfection, and *ne plus ultra's* of art, which are rarely produced, and perhaps only attainable by a happy concurrence of fortunate success in the various circumstances which combine to form these compound object-glasses: for which positive and exquisite degree of perfection, we are, in all mechanical matters, almost as much indebted to accident as to art: for instance, a watchmaker makes a dozen *chronometers*, and bestows an equal degree of attention to the finishing of each of them; so much so, that he has reason to hope they will all perform equally well: however, when put to the trial, he commonly finds, that of the dozen, perhaps four, in spite of all his care and pains, will turn out but indifferent watches; six of them good; and the remaining two extremely fine, and fit "to correct "old Time, and regulate the Sun:" but why they act with such superior accuracy he cannot divine. In every department of art it is the same, and *the acmé of perfection* is always accidental, and not to be attained with undeviating certainty by any rules.

The forty-six inch achromatic, with a treble object-glass of three inches and three-quarters aperture, composed of two convex lenses of crown glass with a concave of white flint between them, was the instrument which established the acknowledged superiority of this sort of telescope for astronomical uses. Before these were made, the refracting telescopes for astronomical purposes, were of the unwieldy length of at least thirty-five feet; and the famous aerial telescope of Huygens *, which is now in the possession of the Royal Society, is one hundred and twenty-three feet focus.

* The best account I have seen of this glass, is in Dr. Derham's preface to his *Astro-Theology*, which is written with more quiet good sense, and the genuine, unaffected spirit of truth, than any astronomical grammar that I have perused. — Vide the last number of *The Guardian*.

In a conversation I had with Mr. P. Dollond, a few years ago, he informed me, that when the great Huygenian glass of one hundred and twenty-three feet focus, six inches aperture, and charged with a power of 218 times, was in the possession of Mr. Cavendish, it was compared with one of his forty-six inch treble object-glass achromatics; and the gentlemen who were present at the trial, thought the dwarf was fairly a match for the giant, the trouble of managing which was tiresome indeed.

Huygens called it an aerial telescope from its being used without a tube, by fixing the object-glass on the end of a long pole, the top of a tree, or roof of a house. To those who know how important it is that the eye-glass and object-glass should be fixed truly parallel to each other, it will be matter of much surprise how any thing could be seen distinctly with such unmanageable machines. Dr. Derham, who had Huygens's telescope some time in his possession, says it was excessively difficult to observe distinctly and accurately with it.

The following Table is an abridgement of the Proportions of Huygens's Refractors, copied from Dr. Smith's Optics.

Dist. of focus object-glass.	Diameter of Aperture.	Power or Magnitude of Diameter.
Feet.	Inch. and Decem.	
3	0,95	34
5	1,23	44
10	1,73	63
30	3,00	109
40	3,46	120
50	3,87	141
100	5,49	200
200	7,75	281

By comparing the foregoing table of the proportions of the old refractors with the following table of the achromatics, it will be seen that the refractor of forty-six feet will not bear a greater aperture thān the achromatic of forty-six inches focus: and when we consider the advantage of the glasses being worked in a most superior manner, and centred to the greatest nicety, there cannot be a doubt but that a forty-six inch achromatic would do more than any aerial telescope ever did or ever can do.

Focal Lengths, Apertures, and magnifying Powers of Achromatic Telescopes.

Focal length in Inches.	Diameter of Aperture in Inches.	Magnifying Powers for Astronomy.
30	2	80
44	$2\frac{8}{10}$	80,130,180
46	$3\frac{6}{10}$	80,130,180,250,350
60	$3\frac{8}{10}$	80,130,170,230,400
72	4	80,130,170,250,400

The thirty inch achromatic, furnished with three day eye-pieces, magnifying about thirty, fifty, and seventy times, will be found sufficient for all the uses of a day-telescope. These are commonly made with double object-glasses of two inches aperture; and experiment has pretty decidedly proved that they cannot be made perfectly fine, for astronomical purposes, of larger aperture, unless the object-glass be treble. The difficulty of doing this has discouraged opticians from introducing them generally; and those who are crazy with the dumpy mania, should recollect, that the advantage derived from achromatic telescopes, for astronomical use, being made short, (if beyond a certain proportion,) is overbalanced by the errors produced by the increase of the aberration of spericity arising from the deep curves of the eye-glasses we are obliged to employ. But I have seen some double object-glasses of thirty inches focus, and two and three-quarters clear aperture, which, for terrestrial purposes, were equal to the best forty-four inch telescopes of that aperture.

For astronomical purposes it is only teasing the eye to use a smaller instrument than a glass of two and three-quarters in the clear aperture: these are usually made of forty-four inch focus.

The astronomical Mr. Aubert always gave an unqualified preference to the forty-six inch, (which has three object-glasses of three inches and three-quarters aperture,) to all other telescopes: and as his superior abilities, liberal mind, and constant attention to these subjects, to which he devoted his ample fortune, gave him more opportunities of gaining accurate information, than any of his predecessors or cotemporaries, it is but fair to conclude that his partiality was well placed. The treble object-glass forty-six inch achromatic was Dr. Maskelyne's favourite instrument, and that which he made most use of. There is a small room in the Royal Observatory * fitted up on purpose for this telescope.

