

thought an Attempt to render it more so, would not be altogether useless, or yet unworthy the Notice of the Curious.

VIII. *A new Method of improving and perfecting Catadioptrical Telescopes, by forming the Speculums of Glass instead of Metal.*
By Caleb Smith.

THE Telescope is deservedly reckoned one of the most excellent of all the Inventions of the Moderns; such noble and useful Discoveries have been made by means of this admirable Instrument, and are still to be expected from its further Improvement, that many of the most eminent Mathematicians have employed their utmost Skill and Industry to bring it to Perfection.

The Imperfections of Telescopes are attributed to two Causes; to wit, The Unfitness of the Spherical Figure to which the Glasses are usually ground, and the different Refrangibility of the Rays of Light.

The first of these Defects only, was known to the Writers of Dioptrics, before Sir *Isaac Newton*; for which Reason (as he informs us himself, *Opt. Lect.* 1, 2.) they “ imagined, that Optical Instruments
“ might be brought to any Degree of Perfection,
“ provided they were able to communicate to the
“ Glasses, in grinding, what Geometrical Figure they
“ pleased; to which Purpose various Mechanical
“ Contrivances were thought of, whereby Glasses
“ might be ground into Hyperbolical, or even Para-
“ bolical,

“ bolical, Figures; yet nobody succeeded in the
 “ exact Description of such Figures; and had their
 “ Success been answerable to their Wishes, yet their
 “ Labour would have been lost (continues this
 “ incomparable Mathematician); for the Perfection
 “ of Telescopes is limited, not so much for want of
 “ Glasses truly figured, according to the Prescriptions
 “ of Optic Authors, (which all Men have hitherto
 “ imagined) as because that Light itself is an hetero-
 “ geneous Mixture of differently refrangible Rays;
 “ so that were a Glass so exactly figured as to collect
 “ any one sort of Rays into one Point, it could not
 “ collect those also into the same Point, which
 “ having the same Incidence upon the same Medium,
 “ are apt to suffer a different Refraction” (*Phil.
 Transf.* N^o. 80.). And again, — “ Diversa diver-
 “ forum Radium Refrangibilitas Impedimento est,
 “ quo minus Optica, per Figuras, vel sphaericas, vel
 “ alias, perfici possint; nisi corrigi possint Errores
 “ illinc oriundi, Labor omnis in ceteris corrigendis
 “ imperite collocabitur” (*Principia, &c. Scholium
 ad finem Libri Primi*).

Now, for this principal and last-mentioned Defect,
 no one, that we know of, has proposed any Remedy;
 apprehending, perhaps, the Difficulty of attaining such
 to be insuperable; inasmuch as the great Author of
 this Discovery, himself, had not shewed us any Me-
 thod whereby to correct those Errors which arise
 from this Inequality of Refraction; but rather dis-
 couraged any such Attempts, by declaring, “ that
 “ on this Account he laid aside his Glass-works,”
 (*Phil. Transf.* N^o. 80.) “ and looked upon the
 “ Improvement of Telescopes, of given Lengths,
 “ by

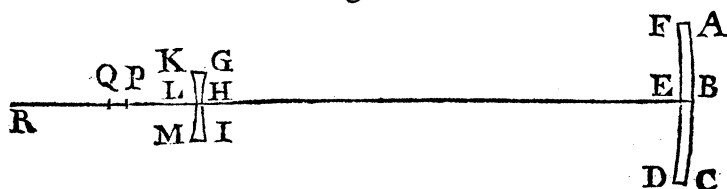
“ by Refraction, as desperate” (*Optics*, 2d Edit. p. 91.).

However, as it has been proved by incontestable Experiments, that this Dissipation of the Rays of Light, from whatever Cause it proceeds, in passing out of one Medium into another, is not accidental and irregular; but that every sort of homogeneous Rays, whether more or less refrangible, considered apart, are refracted according to some constant uniform and certain Law; and as the Removal of so great an Impediment as this of unequal Refraction in the Rays of Light, is of great Importance to the Science of Dioptrics, and absolutely necessary to its further Advancement; we have thought it worthy of a careful Examination, whether, in some Cases at least, it might not be possible for contrary Refractions so to correct each other's Inequalities, as to make their Difference regular; and if this could be conveniently effected, Sir *Isaac Newton* has acknowledged, “ there would be no farther Difficulty” (*Phil. Transf.* No. 88).

