VIII. *An Experiment proposed for determining, by the Aberration of the fixed Stars, whether the Rays of Light, in pervading different Media, change their Velocity according to the Law which results from Sir* Isaac Newton's *Ideas concerning the Cause of Refraction; and for ascertaining their Velocity in every Medium whose refractive Density is known.*

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UPON the supposition that the refraction of light is caused by a certain action of gross and sensible bodies upon it, Sir ISAAC NEWTON has demonstrated, that the sines of incidence and refraction, when the rays pass out of one medium into another of different density, must always be in a constant ratio. This constancy of the ratio of the sines is agreeable to an universal experience, and has been called the law of refraction. Upon the same grounds he has also demonstrated, that the velocity of the rays must be greater in the more refracting medium in the inverse ratio of the sines. Of this property of refraction, however, we have hitherto had no evidence in the way of experiment. The ideas entertained by Sir ISAAC NEWTON, from which this property has been deduced, though they confess their great author, by a most beautiful simplicity, and

and by a very ftriking agreement with fact, have yet been deemed by fome perfons as not perfectly authentic. His contemporary LEIBNITZ and others have attempted demonftrations of the law of refraction from principles very different, and which do not lead to the opinion of the acceleration of light in the more refracting medium. At prefent it is propofed to point out a method of determining experimentally the law of the variation of the velocity of light, according to the change of the medium. If obfervations fhall fhew this law to be agreeable to Sir ISAAC NEWTON's conclufions, we fhall then have a very ftrong additional evidence in favour of his principles. If, contrary to the moft probable iffue of the experiment, fome unfufpected law fhould be difcovered, we muft, according to the rules of induction laid down by that great mafter in philofophy, fo far reftrict our general conclufions, and accommodate our ideas to the real condition of things.

The method of experiment at prefent alluded to is, that of obferving the aberration of the fixed ftars with a telefcope filled with a denfe fluid, fuch as water, or any other equally limpid and of greater refraction, fitted to bring the rays to a focus by the furface of the medium oppofed to the object having a proper degree of convexity. It is enough at this time to fuggeft a general notion of the inftrument, and we now proceed to explain in what manner it can affift us in the prefent inquiry.

Since aberration, taken in its enlarged fenfe, depends on the relative velocities of light and of the telefcope, if the rays were really to move much fafter or much flower in an unufual telefcope of this kind, it feems to follow, that the quantity of aberration given in thefe circumftances, compared with Dr. BRADLEY's angle, would certainly indicate the new rate of velocity. Such an inference would certainly be juft, and it is upon theſe grounds that we propoſe to inquire into the velocity of the rays, as they move forward in denſe media ſo applied to teleſcopes. Granting, however, for the ſake of argument, that light moves down through ſuch an unuſual teleſcope with an increaſed velocity ſuited to the refractive denſity of the medium, it will by no means happen, that the aberration will be changed on that account. This propoſition, which at firſt view may appear paradoxical, and even contradictory to what has been affirmed above, is however not the leſs certain, and may ſerve to ſhew, what caution is ſometimes requiſite in applying general principles to particular caſes: for it ſhall be proved, that the aberration in ſuch a teleſcope will preciſely agree with that of Dr. BRADLEY's only in the caſe of the rays moving ſwifter in the watery medium than in air, in the ratio aſſigned by Sir ISAAC NEWTON, and that this ſameneſs of aberration will itſelf be a proof of light being ſo accelerated within the teleſcope.

In the illuſtrations which follow, the reader is ſuppoſed not to be wholly unaccuſtomed to the diſtinctions betwixt abſolute and relative motion, as this will prevent repetitions and all unneceſſary prolixity.

Let ABC (fig. 1.) be the ſpherical refracting ſurface of ſuch a teleſcope as has been deſcribed, and let the teleſcope be ſuppoſed to be at reſt, or the velocity of light to be infinite with reſpect to that of the earth, and let GBMF be a line drawn from a ſtar at G, in the pole of the ecliptic, through the center M of the refracting ſurface; the image of the ſtar will be formed ſomewhere, as at F, in the line BF; and here the interſection of the croſs wires made uſe of in obſerving muſt be placed. It is evident, that the ſtar will be ſeen in its true direction FG; and we muſt conclude that to be its true direction, becauſe we

know

know that the ray GBF paſſes into the medium without being refracted by it, and BMF would be conſidered as the axis of the teleſcope.