Since Mr. Beauclerc's forty-six inch telescope has been in my possession, I have had opportunities of carefully and attentively comparing it with nine achromatics of five feet focus, with double object-glasses of three inches and three-quarters in the clear aperture †, with three seven feet of four inches in the clear aperture, and a ten feet of four inches aperture; and when the test was a star, Mr. Beauclerc's forty-six inch has always been acknowledged the

* Vide Evans's *Juvenile Tourist*, which contains a very complete account of the Greenwich Observatory.

† The diameter of the forty-six inch telescopes is only three inches and five-eighths in the clear; that of the five feet is one-eighth of an inch larger; of course they afford more light, but not more than in proportion to the increased diameter of their aperture.

more perfect instrument, as it showed every thing the others did; and with it could be discerned some delicate and minute objects, which some of its competitors were not perfect enough to exhibit. This superiority was most manifest when the instruments were turned to double and coloured stars.

I have given this particular account of the performance of my forty-six inch treble object-glass, because there is *a vulgar error*, which has pretty generally obtained, about treble object-glasses, that they do not transmit near so much light as double ones: though it is evident enough to any person who is acquainted with the first principles of Dioptics, that treble object-glasses must give more distinct and more achromatic vision than double ones, inasmuch as the aberration arising from the spherical figure of the glasses can be more perfectly corrected, by the refraction of the crown glass (in which the excess is) being divided, by having two lenses of crown glass instead of one. The very small quantity of light which is lost by the two additional surfaces being much more than compensated by the distinctness which is produced: and after a variety of repeated experiments and comparisons of double and treble object-glasses, I am convinced that the treble possess as much illuminating power as the double ones, with this particular advantage, that three object-glasses generally give a more distinct and smaller image of a star * than

* "The fixed stars, when beheld with a telescope, "appear prodigiously small; and whereas Tycho Brahe "tells us, that those of the first magnitude appear to "the naked sight about two minutes diameter, they ap-"pear not unto us, according to Galileo, but five seconds "diameter, which is twenty-four times less. Tycho "Brahe makes these stars to be sixty or seventy times "bigger than the earth; at this time, on the contrary, "they are found to be 200 times less than the earth †."

"Kepler warns us, that with the telescope the "greatness of any fixed star cannot be determined, "because by how much better the glass is, by so much "the lesser the stars appear ‡, they are judged to be

† "Utrum horum mavis accipe."

‡ A humourist, to whom I read the above quotation, replied, "then in a glass which is quite perfect, I sup-"pose you cannot see any stars at all."

two; and of double stars, their apparent distances from each other will be increased in proportion as their diameters are diminished. The inferiority of the five and

" very far from being all of a bigness: those visible to
" the naked eye are taken to be of six several magni-
" tudes; those of the first rate, are conceived one
" hundred and eight times bigger than the earth; such
" are the bigger Dog Star, the Bull's Eye, &c.: those
" of the sixth and least rate only eighteen times bigger
" than it. But to come to a perfect and exact know-
" ledge of the distance of the heavenly bodies (by
" miles or such known measures), of their bigness,
" substance, frame, and contexture, is not to be
" expected; nor will any, except madmen, pretend
" to have made such discoveries. There are very
" few things which truly wise men will say they
" thoroughly understand, even amongst sublunary
" bodies. By this ingenuous dealing, the reader will
" be able easily to gather what kind of belief he is to
" give to the foregoing calculations, or accounts of the
" distances and magnitudes of these bodies. They
" are, mostly, but the conjectures of men very
" learned, industrious, and knowing in this kind. But
" there is as great a difference betwixt the knowledge
" which artists and speculative men have of the
" heavens, stars, and orbs, and that which the com-
" mon people have, as there is betwixt the common

seven feet telescopes must have arisen either from the rays being more parallel where the image is formed, the impossibility of making two object-glasses as cor-

" people and brutes'* notices of them."—Vide *Astronomy's Advancement*, or *News for the Curious, being a Treatise on Telescopes; a piece containing great Curiosities: done out of the French, by Joseph Walker, London*, 1684.

I fancy these calculations † about the fixed stars, may not exactly coincide with the accounts with which some more modern astronomers have amused the learned,

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* " Man differs more from man, than man from beast."

† How near any of these ingenious calculations approximate to the truth, GOD only knows!

" Trace science then, with modesty thy guide,
" First strip off all her equipage of pride,
" Deduct what is but vanity and dress,
" Or learning's luxury or idleness;
" Or tricks, to show the stretch of human brain,
" Mere curious pleasure, or ingenious pain:
" Then see how little the remaining sum,
" Which serv'd the past, and must the time to
" come."—POPE.

rect and distinct as three, from the dispersive light not being so well corrected; or perhaps it may be accounted for from the aperture of the telescope not bearing the same proportion to the focal length as in the forty-six inch telescope.

