Mathematical elements of natural philosophy, confirm'd by experiments; or, an introduction to Sir Isaac Newton's philosophy

Mathematical

ELEMENTS

OF

Natural Philoſophy,

Confirm'd by EXPERIMENTS;

OR, AN

INTRODUCTION

TO

Sir ISAAC NEWTON's Philoſophy.

VOL. II.

Written in LATIN

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Tranſlated into ENGLISH

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MDCCXXXI.

TO THE

Moſt Noble and Right Honourable

THOMAS Lord *PARKER*,

Baron of *Macclesfield*,

Lord HIGH CHANCELLOR of *Great Britain*, &c.

My LORD,

IF whilſt Your Lordſhip's Hours are taken up with an Employment of the greateſt Fatigue as well as the higheſt Honour, there can be any Time allowed for Recreation, your

Lordſhip makes that your Diverſion, which few can attain to without painful Application and laborious Study. To become a ſkilful Mathematician and a ſound Philoſopher, and at the ſame Time ſhine in other Parts of Learning, requires a great and extenſive Genius: But to lead a Life of Buſineſs, and be eminent in the Law, where Reputation is only got by conſtant Practice, as well as Brightneſs of Parts; and yet, in thoſe few Minutes of Leiſure that are allowed to breathe in, and are, as it were, ſtolen from Sleep, to play with all the Intricacies of Lines and Numbers, to view and underſtand the Syſtem of the World, the Proportion, Symmetry, and Harmony of its ſeveral Parts; to be acquainted with all the Experiments of Conſequence that have been made, and be able to contrive new ones as uſeful as inſtructive; was only reſerved

ſerved to Men of uncommon Capacities, and to none in ſo eminent a Degree as to your Lordſhip.

THE Honour I have had of being admitted into your Lordſhip's Converſation, has given me an Opportunity to know which of the Mathematical Sciences are chiefly lik'd by you: And as *Aſtronomy* and *Optics* ſeem to have the Preference, I thought this Tranſlation of Dr. 'S GRAVESANDE'S Second Volume would not be unacceptable.

HERE you have the Principles of the common Optics reduced into a ſmall Compaſs, and confirmed by new Experiments of the Author's own Invention: A fine Application of the Action of Electric Bodies to diſcover the Nature of Fire: And Sir ISAAC NEWTON'S Doctrine of *Light* and *Colours* proved by the moſt conſiderable of his Experiments, which Dr. *'s Graveſande* performs with an Apparatus very ingeniouſly contrived, and nicely expreſſed by curious Figures. The laſt Part of this Volume not only leads a Beginner gradually on from the moſt ſimple to underſtand the moſt difficult *Phænomena* of *Aſtronomy*; but gives ſuch a phyſical Account of the Celeſtial Motions as muſt be fully ſatisfactory to the beſt Geometricians. There your Lordſhip will ſee with Pleaſure, that there are Profeſſors abroad who underſtand the PRINCIPIA; and have ſo juſt a Value for that excellent Book, as to take Pains to propagate the wonderful Truths which it demonſtrates, ſo as to make them plain to ſuch Philoſophers as are not yet able to go through all the difficult Propoſitions from whence they are deduced. But I will detain your Lordſhip

ſhip no longer, either from the important Buſineſs of your Station, or the pleaſing Truths of the Author, than while I beg Leave to ſubſcribe myſelf,

My LORD,

Your Lordſhip's

Moſt Obliged,

Moſt Obedient, and

Moſt Humble Servant,

J. T. DESAGULIERS.

The AUTHOR's

PREFACE.

I Spoke of the Method of Reaſoning to be uſed in Natural Philoſophy, in the firſt Chapter of the firſt Volume, and in the Preface endeavoured to vindicate the Goodneſs of the Method I have followed. There are ſeveral remarkable Specimens of this Method in the preſent Volume, which evidently ſhew Sir ISAAC NEWTON*'s great Superiority of Genius above all other Philoſophers.*

Before him, Naturaliſts were in the Dark in numberleſs Things relating to Light, and eſpecially to Colours. For Inſtance, whoever ſuſpected before, that the Opacity of Bodies depended upon their Interſtices, ſo that a Body becomes tranſparent, when theſe Interſtices are filled with a Medium of the ſame Denſity as the Particles of the Body itſelf.

His

His Account of the Planetary Syſtem, and particularly of the Motion of the Moon, is not leſs worthy of eternal Praiſes, being likely to carry Aſtronomy to a greater Pitch of Perfection than the niceſt Obſervations alone could poſſibly do. For if a Man is acquainted with the Laws that govern the Syſtem of the World, he will be able to make a better Uſe of his Obſervations, and to compute the Motions of the heavenly Bodies more exactly than if he had nothing but Obſervations to direct him.