Now let the ſpherical refracting ſurface with its wires, or the unuſual teleſcope be carried laterally with the motion of the earth towards Q. Conceive GBF to be a line not partaking of this lateral motion, which at any particular moment paſſes thro' M, the center of convexity. Along this line ſuppoſe one of many rays to paſs from a ſtar ſituated in the pole of the ecliptic. Then will all the contemporary light of this pencil of parallel rays be made to converge ſo as to meet in a focus ſomewhere in the unrefracted ray BF. Let F therefore be the point in abſolute ſpace where the image of the ſtar is ſo formed. Let the parallel motion of the teleſcope, whoſe refracting ſpherical ſurface is ABC, be in the direction of HF, and take FD to FB as the lateral velocity of the teleſcope to the velocity of light in air, and join BD: then it is manifeſt, that BD will be the poſition of a teleſcope ſuch as Dr. BRADLEY's, when the image of the ſtar is formed in the axis BD, and that IBG, or its equal FBD, will be the angle of greateſt aberration.

Moreover, the velocity of the rays as they proceed to the focus F, after refraction at the ſurface ABC, being ſuppoſed the ſame as in air, it is evident, that the line DML drawn through D, and through the center of convexity M, muſt give the poſition of the axis of this kind of teleſcope, when the image of the ſtar is formed there: for, by hypotheſis, the image is formed in F in abſolute ſpace, and ſince BF is ſuppoſed to be to FD, as the velocity of light within the medium to the lateral velocity of the teleſcope, the point D of the axis DL will arrive at F, when the rays arrive there to form the image. And the obferver not knowing, or at prefent not taking account of, the lateral motion of the telefcope, will fuppofe, that the line LMD joining the image of the ftar and the center of convexity M is the true direction of the ftar; juft as before he concluded, that FMBG would be the direction of the ftar when the lateral motion of the telefcope was fuppofed to be nothing. Hence it is evident, that the interfection of the crofs wires, made ufe of in obferving, muft now be placed at D; or elfe, if thofe be ftill ufed that were before fuppofed to be at F, the refracting furface ABC with the line or axis BF muft revolve about the center M till the vertex B comes to L and the crofs wires F to D.

In like manner, if the velocity of the rays were increafed after refraction at the fpherical furface in any ratio, as that of DF to EF, the refraction continuing the fame, then EMO drawn through the center of convexity would now give the pofition of the axis of the telefcope neceffary for receiving the image formed at F. For the fpace defcribed by the rays in paffing downwards to the focus, in this cafe and the former being equal, the times of their converging at F will be reciprocally as the velocities, or as EF to DF. But, on account of the equable lateral motion of the telefcope, DF and EF will be as the times of the points D and E arriving at F: therefore, in the laft cafe, the interfection of the crofs wires fuppofed at E will meet the image at F, and accordingly the ftar will be feen in the axis.

Fig. 2. From what has been faid it will appear, that if DF be taken to EF, as the fine of incidence to the fine of refraction peculiar to the medium which fills the telefcope; then, from the property of the focus, we fhall have this proportion, *viz.* BF : FM :: DF : EF. Hence the line EMO paffing

through

through M muſt be parallel to DB; but DB, as before, denotes the poſition of Dr. BRADLEY's teleſcope, when the aberration of the ſtar is at its maximum, and EMO parallel to it, denotes the poſition of the water teleſcope, at the ſame time, upon the ſuppoſition that the velocity of the rays without and within be as EF to DF, or inverſely, as the ſines of incidence and refraction peculiar to water. Here then we diſcover what muſt be the law of variation as to the velocity of the rays, provided that the aberration given by ſuch a teleſcope ſhall come out the ſame with that found by Dr. BRADLEY. It is the very ſame which follows from the Newtonian principles: for from the manner of obſerving, the angle of aberration is always determined by the poſition of the teleſcope neceſſary for having the image formed ſomewhere in the axis.