Notwithstanding all this, I have been often told, that a double object-glass of two inches and three-quarters aperture, will perform as much as a treble one of three inches and three-quarters. However, the fact is, a fine treble object-glass of three inches and three-quarters aperture, is quite as much superior to a double one of two and three-quarters, as that is to one of two inches. Nor is this an exclusive peculiarity

and amazed the unlearned; but as their reckonings are contained in all the astronomical horn-books of the day, it is unnecessary for me to transcribe them here. Some of them talk of immeasurable space, and distances only not infinite, with an air of as much confidence, as a mail coachman would tell you the distance between London and York. An arithmetician, who pretends to calculate, exactly, the distance or dimension of the fixed stars, deserves as much attention as a madman telling his dream; or as Sir Hudibras, of this telescope: I had lately in my possession a portable telescope, which Mr. Ramsden made for the Honourable Stewart M'Kenzie, of twenty-seven inches focus, with a treble object-glass of two inches and one-quarter clear aperture. I found this equal both in light and distinctness to any double object-glass of that diameter that has come within the *focus* of my observations; i. e. I have seen minute objects more easily and distinctly with it. And as it may be interesting to some to know with how small an aperture and power the faint and close double stars can be discerned *, I

when he reckoned that the sun, and his brethren the stars, were

" ———————— a piece
" Of red hot iron as big as Greece."

And of the moon tells,

" What her diameter to an inch is,
" And prov'd she was not made of cream cheese."

* For the following observations, I am indebted to Mr. Evanson, of the Stamp Office.

" In consequence of your having manifested a desire " to have an account of the powers by which I have " been enabled, with a thirty inch object-glass, to see will here transcribe from my journal some of the observations I made with this little telescope for that purpose. With the

" some difficult double stars, I write this in compliance
" with your request, to inform you, that with a power
" of eighty applied to a thirty inch object-glass, having
" an aperture of two inches, I have very distinctly
" seen the small star near the *Polar;* and also the
" small star near *Rigel,* though this latter was gene-
" rally more faint than the former.

" With a power of 130 times, applied to the same
" object-glass, I have satisfactorily discerned the small
" blue star near ε *Bootes,* and have also observed γ *Leonis*
" to be a double star. With a three foot object-glass,
" of two inches aperture, made by the ingenious Mr.
" Tully, of Territ's-Court, Islington, I have discerned
" γ *Leonis* to be evidently double, with a power of
" 160, and all the other stars forenamed, with perfect
" satisfaction: ε *Bootes* with a power of 160, and the
" other two minute stars with powers of from sixty to
" ninety.

" The number of minutes and seconds comprehend-
" ed in the field by any eye-piece, used with any
" telescope, is easily ascertained by observing the time
" of the transit of any star or planet over the field,
" from the instant of its coming to the meridian; then
" a very easy trigonometrical calculation, shewing the
" number of minutes and seconds which must be

whole aperture, two inches and a quarter, and powers of 70 and 115, I very easily saw the small star near *Rigel*; that most minute point of light, that minimum visible, which accompanies the pole-star, was plainly to be seen with 70. I contracted the aperture to one inch and three-quarters; with the power of 70 the small star near *Rigel* was still distinctly visible, a very delicate and beautiful object; but it was with the greatest difficulty, and only with the most favourable circumstances, and a power of 50, that I could discern the faint star which accompanies the pole-star, when the aperture was thus diminished. With the whole aperture, and an erect eye-piece composed of four glasses, magnifying 130 times, I have several times distinctly discerned a separation between the two stars of ε *Bootes:* but, to perform this, the

" passed in that time, will manifestly denote the " extent of the field of view.

" Hence, likewise, may be deduced another mode " of ascertaining the magnifying powers of telescopes " with the greatest exactness."

telescope must be exquisitely perfect, as I have seen many forty-four inch achromatics with double object-glasses of two inches and three-quarters aperture, which would not show any of these objects.

In reflecting telescopes, Dr. Herschell says, the maximum of distinctness is much easier obtained in a speculum of six inches and a quarter aperture, than in larger ones. As I have before said, this was the size of the telescope he made his astronomical catalogues with, and in his hands it has worked wonders. Dr. H. observes, that the seven feet Newtonian has sufficient light with a single eye-glass, which gives it a magnifying power of 287, to show the belts and double ring of *Saturn* completely well*. What can we wish for more? How many

* The division of *Saturn's* ring and the two belts on the body of the planet, are so easily seen with my forty-six inch achromatic, with eye-tubes composed of two glasses magnifying about 200 and 250 times, that many persons, after viewing *Saturn* with this telescope, have described these appearances accurately, who had never seen them before.

have expended large sums of money on telescopes without having ever seen such an all-repaying sight!

Query: Can the acmé of perfection be obtained in metals of larger diameter? Several of our first-rate practical and working opticians have candidly declared to me, they would not, for general sale, undertake to make speculums of larger size than nine inches, that would show a star round and neatly: and unless they will bear this grand ordeal, it has been the fashion, lately, to suppose its figure cannot be depended on for exhibiting any object * with that faithful accuracy which is the *sine quâ non* of astronomical instruments.

That distinctness of vision appearing to be so limited, may not create one sigh from the breast of any minute philosopher, that further optical assistance cannot be given to his eye; and that art is, as I have before said, so circumscribed; I will venture to account for these impediments and bound-

* See page 57.

aries from the operations of Nature herself; i. e. the rapid rotatory motion of the earth preventing the application of a higher power than 300 times being used with any advantage. This is so true, that, until this obstacle is removed, we need not hunt after monstrous telescopes, unless it be in the true hobby-horsical spirit, *for the sake of the pleasure arising from the trouble of using them,* and being disappointed. Beyond a certain size, telescopes *are only just as useful, as the enormous spectacles which are suspended over the doors of opticians.*