It was my Deſign in theſe two Books, to give my Reader a general Notion of the chief Things diſcovered by Sir ISAAC NEWTON *in Natural Philoſophy, and thereby to encourage him to the Study of the more abſtruſe, and, at the ſame Time, more ſublime Parts of Mathematics, after he has learned the firſt Principles of Geometry, to fit him for the reading of theſe plain Elements. He will, as it were, go to the Fountain Head, when he reads the Writings of our great Philoſopher, which will reveal ſuch Things to him, as were unknown to the profoundeſt Philoſophers before him; and which, though publiſhed, are ſtill a Secret to all but thorough Mathematicians.*

I have only a few Words more to ſay to the Engliſh Reader, concerning the two Engliſh Tranſlations of this Work.

As tedious and diſtaſteful as an Author's Complaints generally prove, they cannot, however, be diſallowed, when they are grounded upon ſuch an Injury done to the Author, as it is his Reader's Intereſt to be informed of.

Soon after the Publication of the firſt Volume of theſe Elements, *it was tranſlated into* Engliſh, *and printed* *ed in* London, *with the Name of a Celebrated Professor of Mathematics, eminent for his Writings, inscribed on the Title Page, as if he had looked over and corrected this Translation. But whoever examines any one Page in the Book, will immediately discover the Wrong done to that Learned Gentleman, and the Abuse made of his Name; since he will every where perceive manifest Signs of the Translator's Ignorance of the very Principles of Physics and Mathematics, not to mention his Negligence with regard to the correcting of the Additions at the End of the Book, to the Numbers in the Margin, and the Distinction of the Propositions.*

Dr. Desaguliers, *whose Knowledge of Philosophy, and Skill in making Experiments, are so well known, began to translate the same Work about the same Time as the other, or rather before. But this obliging him to make more than ordinary Haste, he could not himself wholly avoid the usual Consequences of too much Precipitation,* &c.

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Mathe-

Mathematical Elements OF *Natural Philoſophy*, Confirm'd by EXPERIMENTS.

Vol. II. Book III.

Part I. *Concerning FIRE.*

CHAP. I.

Of the Properties of Fire in general.

THO we know ſeveral Properties of Fire, yet we are ignorant of a great many things relating to it.

I ſhall not invent Hypotheſes, but reaſon from Experiments, and leave untouched what is not fully known.

Fire eaſily penetrates thro' all Bodies, however denſe 544
and hard they are. For we have never yet known

any Body, that by the Application of Fire has not been heated in all its Points; that is, in every Part.

545 *Fire moves very ſwiftly*, as appears from Aſtronomical Obſervations.

546 *Fire unites itſelf to Bodies*; for when they are brought to the Fire, they grow hot, as we ſaid
547 before; *and in that Caſe they expand or ſwell:* Which Expanſion is alſo obſerved in ſuch Bodies,
548 whoſe Parts do not cohere, in which Caſe *they alſo acquire a great Degree of Elaſticity*, as is obſerved in Air and Vapours.

549 That *Fire is attracted by Bodies at a certain Diſtance from them*, will be ſhewn in the following
* 611 Part of this Book. *

If any Bodies are violently moved againſt one another, they will grow hot by ſuch a Friction, and that to a great Degree; which ſhews that
550 *all Bodies contain Fire in them:* for, by rubbing, Fire may be put in Motion, and ſeparated from Body, but can by no means be generated that way.

Having laid down theſe general Heads, we muſt examine ſeveral Things more particularly.

CHAP. II.

That Fire adherers to Bodies, and is contain'd in them; where we ſhall alſo ſpeak of Electricity.

AS we have already ſaid, one may prove that Fire is contain'd in all Bodies, becauſe there are no Bodies but what may be heat-
* 550 ed by Attrition; * and that it coheres firmly with the Parts of Bodies, appears in Smoke and Vapours: for Smoke and Vapours are made up of Parts ſeparated from Bodies, and agitated (ſome-

times very violently) by the Fire that is join'd with them.

There are, besides, several remarkable Phænomena arising from Fire, contained in Bodies, some of which we shall here mention; amongst which, there are such as relate very much to Electricity, for which Reason, we must also treat of the Phænomena of Electricity.

Definition.

Electricity *is that Property of Bodies, by which* 551
(when they are heated by Attrition) they attract, and repel lighter Bodies at a sensible Distance.