Now, upon a due Consideration of this Subject, we have found it possible, by proper Methods and Expedients, to rectify those Errors which proceed from the different Degrees of Refrangibility in different Rays, passing from one Medium into another; admitting only this well-known and established Principle, upon which we ground our Reasoning, *viz.* “ That the Sines of Refraction of Rays differently refrangible, are one to another in a given Proportion, when their Sines of Incidence are equal” (*Optics*, 2d Edit. p. 66.). And our present Design is, to shew what Advantage this will yield towards
im-

improving and perfecting Catadioptrical Telescopes, by making the Speculums of Glass, instead of Metal, in the following Manner :

Fig. 1.



Let the Figure *ABCDEF* represent the Section of a concavo-convex Speculum, whose two Surfaces are Segments of unequal Spheres; call the Radius of the Sphere, to which the concave Side is ground, *a*; and the Radius of the convex Surface, which must be quicksilver'd over, *e*; let *BR* be the Axis of the Speculum, or a Line perpendicular to both the Surfaces; and therein let *P* be the principal Focus, or Point where parallel Rays of the most refrangible Kind are collected, by this Speculum; and *Q* the Focus, or Point of Concourse, of such Rays as are least refrangible; to wit, after they have suffer'd two Refractions, at entering into, and passing out of, the concave Surface *DEF*, and also one Reflection from the convex Surface *ABC*: If the Radius of Concavity be greater than the Radius of Convexity, as we will in the first Place suppose, then *P* will fall nearer the Vertex of the Speculum than the Point *Q*; and the Interval *QP* will be the greatest Aberration, or Error, occasioned by the Separation, or unequal Refraction, of the greatest and least refrangible Rays, after their Emergence from

from the concave Surface FED . Call the common Sine of Incidence, n ; the Sine of Refraction of the least refrangible Rays out of a dense Medium into a rarer, m ; and, of the most refrangible, μ ; then, according to the known and received Laws of Refraction and Reflection, the Focal Distance of the most refrangible Rays, from the Vertex of the Speculum, (neglecting its Thickness, as of little or no Moment in the present Case) will be found

$$= \frac{n a e}{(a - e)^{2\mu + 2ne}} = PB. \quad \text{And the Quantity of the}$$

greatest Aberration, occasioned by the different Refrangibility of the most and least refrangible Rays, PQ , will be to the focal Distance just mentioned, PB , as $(a - e)(\mu - m)$ to $(a - e)m + en$; which Quantity, or Error, thus obtained, (to abbreviate the Calculation) call ε ; and now let it be required to form a Lens, if possible, which, placed at some given Point in the Axis between the Focus of the most refrangible Rays P , and the Vertex of the Speculum (as H), shall refract not only the Rays of the most refrangible Kind tending to the Point P , but also the Rays of the least refrangible Kind tending to Q , in such a Manner, that both Sorts shall concur, after such Refraction, in some other Point of the Axis R ; let HP the given Distance of the Point in the Axis H , from the Focal Point P , be called d ; and then if the Point H has been assumed, so that the said given Quantity, or Distance, d , is greater than $\frac{(\mu - n)\varepsilon}{\mu - m}$, but less than $\frac{m\varepsilon}{\mu - m}$, I say the refracting Superficies GHI , that shall perform what was required, will be part of a concave Sphere, whose

whose Radius is $= \frac{(dd + d\epsilon) \times (\mu - m)}{m\epsilon - (\mu - m)d}$; and HR , the

Distance of the given Point H , from R , the Point to which all the Rays will tend, after Refraction at the said concave Surface, (whose Radius being found, as

above, we call v) will be $= \frac{\mu d v}{(d + v)n - \mu d}$. Lastly,

upon the Point R thus obtained, as a Centre, with an Interval a little less than HR , describe the Circumference KLM , and the Figure $GHIMLK$ will denote the Section of a double concave Lens, which, placed at the given Point in the Axis H , (taken nevertheless within the Limits above-mentioned) will collect all Sorts of Rays proceeding from the Speculum, into one and the same Focus, or Point of the Axis, R , as was required; for the Surface GHI , which first receives those Rays, will refract the most refrangible Sort converging to the Point P , and also the least refrangible converging towards Q , so that both Sorts, after such Refraction, will concur in the Point R ; but the Rays tending to R , 'tis manifest, will suffer no Refraction at their Emergence from the Superficies KLM , because R is the Centre thereof, by Construction; which Point, R , where a perfect Image of an Object infinitely distant will be formed, we call the Focus of the Telescope, to distinguish it from the Point, P , which we have before called the Focus of the Speculum.