When the inventors of the achromatic glasses fixed the powers of their telescopes, it was no doubt done after due deliberation, and a conviction arising from experiment, that for planetary uses the proportion of the diameter of the object-glass to the pencil of rays was most proper when as one to forty, for common telescopes and common observers. Thus the thirty inch, with two inches aperture, magnifies eighty times; and it may be considered a general rule, that to find the most effective magnifying power of a telescope for planetary use, multiply the diameter of the object-glass by forty or fifty: to bear more it must be a very fine instrument, and the planet near the meridian; by the proximity of the object to which, the application of magnifying power must always be governed. When the pencil is much less than one fiftieth of an inch diameter, it is too diluted to perfectly excite the action of the eye: and, when applied to the planets, we lose in distinctness more than we gain, by the magnifying being in too high a ratio to the illuminating power. But we must take into the account not only the bigness, but the brightness of the pencil of rays, which will of course be in proportion to the brilliance of the object observed.

Some stars I have observed with a power which diminished the diameter of the pencil to nearly one hundred and twentieth of an inch; i. e. a power of 420, with an aperture of three inches and five-eighths diameter in the clear. I have never yet seen any object that appeared to require a greater power: and it requires a most perfect telescope, and every other favourable circumstance, to admit of this being used with any advantage. From the rapidity of the diurnal motion of the earth, the limited excitability of the eye, the impediments to vision arising from our magnifying the atmospheric medium we look through in proportion as we magnify the object we look at, which increase in so high a ratio to the magnifying power, more than 100 for terrestrial and 300 for astronomical use, rather impede than assist vision. And again, when we charge our telescopes with a higher power than 300 times, what very uncommon dexterity is required either to find the object, or manage the instrument! It is, indeed, fortunate so high a magnifier is rarely needful, as it cannot be used to much advantage *till the atmosphere be removed, and the earth stand still:* we may then do wonders.

With a good achromatic, of forty-six inch focus, and a treble object-glass of three inches and five-eighths in the clear aperture, I have seen that most minute point of light near the pole-star with the following powers, measured by a dynameter invented and made by the late ingenious Mr. Ramsden: 40, 80, 150, 250, 350, 420, 700; and even with 1123 times the small star was still visible. Mr. William Walker, the astronomer, was observing with me, and also saw this. Mr. Charles Fairbone, mathematical instrument maker, of Great New Street, Fetter Lane, saw it again very distinctly on the 30th August, 1807. Mr. Samuel Pierce, telescope-maker, at Mr. Berge's, optician, Piccadilly, observed the same on the 26th May, 1811. I believe the polar star is as proper as any, for a test of the perfection of a telescope, as to its light and distinctness; and as it is easily found, and always visible, it is the more desirable, as it is a more universally attainable test.

I mention the foregoing observations merely as an authenticated and curious fact, how far magnifying power could be carried on this object, as it was with evident detriment to vision when higher than 80, which showed this star more pleasantly, and the illuminating and magnifying powers for this object appeared to be in more perfect proportion than with any of the higher or the lower powers.

We should never use a greater magnifier than we absolutely want; the lower the power, the more beautiful and brilliant the object appears: the field of view is proportionately large, and the motion of the objects passing it proportionately less: thus they may be observed with greater ease and quiet attention. But here it may be well to observe, there is no use in the pencil of rays being of larger diameter than the optic pupil, which is commonly calculated at one-tenth of an inch, varying in magnitude according to the brightness or obscurity of the object presented to it. The natural state appears to be that of dilatation; and the contraction, a state of violence produced by an effort originating in the mind: when the light is too strong, or the object too bright, we contract the pupil to intercept that excess of light which would injure the eye: when the light is faint, the pupil expands, that a greater quantity of light may enter the eye, and thus make a stronger impression upon it. This contraction and dilatation of the pupil may be observed by holding a looking-glass (or, what is still better, the lowest small speculum of a Gregorian telescope) before the eye at a window, and turning gradually from it, continually looking at the eye. It may be more easily and perfectly seen by attentively watching the eye of another. I think it is most agreeably observed in a fine full blue eye.

To ascertain the magnifying power of a telescope, measure the diameter of the aperture of the object-glass, and that of the little image of it which is formed at the end of the eye-piece, the proportion between these will give the ratio of the magnifying power. To measure the diameter of the pencil of rays with great ease and accuracy, Mr. Ramsden *, about the year 1775, con-

* The highest praise is due to the merits of the late Mr. Jesse Ramsden for his ingenuity, liberality, and persevering endeavours to invent and perfect the various instruments used in Astronomy, Philosophy, and

trived a clever little instrument, which he called a dynameter: for though, when single lenses are used, the power of a glass

Mathematics; to produce which, he devoted all his time, and almost all the profits of his very extensive trade: in carrying on which, his anxiety was not (like the razor-maker, who merely made his goods to sell) to study and contrive how cheap he could make an instrument, and how dear he could sell it; his sole care was to make it as perfect as possible, and he spared neither pains or expense in forming an instrument, or bringing it to perfection; and the method he pursued, though singular, almost invariably produced ultimate success. Without the least ostentation, pride, or reserve in his manners, he was polite, easy, and familiar to all that had business with him.

I have been favoured with the following anecdote from such a source, that I can vouch for the authenticity of it.