Experiment 1.] Take two Pieces of Rock 552
Crystal and rub them together, and immediately they will appear luminous all over, tho' they do not acquire any sensible Heat by that Attrition. Light (as well as Heat) is a Proof that there is Fire in a Body. The greatest Light is in those Points, where the Bodies touch one another.

Experiment 2.] Take a Glass Tube 15 or 18 553
Inches long, and one Inch in Diameter, and rub it with a Linnen or Woollen Cloth, and it will emit Light in the Dark.

Experiment 3. *Plate* I. *Fig.* 1.] This Tube, 554
heated by rubbing, has a very sensible Electricity; for if light Bodies, such as Pieces of leaf Gold, and Soot, be laid upon a Plane, and the Tube be brought near them, they will be put in Motion, attracted, repelled, and driven several Ways by the Tube. The Tube acts at different Distances, according to the different State of the Air; sometimes at the Distance of one Foot; when the Air is full of Vapours the Effect is diminished.

555 There is one Thing remarkable, and very hard to explain in this Experiment, concerning the Direction of the Attrition; when you rub the Tube, one End of it his held in one Hand, whilſt it is rubb'd with the other; which, if it be done from the Hand that holds towards the other End of the Tube, the Effect will not be ſenſible; but if you rub from the free End of the Tube towards the End held in the Hand, the contrary will happen. And this happens indifferently, whether you hold the open or the ſhut End of the Tube in your Hand.

556 In the following Experiments (*Plate* I. *Fig.* 2.) Glaſs Globes are ſwiftly whirl'd about; to perform which, there muſt be a cylindric Neck at each End of every Globe; but only one of theſe Necks is to be open, and both are to have Braſs Ferrels, ſuch as are repreſented at G; a Cock E muſt be ſcrew'd on to the Ferrel at the open Neck, and the oppoſite Braſs Ferrel muſt have a little Wheel *r* of about an Inch and a half Diameter, join'd to it, with a ſmall Braſs Axis ſtanding out: There is juſt ſuch another Piece of Braſs ſcrew'd on to the Cock, ſo that it may be taken on and off at Pleaſure. Theſe Axes go about a Quarter of an Inch into the Pillars S S, that ſupport the Globe, and are Centers for it to whirl upon when it turns about its Axis.

The Pillars S S ſtand upon a ſtrong horizontal Board of about an Inch and a half thick, framed into three other Boards, as may be ſeen in the Figure: In that which ſtands foreright, there is an Hole *f* that you may come at the lower Part of the Pillar, to make it faſt with a Nut or Screw. The other Pillar S is likewiſe faſten'd by a Screw applied under the horizontal Board, and moved forwards and backwards in a Slit of 4 or 5 Inches long, before it be made faſt, in order to take the

Glaſs Globes in and out, and to take in ſuch as are larger or ſmaller than others, according to the different Experiments to be made.

There is a great Wheel R which is turn'd round by means of the Handle M, and thereby gives a very ſwift whirling Motion to the Globe G.

In the Side of the upper Board, there is a Slit, along which the Pully *t* may be moved, by means of the Screw *c*, in order to keep ſtretch'd the Rope that goes round the Wheels R and *r*.

Experiment 4 & 5. *Plate* II. *Fig.* 1.] Apply a 557
Glaſs Globe of about 8 or 9 Inches Diameter, to the Machine above-mention'd, and let it be briskly whirl'd in a dark Place, the Hand all the while being held againſt it, to give it Attrition.

If the Globe be exhauſted of its Air, it will appear all luminous within, but moſtly ſo where the Hand touches the Glaſs.

But if the Globe has Air in it, and being 558
whirl'd in the ſame Manner, the Hand be applied to it, no Light appears, either in the inner or outer Surface of the Glaſs; but Bodies at a ſmall Diſtance from the Glaſs (as for Example, at a Quarter of an Inch, or nearer) become luminous; and ſo only thoſe Parts of the Hand held againſt the Glaſs, which terminate, or rather environ the Parts that immediately touch the Globe, are luminous.

Experiment 6. *Plate* I. *Fig.* 2.] Take the Globe 559
made uſe of in the foregoing Experiments, and put it in between the Pillars, to whirl it as before: Then take a Braſs Wire *a b d*, circularly bent in the upper Part, and fix it ſo that its curve Part may be about 4 Inches off of the Globe, with ſmall Threads hanging from it, which being extended towards the Center of the Globe

come within a quarter of an Inch of the Surface of the Globe.