But ſuppoſing that in the courſe of obſerving with ſuch a teleſcope, the aberration ſhould come out different from what has already been aſcertained by Dr. BRADLEY, it may next be enquired, how from the difference given the velocity of light within the teleſcope is to be deduced.

Fig. 3. Imagine then ſuch a teleſcope actually to give FMD as the greateſt angle of aberration, and let this be ſuppoſed greater than that of Dr. BRADLEY's, which, for example, let be FME. From what has been already ſaid, the velocity of light correſponding to this laſt mentioned angle, is deducible from the known refraction of the medium which fills the teleſcope; and, by conſtruction, the velocity correſponding to FMD, the angle given, muſt be to the former inverſely as the tangents of theſe angles. From this conſideration we have the following analogy for finding the velocity correſponding to whatever difference there may be obſerved between the two aberrations at preſent alluded to. The rule in all caſes muſt be;

" as the tangent of the obſerved angle is to the tangent of the " Bradleyan angle, ſo is the velocity of light deducible from " the hypotheſis of the obſerved angle being the ſame with " that of Dr. BRADLEY to the velocity ſought." It has already been ſhewn, how the former of theſe velocities can be univerſally aſcertained, from the known refraction of the medium which is taken to fill the teleſcope, and therefore the laſt term of the above proportion, which is the velocity ſought, is thereby given.

Fig. 2. In a teleſcope of this kind it will not have eſcaped notice, that the ray BF, which, on account of its paſſing to the focus unrefracted, may be called the axis of the pencil, can never be found in the axis of the teleſcope EO, except at the focus F, where D and F meet. That ray, however, OP, parallel to BG, which falls obliquely on the axis of the teleſcope EO, will continue to paſs along it after refraction, and for that reaſon it may be called the relative axis of the pencil.

This will appear, by conſidering that the particle of light, which at any moment is refracted at the vertex O of the ſpherical ſurface, is found by hypotheſis in the axis a ſecond time, when it meets the cotemporary light at the focus. But ſince both the motion of the axis and of the particle is uniform and rectilinear, the former cannot be found in the latter at two different times, without being found in it continually during the whole interval. In like manner, a part of every other ray from the ſtar, which ſucceſſively falls upon the vertex, muſt move relatively along the axis after refraction: and thus a conſtant ſucceſſion of theſe particles conſtitute a viſual refracted ray, whoſe relative path muſt always be in the axis OE.

All that has been ſhewn concerning the teleſcope already conſidered, will receive ſtill further illuſtration, by tracing the motion

motion of this particular refracted ray till it arrives at the focus. This way of viewing the ſubject will alſo render the reaſoning more general, and make it apply to teleſcopes when the denſe fluid within is ſuppoſed to be confined by object-glaſſes of any figure. But in order to this, it will be convenient to premiſe, and briefly to demonſtrate, what ſhall afterwards be referred to by the name of

PROP. A.

Fig. 4. If any very ſmall body or particle of light as it moves uniformly in the abſolute path SB, has paſſed relatively along a part of the line CD, which advances equably and parallel to itſelf in the direction DK; and if at any inſtant the abſolute path of the particle be changed into any other, as BR; I ſay, it will ſtill paſs relatively along the moving line, provided its velocity now be to its former velocity as the ſine of the angle DBF to the ſine of the angle DBR; theſe being the angles which the moving line BD makes with BF and BR the abſolute path or direction of the particle in the two caſes.

The conſtruction of this figure is ſo ſimple, that it is unneceſſary formally to point it out. Since, by hypotheſis, the velocity of the particle along BR is to its former along BF as the ſine FZ to the ſine RT; or, on account of ſimilar triangles, as DF to IR, and, on account of parallels, as DF to DW, it follows, that the time of its deſcribing BR now, is to the time of formerly deſcribing its equal BF, as DW to DF. But the line BD advancing with a uniform motion, the time of its arriving at W is to the time of its arriving at F, alſo as DW to DF. Therefore, when the particle arrives at R, the point D of the moving line will have arrived at W, and WRP will be its poſition. Hence the particle at that moment muſt be found in the interſection R of this line, with its abſolute path BR. In the

 ſame

fame manner it may be fhewn, that at any other time the particle will be found in the interfection: it, therefore, from the time of its direction being changed at B, muft pafs relatively along the moving line as before. By a fmall alteration in the conftruction it may be fhewn, that if the abfolute path had been fo changed at B as to have augmented the angle FBD, ftill the particle would have moved relatively along DB, provided its velocity after had been to its velocity before as the fine of FBD the firft angle to the fine of the increafed angle.