"It was his custom to retire in the evening to what he considered the most comfortable corner in the house, and take his seat close to the kitchen fire-side, in order to draw some plan for the forming a new instrument, or scheme for the improvement of one already made. There, with his drawing implements on the table before him, a cat sitting on one side, and a certain portion of bread, butter, and a small mug of porter placed on the other side, while four or five apprentices is readily discovered by dividing the focal length of the object-glass by that of the eye-glass, in eye-pieces of the common con-

commonly made up the circle, he amused himself with either whistling the favourite air, or sometimes singing the old ballad of,

> " If she is not so true to me,
> " What care I to whom she be?
> " What care I, what care I, to whom she be!"

And appeared, in this domestic group, contentedly happy. When he occasionally sent for a workman, to give him necessary directions concerning what he wished to have done, he first showed the recent finished plan, then explained the different parts of it, and generally concluded by saying, with the greatest good humour, " Now, see man, let us try to find fault with " it;" and thus, by putting two heads together, to scrutinize his own performance, some alteration was probably made for the better. But, whatever expense an instrument had cost in forming, if it did not fully answer the intended design, he would immediately say, after a little examination of the work, " Bobs, man! " this won't do, we must have at it again:" and then the whole of that was put aside, and a new instrument begun. By means of such perseverance, he succeeded in bringing various mathematical, philosophical, and astronomical instruments to perfection.

struction, especially those of a negative focus, it is very difficult to measure in this manner; nor can it be done with any accuracy with those eye-pieces which are made for erect vision with four eye-glasses.

The dynameter is principally composed of a fine micrometer screw, and a divided plano convex glass; by means of which the image of the pencil of rays is completely separated, and the diameter of it known to the greatest nicety. The wheel or head of the micrometer is divided into a hundred equal parts, and a figure engraven over every fifth division, which is cut rather longer than the others; 1, 2, 3, and so on to 20: but adding an 0 to each figure in calculating, it will then read off, 10, 20, 30, and so on to 200. The nonius is divided

The large theodolite for terrestrial measurements, and the equal altitude instrument for astronomy, will always be monuments of his fertile, penetrating, arduous, superior genius! There cannot be a lover (especially of this more difficult part) of philosophy, in any quarter of the globe, but must admire the abilities and respect the memory of Jesse Ramsden!"

into 15, 10, towards 0, and 5 on the contrary side.

The revolutions of the micrometer head will bring the edge of the circle round it, and the division on the nonius, to coincide at 10: each division, therefore, is equal to the ten thousandth part of an inch.

Applying this little instrument to the eye-glass of a telescope, when adjusted to distinct vision at any distant object, and turning the micrometer head, the emergent pencil will begin to separate; and when the extreme edges are brought into contact, the number of divisions will show the diameter of it in thousandths of an inch; then reduce the diameter of the object-glass into thousands, and divide that sum by the diameter of the pencil, the quotient will be the real magnifying power. But as it is requisite for the emergent pencil of rays to be in the focus of the divided glass, a thin transparent piece of ivory, precisely one-tenth of an inch in diameter, is set in the sliding cover, to adjust for that distance, which must always be done before it can be used with accuracy.

When this transparent piece of ivory is brought over the hole in the cover of the dynameter, and appears perfectly round, the nonius will then be at 0, and is properly adjusted. Five revolutions of the micrometer screw will make a complete separation of the diameter of its aperture, which is one-tenth of an inch: and when the opposite sides are brought into contact, the nonius will coincide at the fifth division of it, which is five two-hundredths of an inch; thus dividing each tenth of an inch into a thousand equal parts. Another method of discovering the magnifying power, is to set the telescope in such a position opposite the sun, that the rays of light may fall perpendicularly on the object-glass; and the pencil of rays may be received on a piece of paper, and its diameter measured: then as the diameter of the pencil of rays is to that of the object-glass, so is the magnifying power of the telescope. Or, thirdly, a thin piece of mother of pearl, with a very acute angle two inches long marked thereon, and only one-tenth of an inch at its base marked thereon; the length being divided into ten equal divisions, making a visible line to each division, with a figure over it, these divisions will express or show the hundredths of an inch: apply this scale to the eye-tube of the telescope, observe where the emergent pencil of rays fills up a certain space at or near any of the divisions; multiply the diameter of the object-glass into hundredths on the scale, and the quotient will be the magnifying power.

Before any of these methods of finding the magnifying power be made use of, remember to look through the tube, and observe carefully if some of the object-glass be not cut off, and part of the original pencil intercepted by the stops in the tube, &c. This is a very common trick, and will render your calculation on the whole aperture erroneous; for in all cases the magnifying power of telescopes, or microscopes, is measured by the proportion of the diameter of the original pencil to that of the pencil which enters the eye.

The degree in which magnifying power may be advantageously applied, depends so much on the perfection of the telescope and the state of the atmosphere, that it is hardly possible, by any general rules, to fix precise limits to it: but, to afford an opportunity of trying this and many other entertaining experiments, the day eye-piece should have a pipe-drawer; and the screw, which receives the tube containing the two first glasses, should be the same as the screw which fixes the eye-drawer to the telescope: and the two first eye-glasses should be made to separate (by a sliding tube within the pipe-drawer) from the third and fourth. This will give a very pleasing variety, and be extremely convenient to those who wish to obtain a certain, exact degree of magnifying power.