Whirl the Globe and apply the Hand, and immediately the Threads will be moved irregularly by the Agitation of the Air; but when the Glaſs is heated by the Attrition, all the Threads are directed towards the Center of the Globe, as may be ſeen in the Figure: And if the Hand be applied a little on one Side, or nearer the Pole of the Globe, the Threads will be directed towards that Point of the Axis which is under the Hand.

560 If the Air be drawn out of the Globe, this whole Effect ceaſes.

561 *Experiment* 7. *Plate* I. *Fig.* 3.] Take another Globe like the former; only differing in this, that the open'd Neck muſt have a larger Opening than that of the Globe G, ſo that you may put into it a round flat Piece of Wood *o*, that has a Braſs Wire for its Axis. In order to fix this Piece of Wood in the Middle of the Globe, its Axis muſt be firmly ſcrew'd to the Middle of the Cover that is join'd to the open Neck of the Globe at *h*: and the Cock E is alſo join'd to the Middle of the Cover on the outſide.

To the wooden Circle ſmall Threads are faſten'd, which, being extended, almoſt touch the inner Surface of the Globe.

Turn the great Wheel ſo as to whirl the Globe, and rub it till it becomes warm, as was done in the former Experiments; if you ceaſe to whirl the Globe, and the Hand be taken off, the Threads will immediately ſtretch themſelves out like Radii from the Center towards the Surface of the Globe, yet they hardly remain one Moment at reſt; for tho the Globe be exactly ſhut, theſe Threads will be put in Motion, as appears

appears by blowing againſt the Globe, tho you ſtand two Foot off, or farther, from the Globe. If you bring your Finger towards the Globe, tho you do not touch it, the Threads next to it will be attracted by the Finger, and directed towards it; nay, and ſometimes they fly from it. If you apply the whole Hand to the Globe, the Threads will be mov'd violently and irregularly.

And if all the Air be drawn out, as in the 562
foregoing Experiment, the whole Effect ceaſes; and the Threads (both before and after the Friction) only hang down by their Gravity.

If we attend to all the foregoing Experiments, the following Concluſions ſeem to be naturally deduced from them, which we do not give out as certain, but very probable; for we muſt always diſtinguiſh Certainty from Probability.

That Glaſs contains in it, and has, about its Sur- 563
face, a certain Atmoſphere, which is excited by Friction, * *and put into a vibratory Motion*; for it at- * 554,
tracts and repels light Bodies; * the ſmalleſt Parts 559, 561.
of the Glaſs are agitated by the Attrition, and by * 554.
reaſon of their Elaſticity, their Motion is vibratory, which is communicated to the Atmoſphere above-mention'd; and therefore that Atmoſphere exerts its Action the farther, the greater Agitation the Parts of the Glaſs receive when a greater Attrition is given to the Glaſs.

The Fire, contained in the Glaſs, is expell'd by 564
the Action of this Atmoſphere; at leaſt it is mov'd with it. For when light Bodies are put in Motion at a Diſtance from the Glaſs the Bodies alſo * 559,
become lucid at a Diſtance. * 558.

It is plain, that *this Atmoſphere and Fire is more* 565
eaſily mov'd in a Place void of Air: For if the Globe be exhauſted of its Air, there can be perceiv'd no Light, nor any Effect of Electricity on the outſide of the Globe *, but the inſide of the * 557,

 Globe 560.

Globe appears very luminous, and this Fire is perceiv'd to be in greater Quantity in this Experiment, than in that immediately after men-
* 558 tion'd *.

But the Action of the Electricity does alſo
* 562 ceaſe on the Inſide when the Air is drawn out *, which ſeems to overthrow what we ſaid of the more caſy Motion of the Atmoſphere of Glaſs *in Vacuo*: But yet it is not probable that it ſhou'd move no whither in this Caſe. On the contrary, it ſeems to go the ſame Way as the Fire, and to move that way where there is the leaſt Reſiſtance; and that the ceaſing of the Action of Electricity is to be attributed to the Want of Air,
566 by means of which, *the Threads are moved by the*
* 605 *Atmoſphere*; as we ſhall hereafter ſhew *; and the
* 607 Fire, which freely penetrates all Bodies, acts upon them violently *by means of the Air* or Vapour.

But laying aſide Conjectures, tho they have a great many Experiments for their Foundation, let us return to other Things relating to Fire; as ſeveral Experiments are to be made *in Vacuo*, we muſt deſcribe the following *Machine* contriv'd to give Attrition to Bodies *in Vacuo*.