To apply, therefore, this propofition to the prefent inveftigation, let DB be conceived as the axis of a telefcope perpendicular to the fpherical furface of a refracting medium which accompanies it in its lateral motion, SB the abfolute path of a particle of light which had paffed relatively along DB produced, till its arrival at B, and BR its abfolute path within the medium of the telefcope. Then it is evident, that FBD, or its equal CBS, will be univerfally the angle of incidence, and RBD the angle of refraction. Hence, by prop. A. that ray of the parallel pencil which is refracted at O, the vertex of the fpherical furface in fig. 2. muft ftill pafs relatively along the axis, provided the velocity within the telefcope be to its former in air, as the fine of incidence to the fine of refraction. But the image of the ftar being produced by the meeting of all the contemporary light, will confequently be found in the axis, which, by hypothefis, deviates from the true place of the ftar by the fame quantity as Dr. BRADLEY's angle; fo that in this way of confidering the matter, the fame thing refults which was formerly fhewn in regard to a telefcope fo conftructed.

By prop. A. it is alfo manifeft, that whatever number of refractions that ray which falls upon the extremity of the axis fuffers in pervading object-glaffes of any figure, or even denfe

media.

media beyond the object-glaſs if bounded by tranſparent planes to which the axis produced is perpendicular, yet if the velocities and refractions ſo correſpond, ſtill the ray in queſtion will paſs relatively along the axis till it meet the reſt at the focus: for here the refracted ray in the firſt medium becomes the incident ray in relation to its path in the ſecond, and this in its turn becomes an incident ray in relation to its path in the third medium, &c. and therefore by the prop. A. can never deviate from the moving axis whatever be the refractive denſity of the media, or however theſe are diſpoſed in the order of ſucceſſion. And ſince, by Sir ISAAC NEWTON's theorem, the ratio of the ſine of incidence to the ſine of refraction in the paſſage of a ray out of one medium into another, is compounded of the ratio which the former has to the latter in the paſſage of that ray out of the firſt medium into any third, and of the ratio of the former to the latter in the paſſage of the ſame ray out of the third medium into the ſecond, &c. it follows, that if the velocities be related to the degree of refraction as before mentioned, the ray in the laſt denſe medium will, notwithſtanding any number of previous refractions by glaſſes, &c. have the ſame final velocity that would have been acquired on its paſſing immediately out of air into that medium. This being the caſe, it appears, that though the intervention of an object-glaſs may ſhorten the focal diſtance of ſuch a teleſcope, yet it will not diſplace the image nor alter the rule of inferring the final velocity of the rays in the denſe medium from the aberration given; at leaſt when this is ſuppoſed to be the ſame with Dr. BRADLEY's.

Fig. 3. But further, if the aberration of ſuch a teleſcope ſhould differ from the Bradleyan one, and give, for example, the angle OMB, ſtill the ray PO, which falls on O the vertex, muſt be conſidered as an incident ray, which, after refraction,

 paſſes

paffes along the axis. By prop. A. therefore, the velocity of the ray, whatever this may be after refraction, muft be to that velocity by which it would have moved relatively in the axis, fo inclined to its path, previous to the refraction, inverfely as the fines of incidence and refraction. Now this being duly confidered, it will be found that the velocity within the medium, correfponding to this fuppofed aberration, or the abfolute velocity within the medium, muft be to the velocity within the medium correfponding to the Bradleyan aberration, inverfely as the tangents of thefe two angles: for let V and v exprefs the velocities before and after refraction correfponding to the Bradleyan angle, and X and x the velocities before and after correfponding to the fuppofed uncommon angle, x being the actual velocity after refraction; then, becaufe by prop. A. the antecedent is to the confequent, in both cafes, in the fame ratio, *viz.* as the fine of refraction to the fine of incidence, it will be $V : v :: X : x$, and therefore $V : X :: v : x$. But from the nature of the aberration V muft be to X (this fuppofititious velocity before incidence) inverfely as the tangents of the angles of the two aberrations. This therefore muft be the ratio of v to x. But v is given as before fhewn; therefore x the velocity within the medium correfponding to the fuppofed obferved aberration is alfo given, and by the fame rule as was found formerly in the cafe of the firft telefcope.