For large adjustments, and also that the telescope may be used for near objects, it should have a sliding tail-piece; and the tooth and pinion for the fine adjustment should be made carefully, so as to move easily and smoothly, that it may not shake the glass while adjusting it. This is one of those defects we must expect to find in instruments which are so very rarely used by those who make them — the workman not being aware of the great importance of the telescope being perfectly steady during the adjustment of the focus. For this purpose, there should be two steadying sliding tubes applied from the eye-end of the telescope to the stand. These will in a great measure prevent the vibrations, which are such impediments to vision. When the eye is perfectly satisfied with the adjustment of the focus, let the telescope be so placed that the object may pass through the field, the instrument remaining at rest during the time: this answers better than running after it with rack-work.

The telescope should be suspended in the centre of gravity, and mounted on a portable and folding mahogany stand, with divided circles, and an universal polar adjustment. If the instrument be then placed in the plane of the equator, only one motion will be required to follow the object; which, when large magnifiers are used, is a very great advantage, as the tremors occasioned by the movement of the rack-work are of course proportionably diminished. And be it always remembered, that steadiness is of the first importance. When high magnifiers are used, we need every assistance that can be contrived; as, even with the best constructed stands, a person walking in the room will prevent our seeing distinctly; nay, the very pulsation in the body of the observer will sometimes agitate the floor enough to produce this effect.

The atmosphere always appears most diaphonous on those evenings when there is least wind; and vision seems better, perhaps, because the instrument is still. For this reason, and to avoid currents of air passing before the glass, whenever the weather will permit, let the telescope be taken out of doors; for it will never do its utmost unless it is placed on the ground, in the open air. If the instrument has been kept in a room, the temperature of which is much warmer than the open air, I usually take off the cap of the object-end, and take out the eye-piece, and let the air pass through the tube for ten minutes; and for at least the same space of time we must carefully avoid all stimulating and bright objects; so that the pupil may be in its most expanded state. When the eye is thus prepared, the sensibility of the visual organ will be much increased. I have also found it very advantageous to occasionally rest the eye for a few minutes: this will restore its irritability, which is soon exhausted when stimulated by an intensely bright object: and when a light is necessary to find an eye-piece, or rectify the instrument, to prevent the adjustment of the eye being disturbed, I use a small lantern, which gives a very faint light only on one side, and that may be made dark.

For those who have not courage, or constitution, to brave the inclemency of midnight frosts and damps, the most steady way of supporting a telescope within doors, is by a clamp made to fasten on the sashes when the top sash is put down: the object-end of the telescope is then in the open air, and out of reach of the undulating motion occasioned by looking through a medium of atmosphere which is undergoing a change of temperature, by the cold air rushing into the warm room. By this contrivance we have almost all the steadiness of being on the ground without being exposed to the cold, &c.

I must here endeavour to impress on the mind of my readers another most important observation: when they have done using the telescope, let the object-glass be taken out and laid in a dry warm place, for a sufficient time to evaporate the damp air, which on dewy evenings too plentifully condenses on the object-glass; and however closely the lenses constituting the object-glass are burnished into the brass cell, unless they are very carefully kept dry, the damp air will penetrate between the glasses, and produce a sort of fog, or sometimes an arborescent vegetation like sea-weed, which I have seen spread all over the object-glass. Unless these evils exist in a very extreme degree, experience has proved the only detriment they do to the performance of the glass is, that it does not transmit quite so much light: and if the instrument be a very fine one, it is more advisable to put up with an almost imperceptible diminution of its brilliancy, than run the risk of destroying the telescope — for the object-glasses cannot be separated from each other, without perhaps irreparably disordering the adjustment; from the perfect harmony of which, the instrument may, possibly, in a great measure derive its superior excellence, from certain circumstances, which, once disturbed, can never be restored — the acmé of perfection being always accidental.

Moreover, it is equally indispensable, when we wish to discern those delicate and minute objects, which are the most interesting and curious exhibitions our telescopes display to us, and with the finest instruments are only discernible with the most favourable circumstances, that we should be in a position of the greatest ease: no cramp or painful posture must distort the body, or irritate the mind; the whole powers of which must be concentrated in the eye: for such is the sympathy between the various organs of the human body, that we may as well attempt to think accurately on two subjects at the same time, as to use two senses at the same moment:—each must be used alone. As our immortal Shakspeare has observed of listening, with such profound attention, that "each other sense was lost in that of hearing."

The smallest achromatic that can be used with effect for astronomical purposes, is the three and a half feet. These telescopes were originally furnished with three object-glasses of three inches and three-quarters diameter; but they are now usually made with two object-glasses of two inches and three-quarters aperture. With this telescope all the principal and most interesting celestial phenomena may be pleasantly observed: and, indeed, if exquisitely perfect, it will discover the minutest objects in the heavens: and as there are more made of this, than of the larger sized telescopes, it is proportionably more easy to obtain a good one. In astronomical, as well as in all other concerns, truth and perfection are the first *desiderata:* our telescopes only delude us, unless, like the juryman's oath, they display the truth, and nothing but the truth. And, in future, I hope astronomical amateurs will rather seek for *perfect* telescopes, than *large* ones; for as the pupil of the eye contracts and dilates *pro re-natâ*, bright objects would often be better seen by reducing the aperture, than by loading the telescope with magnifying power, to save the eye from being drowned in light.