567 *Plate* II. *Fig*. 2.] Let M be the Air-Pump de-
* 437 ſcrib'd before *, L L the Braſs Plate of the Pump on which the Glaſs Receivers are ſet; on each Side of the Plate there is a wooden Pillar, A D, A D, which Pillars ſtand on the Board that carries the Air-Pump Plate, having their Baſe upon it, and a Part below the Baſe, and going thro' the Board with an Hole in it, to receive two croſs Pieces of Wood or Wedges, that make them faſt during the Experiment, but ſo that the ſaid Pillars may be taken away afterwards.

The Glaſs Receiver, in which the Experiments are to be made, is about 9 Inches high, and 6 in

in Diameter, with a Cover * that has annex'd to * 440
it a Box or Collar full of oil'd Leathers thro' which a Braſs Axis paſſes; and leſt in the whirling round of the Axis the lower End ſhou'd move, Part of the Box is made ſquare, ſo as exactly to fit a ſquare Hole in the Horizontal Board E E that preſſes on the Cover, and is made faſt by bringing down the Nuts or Screws B B at each End, without bearing upon the Shoulders of the Pillars.

Towards the upper Part of the Pillars, there is a narrower horizontal Board F F preſs'd down alſo and faſtened with Nuts, which has fix'd to it, on the under Side, a Piece of Braſs *g*, with an Hole in it for the upper End of the above-mentioned Axis to turn in, whilſt the biggeſt Part of this Axis, being in the middle of the Glaſs, has an outſide Screw upon it, with the two Wing-Nuts *d*, *d*, moveable upon it, in order to faſten ſeveral Bodies upon the Axis.

The lower End of the Axis turns in the Hole *c*. The Braſs Spring *f f* is joined to the Piece *c*, which ſcrews it down to the Air-Pump Plate at the Hole where the Air is drawn out; but there muſt always be made a ſmall Hole or Paſſage in the Piece *c*, for the Air to be drawn out at.

Having exhauſted the Receiver, the Axis above-mentioned (by reaſon of the oiled Leathers in the Collar P) may be turned round without admitting any Air; but to give it a quick Motion, there is a little Braſs Wheel *r* of about 2 Inches Diameter, with Points in its Groove, that the Rope, that turns it round, may not ſlip.

The great Wheel R, of about 3 Foot Diameter with its Frame, is brought up cloſe to the Air-Pump, and made faſt to its Foot by a Screw.

The Rope, that goes about the leſſer Wheel *r*, is brought down over Pullies obliquely placed

in

in the upper Part of the Pillars C, C, and being over them, comes down to the great Wheel which it goes round; so that by turning the vertical Wheel R, the Brass Axis, above described, is carried round very swiftly, whereby a Motion is communicated to Bodies *in Vacuo* for several Experiments.

586 *Experiment* 8.] Take a Glass Globe of three Inches Diameter, or of two Inches and a half Diameter, with an Hole on each Side, where it may also have cylindric Necks. The Axis abovemention'd must go thro' those Holes, in order to give the Globe a whirling Motion; Pieces of Cork must be put on each Side of the Globe to cover its Holes, and made fast with the Nuts *d*, *d*, in the Manner that they appear in the Figure, to hold fast together the Plates or little Wheels, thro' which the Axis goes.

This Globe, thus fix'd, will be swiftly mov'd *in Vacuo* with its Axis, by turning the Wheel R: To cause Attrition, a Piece of Woollen Cloth must be tied on to each Side of the Brass Spring *f*, *f*, which by its Elasticity presses the Globe hard on each Side.

Making the Experiment in the dark, the Globe will appear luminous; and if the Motion be continued till the Globe grows hot by the Attrition, the Light will indeed be increased, but will appear fix'd in the Places where the Attrition is made.

569 It follows from that Experiment, that *the Fire, contained in Glass, does not want Air to make it visible*, for it grows hot, and shines when both the internal and external Air are taken out.

570 *Experiment* 9.] Take a round Piece of Wood of 2, or 2 $\frac{1}{2}$ Inches Diameter, and about $\frac{1}{2}$ an Inch

Inch thick, and let it have several Hollows cut in its Edge, that it may be encompass'd round with Beads of Plaister, which may be made fast to it with Threads going thro' them. Let this Piece of Wood, thus prepar'd, be made fast upon the Axis above-mention'd, in the same Manner as the little Globe had been fasten'd; then give Attrition *in Vacuo*, as in that Experiment, and Light will be thereby produced in the dark.