What has been at prefent advanced is unconnected with any hypothetical notions concerning the rays or the caufe of refraction. Light has been confidered only as fomething which moves uniformly from one place to another, and which is always refracted according to a known law. The firft of thefe properties has been put beyond all doubt by the obfervations of Dr. BRADLEY and Mr. MOLYNEUX; and it is has been long known that the laft is quite agreeable to experience.

It has indeed always been taken for granted, that the velocity of the ray which paſſes through the center of convexity, repreſents the common velocity of all the contemporary light of the converging pencil. This may perhaps be reckoned a circumſtance of which we have no proof. But it muſt be conſidered, that if the rays of light, after being variouſly bent towards the focus, were no longer to move with the ſame common velocity, the image formed at the focus of Dr. BRADLEY's teleſcope, would be elongated in the direction of the aberration. Thoſe who have attended to this ſubject will be at no loſs in diſcerning the reaſon of this. The extent of that lengthened image would depend upon the difference of velocity which would obtain among the converging rays, and would probably increaſe according to the largeneſs of the aperture of the object-glaſs. But ſuch a phenomenon being contrary to experience, it follows, that the unequal bending of the rays does not give them unequal velocities, whilſt moving in the ſame medium. This is another property with regard to the motion of light which may be conſidered as proved experimentally by Dr. BRADLEY's obſervations, and which doubtleſs would have occurred to him if he had had occaſion to trace the refraction of a pencil of parallel rays at the object-glaſs of his teleſcope.

To conclude: in bringing this queſtion concerning the velocity of light to the iſſue of an experiment, that fluid would doubtleſs be moſt proper for the teleſcope which abſorbs the feweſt rays, and poſſeſſes the greateſt refractive denſity, and which at the ſame time is not liable to generate air-bubbles. To compenſate for the unavoidable loſs of light, which by Mr. CANTON and Dr. PRIESTLEY's experiments is found to be conſiderable in ſuch caſes, it perhaps may be neceſſary to uſe an

achromatic

achromatic object-glaſs for the ſake of a large aperture, and of ſuch a figure as to ſhorten the focal diſtance as much as the obſervations of ſuch a ſmall angle can admit of. Some contrivance too will be requiſite to keep the whole ſpace between the object-glaſs and the eye-glaſs always full, notwithſtanding the expanſions and contractions of the confined fluid by heat and cold, or its waſte by evaporation.

It might prove a very conſiderable abridgement of the neceſſary apparatus, if this kind of teleſcope could be connected with the common teleſcope of a mural quadrant, or zenith ſector, and their axes made perfectly parallel by previous obſervations of a proper terreſtrial object. But as there would be ſome room for apprehending that the exact adjuſtment of the axes might be affected in raiſing the teleſcopes afterwards for celeſtial obſervations, this might be examined into by directing them to ſome ſtar ſituated in, or very near, the ecliptic, and taking its meridian altitudes at a time of the year when it is in quadrature with the ſun, in which caſe it would have no aberration. But either in this way, or with two ſeparate inſtruments ,the experiment might be made in a few nights, by taking the zenith diſtance of a proper ſtar, the plane of the inſtruments being alternately turned different ways in obſerving, to get the true zenith diſtance independent of the error of the line of collimation; or the meridian altitude of the pole ſtar may be obſerved in December above and below the pole, which will give the apparent diſtance of the ſtar from the pole at that time as affected by aberration. The error of the line of collimation would not affect the reſult in this way, being the ſame in the obſervation both above and below the pole.