Having already given sufficient directions for ascertaining the goodness and power of the instrument, there now only remains for me to point out what eye-pieces are needful, for the application of the telescope to the greatest possible advantage. It will be found much more convenient if the eye-pieces are made to slide into the tube instead of screwing in; they are so much more readily changed, especially in cold, dark nights, when the hands are benumbed and almost frozen.

If the telescope furnish a sufficient quantity of rays to fill the aperture of the pupil, whose diameter, when dilated, is calculated at one-tenth of an inch, we shall obtain every advantage illuminating power can give us, by multiplying the number of inches diameter of an object-speculum, or object-glass, by ten; for the next power by fifteen; the third by twenty; and the fourth by thirty. This, in a telescope of three inches aperture, will give a magnifying power of ninety times, which will be the maximum* that can generally be used in this country, except in very fine days, and on

* Where the purple light is predominant in an achromatic, we may, for day purposes, use a higher power than in those glasses which are under-corrected. I have a thirty inch, of two and three quarter inches aperture, made by Mr. George Dollond, of which the illuminating power is so abundant, that it will bear a magnifying power of seventy, for terrestrial uses.

objects that are uncommonly well lighted up, the extent of vision being limited by the myriads of heterogeneous particles that are constantly floating in the air: these, by their opacity and reflective power, form a kind of veil that obscures the vision of remote objects: and the more the medium is loaded with these particles, and the more distant the object, the more obscure and indistinct it will appear. So, for determining the distinctness of our telescopes, we try them at objects not more than a few hundred feet distant from us. The exhalations which continually rise from the earth, augment this impediment, and render the air less transparent, especially near the earth. But the obscurity arising from the exhalations, is not the least part of the inconvenience they occasion; they have a kind of undulating motion, like that of smoke or steam, so that objects seen through them appear to have a tremulous, or dancing motion, which is sometimes sensible even to the naked eye. If distant objects be viewed on a hot summer's day, this effect is sometimes so sensible in telescopes, as to render them entirely useless for terrestrial objects, when they magnify more than seventy or eighty. These circumstances prevent our using large glasses with that advantage with which those who are unacquainted with these things imagine they may be employed; and for objects a mile or two distant, an achromatic of two inches aperture, or a reflector of four, will do very nearly as much as any larger telescope. And for this purpose, a Gregorian reflector, of twelve inches focus and four inches aperture, is a very handy telescope, and will be found as powerful an instrument as the opacity of the atmosphere, near the horizon, will permit us to use; and its shortness makes it so very convenient, that for a day telescope it is preferable to an achromatic, which, to be equally powerful, will not be less than thirty or forty inches focus. Very remote terrestrial objects are best seen about an hour or two after sunrise, or an hour or two before sunset. When I was at Brighthelmstone, some years ago, I could, in the early part of the morning and evening, very easily see the Isle of Wight; which, in the intervening hours of the day, was not discernible.

For astronomy, the following powers:

1st. A comet eye-piece, made with two plano convexes, with the plane sides outwards, and a very large and uniformly distinct field, not magnifying more than twelve times. During the appearance of the comet about five years ago, *a vulgar error* prevailed, that a common opera-glass would afford the eye more assistance than a telescope. This must have arisen from telescopes not being usually furnished with a sufficient variety of eye-pieces; for, although comets are commonly enveloped in a veil of dense atmosphere, which defies the operations of *magnifying* power, the *illuminating* power of a large glass may be employed with much advantage: and with a proper comet eye-piece, the larger the telescope, the more readily and distinctly we shall discover the nucleus and its appendages. I have an eye-piece of this kind, that exhibited the comet of September, 1811, very satisfactorily, the field of view being large enough to show the comet and its paraphernalia of light which accompanied it: and as it is a delightful eye-piece for viewing nebula and the milky way, &c. it will be found a very useful addition to the apparatus of the telescope, and will serve for all the purposes of a night-glass. Nevertheless, a large night-glass will be found a very useful instrument in the observatory, for obtaining a more intimate acquaintance with the constellations, and for doing the business of a sweeper. By using a prism eye-piece, it may be slung in as convenient a manner as a Newtonian reflector, and the eye of the observer remain at rest while the telescope moves from the horizon to the zenith: it is also well adapted for observing comets; perhaps, for these purposes, equal to most telescopes. These instruments are usually made with a single double convex lens of three inches aperture, for the object-glass; and the eye-tube composed of two plano convex lenses, magnifying not more than twelve or fifteen times; the field of view extraordinarily large and distinct to the very edges of it. These were first invented for the sea service, and are found so useful, that they are invariably considered an indispensable part of a ship's stores. But, as they show the object inverted, it is difficult to find with it; and it will require practice to retain it steadily in the field, especially at sea, where both the vessels are continually in motion. The complaint raised against them on this account, induced opticians to make another kind, to show the objects in their proper position, with an achromatic object-glass of one inch and three quarters aperture: these are called night or day glasses, and magnify about twelve or fifteen times. But as there are four glasses in the eye-tube, and the object-glass is so small, it becomes too dark to be of much use at night: its principal superiority is in hazy weather.