Experiment 10.] That Quicksilver contains Fire is plain, from Experiments made upon it, *in Vacuo*. For if Mercury well clean'd be shak'd about in an exhausted Glass, it will appear luminous. 571

If you put Mercury into a Glass Globe, the Globe may be whirl'd round, as in the former Experiments, which will be delightful to see, if the Glass be mov'd slowly. If Mercury has no Tin mix'd with it, it may be clean'd with boiling hot Vinegar. 572

The Globe, that has the Mercury in it, may be exhausted by screwing on to it a Pipe about 2 Foot long, the lower End of which must be screw'd on to the Hole in the Middle of the Plate of the Air-Pump. 573

Then, if you cover both that Hole and the Hole thro' which the Air is drawn out with one of the Receivers above-mention'd, the Air will be easily drawn out of the Globe.

Plate I. *Fig.* 4.] Take a Plate O, and having screw'd on to it the Pipe E E, whose other End is screw'd to the Air-Pump, put the Glass Receiver R upon it, and pump out the Air from it. The Pipe, thro' which the Air is drawn out, must stand up beyond the Plate in the Receiver about 4 or 5 Inches, be bent, and have a small Hole in it; which must be taken 574 ken care of, for fear any Mercury ſhou'd get into the Air-Pûmp.

The middle of this Plate, has a Braſs Pipe B; whoſe lower End, that is without an Hole, comes down almoſt to the Bottom of the Veſſel V, that contains very clean Mercury: There is an Hole in the Side of the Pipe, exactly ſhut by the Pin A. The upper End of this Pipe has a very ſmall Hole in it, and comes up thro' the Plate into the Receiver.

The Height of the Receiver R is about 16 Inches, and its Diameter 4 Inches; pump the Air out of it, and then open the Hole in the Side of the Pipe B, and the Mercury by the Preſſure of the external Air will go up to the Tube, and will ſpout very ſtrongly into the Receiver, ſtriking againſt the Top of it.

The Experiment muſt be made in a dark Place, and the Mercury will appear luminous.

575 *Experiment* 11.] Chymiſts make a certain Preparation of Urine, which they call *Phoſphorus of Urine*; which muſt be kept in Water. If it be roll'd up into ſmall cylindrical Pieces like a Pencil, and you write with it upon a Paper, when you hold the Paper in a dark Place, you will ſee Letters of Fire. The *Phoſphorus* itſelf, when you take it out of the Water, will grow hot and ſmoke; all which ſhews that the *Phoſphorus* contains a great deal of Fire.

576 In this Experiment, *we may obſerve that Water acts upon the Fire contain'd in the* Phoſphorus; for *it keeps it in*, ſo that it cannot get out ſo long as the Phoſphorus is cover'd with Water; but as ſoon as the Water is taken away, the Heat and Smoke immediately ſhew that the Fire iſſues out of the Phoſphorus. *The Air* alſo *does*, *in ſome*
577 *meaſure*, *keep in the Fire contain'd in hot Water*; that