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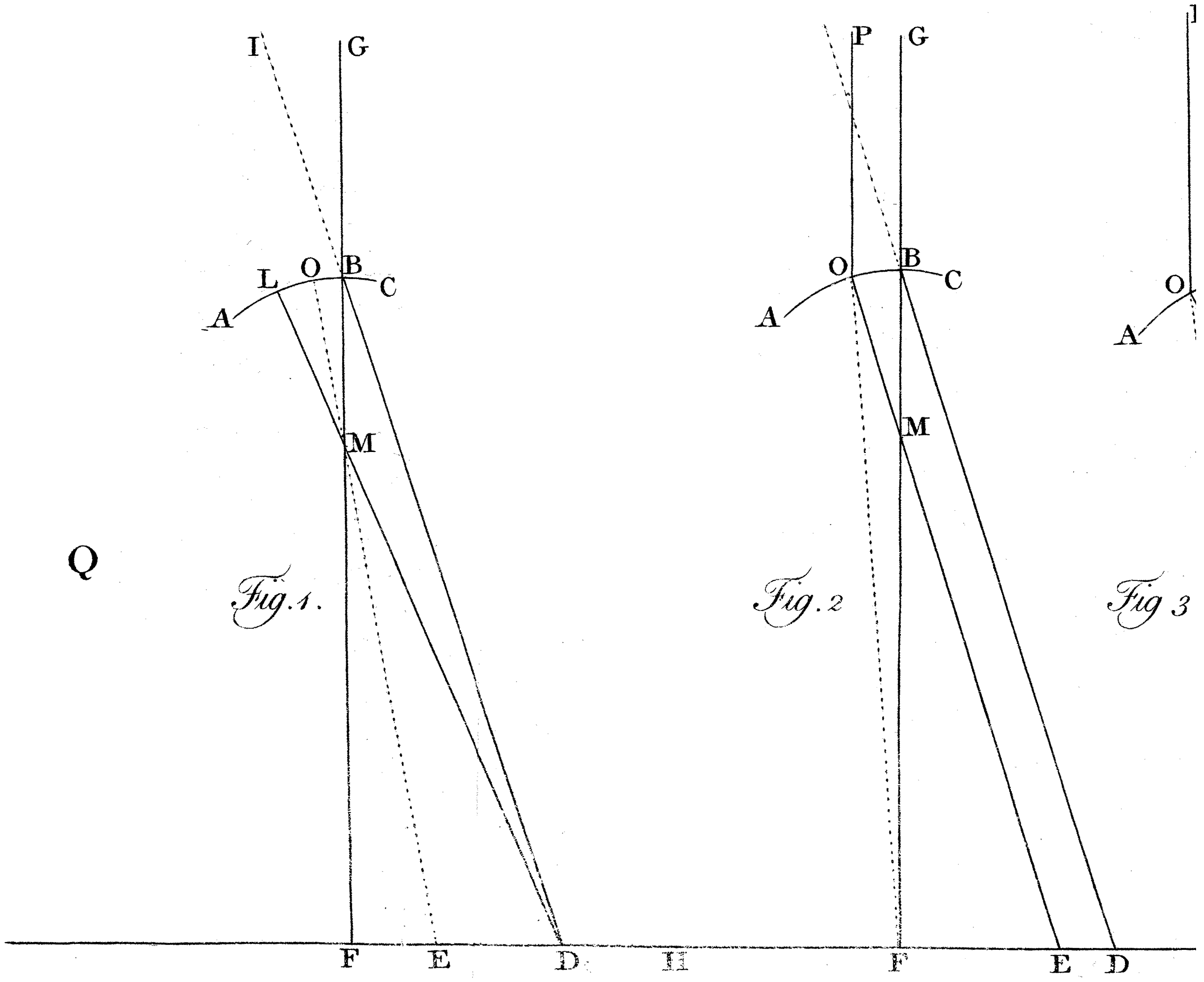


Fig. 1.