I decidedly prefer, to all others, the improved night-glasses, which are constructed to show objects in their natural position by using an eye-piece made with three glasses of equal foci, and placed equidistant from each other in the eye-drawer, similar to the eye-piece of the common old refracting telescope. These I have heard equally approved by many persons, who have made repeated trials of them, as being the most preferable night-glasses at sea. The object-glass is a single double convex lens of three inches and 5-8ths diameter, which affords more light than those that invert of three inches diameter. It may be objected, that a single object-glass of large aperture will always produce an indistinct image, because the area of the circle of dispersion is as the area of the object-glass, and this indistinctness will be proportionably increased by the aberration of the eye-glasses. But let it be observed, as those glasses are intended to be only used at night, and only magnify twelve times, the refrangibility is not perceptible, and the aberration is of no moment.

But as two eye-glasses certainly do transmit more light than four, it is desirable to have an astronomical eye-piece, composed of two glasses, to afford as much illuminating power as possible. For this purpose, multiply the diameter of an object-glass by ten, and the product will be the magnifying power required: for the next power, multiply by twenty; for the third, by thirty; the fourth, by forty; the fifth, by fifty; and the sixth, by sixty. This is the maximum that can be used with advantage for planetary observation, and requires a very perfect telescope, and every circumstance to be favourable, to admit of its application with good effect: for as sound, when diminished beyond a certain degree, becomes too faint to excite a sufficient vibration of the tympanum, to convey tones distinctly and decidedly to the sensorium commune, and at length becomes inaudible; in like manner, when the pencil of light is less than 1-50th of an inch, unless it be extremely bright, its stimulus to the optic nerve becomes too languid to excite its perfect action.

For the moon, the lowest day eye-piece will do as well as any. If it does not magnify more than forty, it will show the face of the moon, and leave a margin round it.

There is *a vulgar error* almost universally prevalent, that *Saturn* will bear a higher magnifying power than *Jupiter,* notwithstanding *Jupiter* is a much brighter object than *Saturn.* My own experience is diametrically opposite; for, as common sense would teach any thinking mind, *Jupiter* will bear a high power better than *Saturn,* in proportion as he shines with more vivid light*. And the reason why this vulgar error is so universal, I fancy, must be because *Jupiter* is so bright an object, that only a very perfect glass will show it well; whereas *Saturn,* from its distance and dingy colour, will look

* Though many optical writers have offered observations on the requisite diameter, &c. of the pencil of rays, none, I believe, have considered the quality of them. A pencil of rays, of the 50th of an inch diameter, proceeding from an intensely bright object, i. e. a fixed star, will stimulate the optic nerve as much as a pencil of the 20th of an inch diameter, from a body that is badly illuminated.

tolerably well in a telescope, and with a magnifier, whose defects, when applied to *Jupiter*, would be glaring. This is a fact which I have myself discovered, by investigating, with some industry and perseverance, what always appeared an unaccountable paradox to me, that an obscure object would bear a greater power than a bright* one; which were the positive assertions of almost all the opticians and astronomers, &c. I have conversed with on the subject. However, I recommend the reader to be very slow in believing any assertions that are contrary to common sense, which should always be referred to in occult questions, as well as in ordinary ones; and, since miracles are no more, and oracles are obsolete, is the standard by which all marvellous and unaccountable stories should be most scrupulously mea-

* Let it be always remembered, that magnifying power may be applied in proportion to the brightness of the object we are observing: to some of the fixed stars there is hardly any limit to it but the rotatory motion of the earth.

sured, before rational beings suffer them to pass current for facts.

5thly. A positive eye-piece, magnifying 300 times, for close double stars: yet, unless the telescope be an uncommonly fine one, a higher power than 200, instead of rendering the object more distinct, will only help us more easily to discover the defects of our glass.

A circle of single double convex lenses, magnifying 50, 100, 150, 200, 300 times: but so great an impediment is the aberration arising from the sphericity of these, when the highest power is used, that the distinct field of view is reduced to a very small diameter: I therefore applied to Mr. Pierce, to construct for me some compound eye-piece, which should be free from this imperfection; and he has been very successful in contriving three, which, with a telescope of three and a half feet focus, magnify 220, 315, and 425 times; and, after repeated trials and comparisons, appear to answer the purpose extremely well. They are composed of two plano convex (or nearly so) lenses of very short *foci*, placed with their convex sides towards each other. Thus is obtained a very high magnifying power; a distinct, extensive flat field* of view; and, by means of a stop fixed just within the focus, the remaining aberration is entirely removed; while they afford all the brightness of a single lens. Moreover, they are so constructed as to be very easily cleaned. These advantages give them a decided preference to the negative eye-pieces, especially for very high powers, where a large field and as much light as possible are so important. We may use a great magnifier to most

* The apparent field may be easily ascertained by measuring the number of degrees contained in the space taken in by the telescope when directed to the heavens, or to some very distant objects. Thus, as the apparent field of the full moon is about half a degree, if the telescope only take in the moon, we say its field is half a degree; and "cæteris paribus" the field of view becomes smaller as the magnifying power becomes larger. The distance between the two pointers of the Great Bear is nearly five degrees. I mention this, to help the eye to estimate distances in the heavens.

advantage when the object of our observation is near the meridian; and to observe objects in high altitudes, and near the zenith, these eye-pieces are fitted into a frame containing a plane prism, which enables us to observe with as much comfort and convenience of posture as in a Newtonian telescope.

I now take leave of this subject, returning my thanks to the patient and persevering reader, heartily wishing that my remarks may have afforded him some useful information.

FINIS.

J. MOYES, PRINTER,
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