In this manner a Lens, (or instead thereof a triangular Prism with two of its Sides ground concave, and the third plain, if that be found as practicable) may be formed and situated, so as to correct the Errors of the Speculum arising from the different

Refrangibility of the Rays of Light. But, in order to render this kind of Telescopes absolutely perfect in their Construction, the Errors also that result from the spherical Figure, must be rectified; and with regard to this, we assert, that it is possible to assume a Point in the Axis, between the Focus of the Speculum and its Vertex, (as we have taken the Point *H*, in the following Example, see Fig. 2. p. 337.) at which, if a refracting Superficies, or Lens, be constituted, according to the Method already delivered, it will not only correct the Errors occasioned by the unequal Refraction of the Rays of Light, but also rectify such as proceed from the spherical Figure of this Speculum, to a much greater Degree of Exactness than is requisite for any Physical Purpose (meaning always the Errors of those Rays which respect the Axis). Now to find or determine this Point, affords a Problem not easy to be solved; and we recommend it, as worthy of the Consideration of Geometricians.

Seeing therefore it is possible, and we believe also practicable, to remedy the Imperfections of this kind of Speculums, (from whatsoever Cause they arise) by the Method we have here proposed; it seems to follow, that Catadioptrical Telescopes may be carried, by this means, to as great a Degree of Perfection, as they are capable of receiving; provided spherical Figures can be truly communicated, with an exquisite Polish, to Glasses of a large Aperture, and a Foil of Quicksilver made also to retain that Figure accurately, and without any Inequality; for the Object-glass or Speculum being rendered perfect, so as that all sorts of Rays, proceeding from one lucid Point in its Axis,

Axis, shall be collected by means of the Lens exactly in another Point, its Aperture may then be extended to its furthest Limits; and that is, till the whole Pupil of the Eye (or the whole Portion of the Eye-glass to be used, when that becomes necessarily less than the Pupil) be filled with Rays proceeding from the Speculum, and flowing from one Point of the Object, but no farther; because this is a Limitation made by Nature in the Structure of the Eye itself: And in Telescopes whose Construction is such as we have now described, the largest Aperture of the Speculum that can ever be of Use, will be to the Diameter of the Pupil of the Eye, very nearly, in a *Ratio* compounded of the *Ratio's* of the Focal Length of the Speculum to the Distance of that Focus from the Lens, and of the Distance of the Lens from the Focus of the Telescope, to Unity: That is, of BP to PH , and of RH to 1; which Proportion holds, whatever be the Charge or the Power of Magnifying.

But if Inquiry be made as to the Charge most proper and convenient, that will be determined best by Experience, in these, as well as in all other sorts of Telescopes: However, on Supposition that one of a given Length has its Aperture and Charge rightly ordered and proportioned, the Rule for preserving the same Degree of Brightness and Distinctness, in all others of a like Construction, will be, to make the Apertures, and magnifying Powers, directly as the Focal Lengths of the Speculums; which shews the vast Advantage and Perfection of these Telescopes, above the common reflecting ones; where, according to Sir *Isaac Newton's* Rule, the Apertures, and

Powers of Magnifying, must be as the Biquadrate Roots of the Cubes of their Lengths (See his *Optics*, 2d Edition, p. 97.).

It is likewise a considerable Advantage in this Construction, that the Reflection from the concave Side of the Speculum will do no sensible Prejudice; because the Image of any Object made thereby, is removed to so vast a Distance from the principal Image, formed by the convex Surface, as to create no manner of Confusion or Disturbance in the Vision; which necessarily happens, in some Degree, from the Vicinity of those Images, when the Glass is ground concave on one Side, and as much convex on the other; according to the Method propounded by Sir *Isaac Newton*, in his most excellent Book of *Optics*.

It may be imagined, perhaps, at first View, that (if our Reasoning is just) the Errors of refracting Telescopes, occasioned by the different Refrangibility of Light, may be corrected by a like Artifice: But the Aberration of the Rays from the principal Focus is there so great, and bears so considerable a Proportion to the Focal Length of the Telescope, that the Error cannot be rectified by the Interposition of any Lens, until the Rays are, by a contrary Refraction, collected again at an infinite Distance, which renders this Expedient quite useless; however, there is no need to despair of accomplishing even this, by other Methods: And, by the way, we may observe, if it were worth while to seek a Remedy for the Errors occasioned by the spherical Figure of the Object-glass only, in Dioptrical Telescopes; that might be obtained by the proper Application of a
suitable

suitable Lens, between the Focus and the Vertex of the Object-glass; which is much more easy and practicable, than the grinding of Glasses to Hyperbolic or Elliptical Figures.