Fig. 2

Fig 3

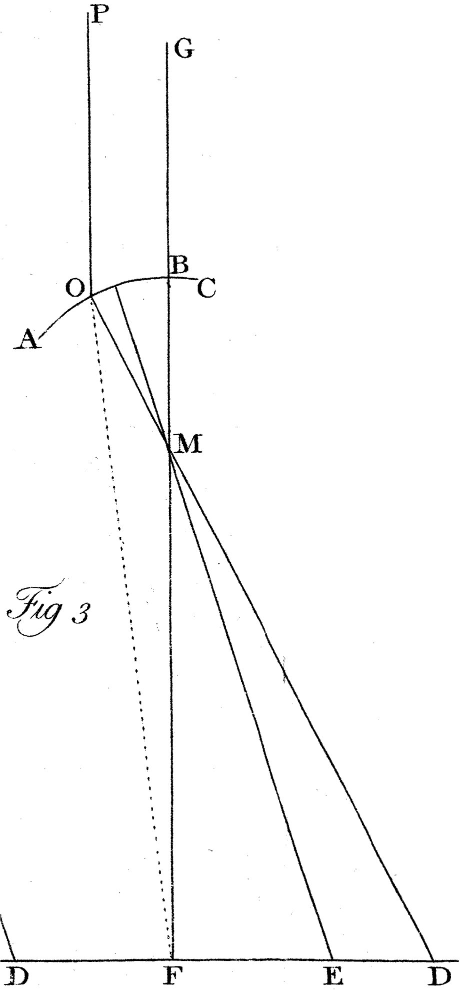


Fig 3

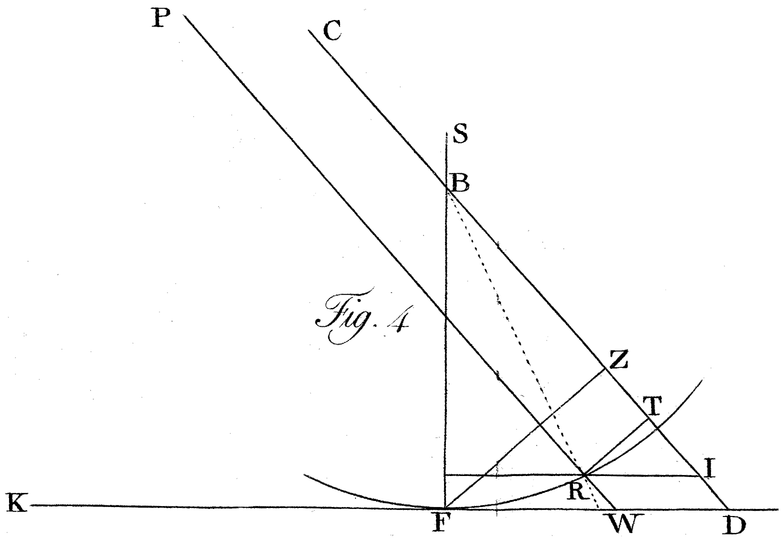
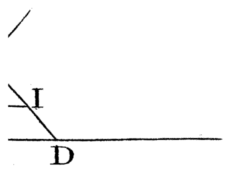