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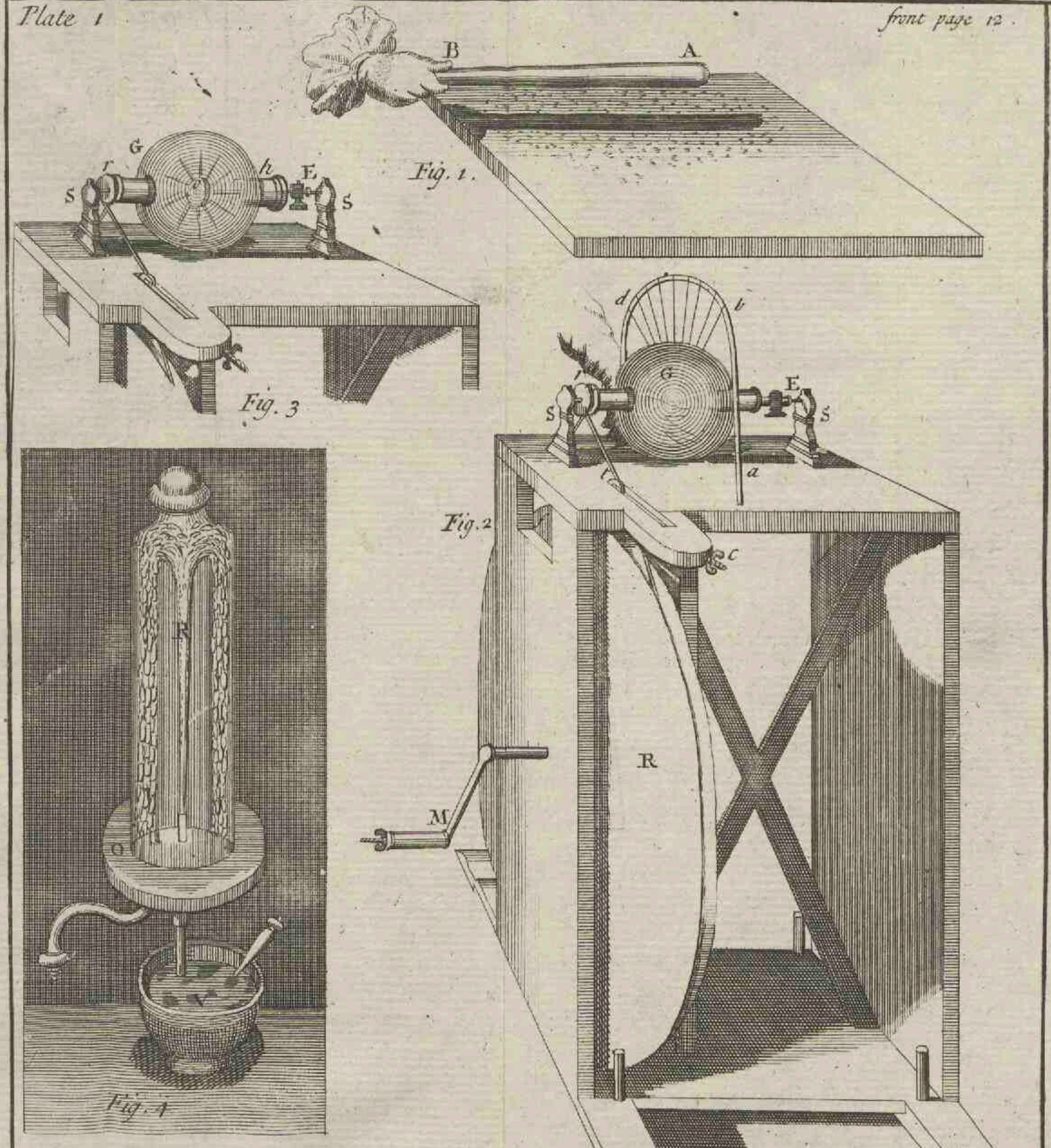

that is, hinders it from going out of it ſo faſt as it will do *in Vacuo.*

Experiment 12.] Take two Veſſels that are equal and alike, and put an equal Quantity of boiling Water into each of them. Let one of them be ſet upon the Air-Pump Plate under a Receiver, and pump out the Air; when you are pumping, the Water boils violently by the Action of the Fire that goes out of it; and then ſoon becomes only lukewarm, whilſt the Water in the other Veſſel, which remain'd in the open Air, has ſcarce loſt any of its Heat.

One may obſerve ſomething like this in ſhi- 578
ning Wood; for ſome Wood that is rotted in the Ground, ſhines when it is taken out; the Earth that encompaſs'd the Wood kept in the Fire, which goes out when that is remov'd, and the Wood continues to ſhine for ſome Days. In an exhauſted Receiver, the Light is ſoon deſtroy'd, and is not reſtor'd by the Re-admiſſion of the Air.

But it cannot be eaſily determin'd how Fire is confined in a Body by the ambient Bodies, nor is it eaſy to find out what Action produces this Effect; it is hardly probable that Preſſure is here much concerned, ſince Fire does eaſily penetrate all Bodies by its Subtilty.

C H A P. III.

Concerning the Motion of Fire, where we ſhall ſpeak of Heat and Light.

WE have ſaid that Fire moves very ſwiftly *, and this Motion, in different Cir- * 545
cumſtances, produces different Effects. Heat and

Light

Light are to be attributed to the different Mo-
579 tions of Fire. *Heat, in a hot Body, is the Agitation of the Parts of the Body and the Fire contained in it*, by which Agitation, a Motion is produced in our Bodies, which excites the Idea of Heat
580 in our Mind. *Heat, in respect of us, is nothing but that Idea, and in the hot Body is nothing but Motion.* Here we must call to mind what has been said of the Sensations in general (N. 502.) which also may be referr'd to Light.

581 *When Fire enters our Eyes in Right Lines, by the Motion that it communicates to the* Fibres *in the Bottom of the Eye, it excites the Idea of Light*; of which Motion of the Fibres we shall speak more
*716 particularly hereafter. * *A rectilinear Motion* is
582 the Motion of Light, as it appears from its being easily stopped by an Obstacle. On the contrary, such a Motion *is not requir'd in Heat*: and that *an irregular Motion is more for it*, may be proved, because the Rays, that come directly from the Sun to the Top of a Mountain, produce no sensible Heat; whilst in the Valley, where the Rays are agitated with an irregular Motion by several Reflexions, there is often produced a very intense Heat.