For a further Illustration of what is gone before, it may be proper to exhibit the several Parts and Proportions of a Telescope in Numbers computed according to the Theorems already delivered; and in Practice we judge it will be most convenient, that the *Radii* of the Spheres to which the concave and convex Sides of the Speculum are ground, be nearly in the Ratio of 6 to 5; as in the following Example; where (see Fig. 2. p. 337.)

ABCDEF, represents the great Speculum of Glass, ground concave on one Side, and convex on the other; quicksilver'd over the convex Side, and of an equal Thickness all round its Circumference.

The *Radius* of Concavity $= a = 48$ Inches.

The *Radius* of Convexity $= e = 40$ Inches.

Then putting n , the Sine of Incidence $= 100$; m , the Sign of Refraction of the least refrangible Rays, out of Glass into Air, $= 154$; and μ , the Sine of Refraction of the most refrangible Rays, $= 156$; as Sir *Isaac Newton* found them by Experiments; we shall have,

PB, the Focal Length of the Speculum with regard to the most refrangible Rays $= 18.2926$ †, which will be somewhat increased by the Thickness of the Glass, when that is considerable.

PQ, the greatest Aberration of the Rays, occasioned by their different Degrees of Refrangibility, $= .05594$ †, which Quantity, in Practice, should be

be a very little augmented, rather than otherwise ;
wherefore we put it here $= .056 = e$.

The *Radius* of the concave Surface of the Lens,
turn'd towards the Speculum, *viz.* of *GHI*, $= 0$
 $= 2.8$ Inches.

The *Radius* of the concave Surface of the Lens,
turn'd from the Speculum, *viz.* of *KLM*, $= 6.7$
Inches.

The Thickness of the Lens at the Vertex *LH* $= \frac{1}{10}$
of an Inch.

The Aperture of the Lens must be about $\frac{1}{6}$ of the
Aperture of the Speculum.

HP, the Distance of the Focal Point *P* from the
Point *H*, where the abovesaid Lens is to be placed,
so as to correct the Errors arising from the different
Refrangibility of the Rays, and also the Errors of
the spherical Figure, $= 2.\frac{2}{3}$ Inches.

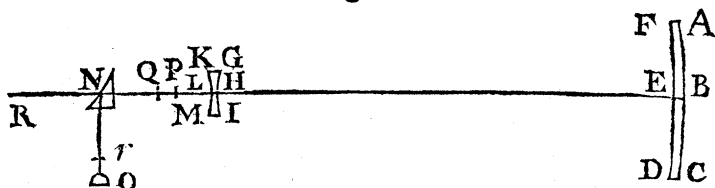
HR, the Distance of *H* the Vertex of the Lens from
R the Focus of the Telescope, $= 6.8$ Inches.

And if we suppose the Diameter of the Pupil of the
Eye to be $\frac{1}{2}$ of an Inch, (though it has not one
certain Measure) then the Diameter of the greatest
Aperture of the Speculum, that can ever be of Use,
will be $6\frac{2}{3}$ Inches, nearly.

The small plano-convex Eye-glass *O* must always
have one common Focus with the Telescope, to
wit, the Point *R* translated to *r*, by Reflection from
the Base of the Prism *N*; for which Reason it must
retain, at all times, an equal and invariable Distance
from the Lens *GHIKLM*; which Distance will be
the Focal Length of the said Eye-Glass more *HR*
($= HN + Nr$) the Distance of the Lens from the
Focus of the Telescope *R*.

The

Fig. 2.



The Form and Position of the Prism *N*, and the Contrivance of the other Parts necessary, will be much the same as in the *Newtonian* Telescope.

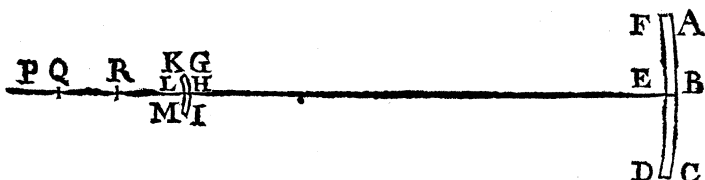
If the Focal Length of the Eye-glass be $\frac{1}{4}$ of an Inch, the Telescope will magnify about 200 times.