Fig. 4



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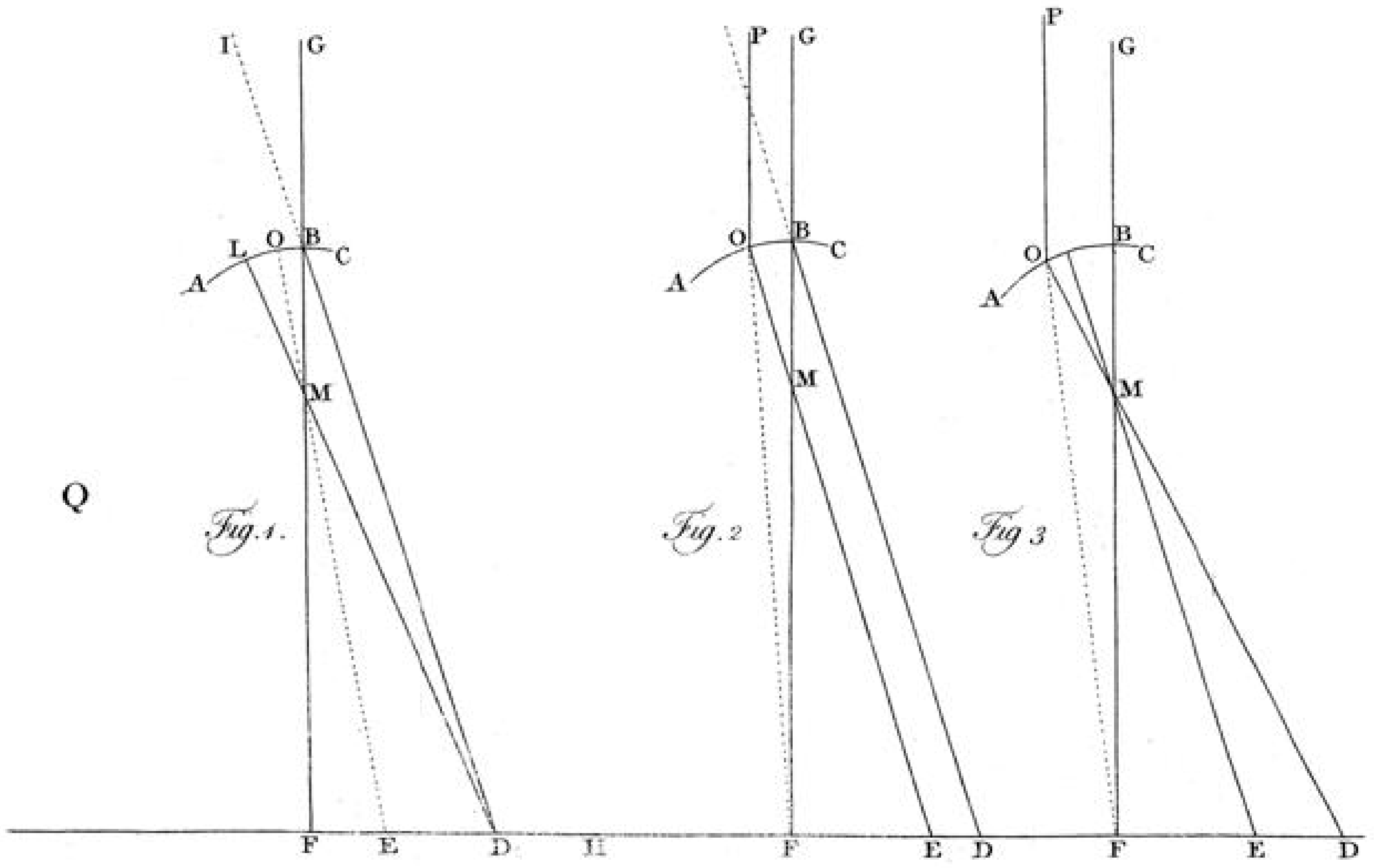

Fig. 1. Fig. 2 Fig 3

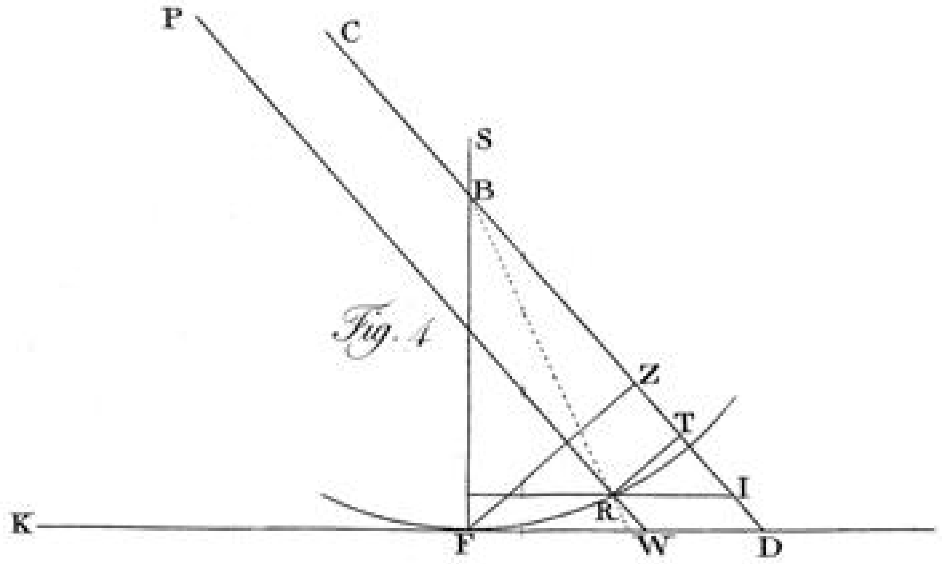

Fig. 4