This Telescope may be contrived in the *Gregorian* way, by using, instead of a Lens and Prism, a small Speculum spherically concave on one Side, and convex on the other; but we think it not worth while to attempt this Construction, as an Investigation of the Proportion between the two Surfaces necessary, in this small Speculum, to unite the Rays proceeding from the great one, into one Point, would be intricate, and the Practice also very difficult; by reason that a little Inaccuracy will, in this Case, occasion Errors much more considerable than a like Imperfection in the refracting Lens.

We have hitherto supposed the *Radius* of the Concavity greater than that of the Convexity; as being most convenient and useful, on several Accounts, in forming this kind of Telescopes; however, it may be proper to remark, that the same Method may be used for correcting the Errors of the Speculum, when the *Radius* of its Concavity is less than that of the Convexity; only the refracting Superficies of the Lens, placed between its Vertex and Focus, will be

be convex, and not concave, as in the former Case. And there is another thing worthy of Remark, that the Focus, or Point (*P*), where the most refrangible Rays are collected, will fall farther from the Vertex of this Speculum, than the Focus of the least refrangible (*Q*); a Circumstance which never happens by Refraction alone, in Glasses of any Figure whatsoever, or howsoever they be disposed.

Fig. 3.



Now all things being put as before, and making (Fig. 3.) $HQ = d$, I say the convex Superficies *GHI* of a Lens placed at *H*, that shall correct the Errors arising from the different Refrangibility of Rays, in this kind of Speculum, will be part of a Sphere, whose *Radius* is $= \frac{(\mu - m) \times (dd + d\epsilon)}{(\mu - m)d + n\epsilon} = v$. And

HR, the Distance of the Point *R*, where the Rays of all sorts will unite, after this Refraction, from *H* the given Point in the Axis, will be $= \frac{\mu dv}{(\mu - n)d + nv}$; which Point *R* being taken as a Centre, describe thereon the Arch *KLM*, and the Figure *GHIMLK* will represent the Section of a Meniscus-glass, or Lens, which, placed at the Point *H*, assumed between the Vertex and Focus of the Speculum, will collect all sorts of Rays proceeding therefrom into one and the same Point, or Focus, *R*. We might also shew, how

how this Error may be rectified by one or more Glasses, placed in the Axis, at a Distance farther from the Vertex than the Focal Point *P*; but the former Speculum is so much preferable to this, for the constructing of Telescopes, that we think it not worth while to prosecute this Matter farther. To conclude this Essay;

Whoever shall think fit to put the Method here proposed in Execution, we dare venture (from a Trial that has been made) to assure him of Success; provided the same Diligence, Care, and Accuracy, be applied, in choosing, figuring, polishing and foiling, the Glass, that has of late been employed for the forming Speculums of Metal; and let none be discouraged, though the first and second Attempt should fail; for that must be expected, if the ordinary way of grinding and polishing be used: Greater Exactness is here required, than is usually thought sufficient for the Object-glasses of refracting Telescopes: Let it be also considered how many Essays, for a long Term of Years, were made by Mr. *Gregory*, Sir *Isaac Newton*, and others, to reduce their Constructions of the reflecting Telescope into Practice, without answering, in any tolerable Degree, what their Theories promised: The Workmen they employed were chiefly Optical Instrument-makers, and had it been left to such Persons only to perform by themselves, we have reason to think, that it would have been pronounced impracticable to this Day, to make a reflecting Telescope that should equal or excel refracting ones of Ten times its Length; though we now see, that most of these Artificers are

capable of making them to such a Degree of Perfection as was formerly despaired of.

April 5. 1739.

IX. *Extract of a Letter from the Hon^{ble} Henry Temple, Esq; to his Father the Right Hon^{ble} the Lord Viscount Palmerston, concerning an Earthquake at Naples; communicated to the Royal Society by Claudius Amyand, Esq; F.R.S. and Sergeant Surgeon to His MAJESTY.*

Naples, Dec. 12. N. S. 1732.

— **T**HEY tell me, the last Earthquake here has made a great Crack in the Side of Mount *Vesuvius*, above 30 Yards long. I am not sure if this be true or not, though I think it very possible; but I made another Observation upon it, which I think much more extraordinary; which is, that the second Shock, which was a very slight one, had a great Effect upon the Nerves: I and all the Company where I was, as soon as the Shock was over, were seized with a Shaking, just as if we all had the Palsy, our Teeth chattering in our Heads to such a degree, that we could hardly speak; and I find, that half the Town felt the same Effect from it. It would be natural to imagine, that this Shaking was caused by the Fright, but it is easy to prove the contrary; because, in the first place, the first Shock, which was much more terrifying, had not that Effect:

Secondly,