Definition.

A Body *is said to be* Lucid, *when it emits Light*, that is, when it gives Fire a Motion in right Lines.

583 That *there is not always Light, where there is Fire*, is beyond all doubt; for we daily see hot Bodies that do not shine.

584 But *whether there be any Body without Heat, cannot be determin'd.* Heat, in all Bodies, is a Motion that may be infinitely diminish'd; and there may be such a Motion, tho it be not sensible to us, because often we cannot discover any

any thing of Heat; for certainly there are a great many lucid Bodies, in which we can perceive no sensible Heat.* Concerning which it * 571
may be observ'd, that no Heat is sensible to us, unless the Body, that acts upon our Organs of Sense, has a greater Degree of Heat than that of our Organs. Which shews us, that the Judgment of our Senses, concerning Heat, is wholly uncertain.

When the smallest Parts of which any Body is made up are agitated, either by Attrition, or the Action of Fire applied externally to it, or any other Way; the Fire is separated from the small Particles and agitated in the Body; then also the Fire and the Particles of the Body act upon one another by their Attraction, as is prov'd by the Experiments which we shall hereafter mention.* By this Action some Parts are * 611
separated from the Body, and carried off from it by the Motion of the Fire. And this is the Cause why *hard Bodies are often set on Fire by a* 585
violent Attrition.

Hence we deduce, that *the burning of Bodies* 586
is a Separation of their Parts by the mutual Action of the Fire, and those Parts on each other; some of *those Parts, carried off by the Motion of the Fire,* 587
make Flame and Smoke.

We see besides, that a Body, that is burn'd by the Application of Fire, is not only dissolv'd by the Action of the external Fire, but also by the Action of the Fire contained in the Body itself; and that the Heat is encreased by the Application of new Fire, and the Augmentation of the Agitation of the Fire which the Body itself contains; and therefore that *the Heat is not in* 588
proportion to the Quantity of Fire.

As to the Motion of Light, it is plain, as we said *, that it is perform'd in right Lines; but * 581
whether

whether it be ſucceſſive or inſtantaneous, is diſputed; that is, whether at the ſame Moment that a Body begins to ſhine, the Light is ſenſible at any Diſtance, or whether the Light goes on ſucceſſively to Places more and more diſtant.

589 It ſeems clearly to follow from ſeveral Aſtronomical Obſervations, that that Motion is ſucceſſive, and Philoſophers did not long doubt of it; but by ſome later Obſervations, the Concluſions, drawn from the former, are weaken'd, and we are obliged to confeſs that the Motion of Light has ſomething unknown to us.

To ſay that a Motion from one Place to another is not ſucceſſive, implies a Contradiction,
590 and *it can ſcarce be doubted, that Light moves from one Place to another.*

For we obſerve that Fire is carried off in Vapours and Smoke; in which Caſe, Fire carries with it the Bodies to which it adheres, and yet is often mov'd very ſwift: If the Subtilty of Fire be conſider'd, it will eaſily be found that it is immenſly retarded by the Bodies to which it adheres; and, that, as ſoon as it is freed from them, it is mov'd with a very great Velocity.

There are ſeveral other Things very well worth obſerving, in reſpect to Light and Heat, but a great many of them are hard to explain. In natural Philoſophy, when we are ignorant of the Cauſes, we muſt only mention the Effects.

591 We ſee *ſeveral heated Bodies* that *become lucid, if their Heat be increaſed*; ſuch are Metals: They emit Fire by the Agitation of their Parts, but if the Motion of the Parts be increaſed, Part of the Fire is mov'd in right Lines, and the Body ſhines.

Thus

Thus if Smoke be made hotter by applying 592
Flame to it, it is chang'd into Flame; that is, it becomes a lucid Body.

Experiment 1. *Plate* II. *Fig.* 3.] Having blown out the Candle C, which ſends out the Smoke F; let another lighted Candle A be brought to it, and the Smoke of the firſt will be chang'd into Flame, and that ſucceſſively quite to the Candle C, which is thus lighted by the Candle A, tho it be 7 or 8 Inches from it.

We have ſaid that Air acts upon Fire *; one * 577
of its Effects upon it, that in many Caſes is not to be overlook'd, ſhews itſelf in Reſpect of Light.
For *the Preſence of the Air is often neceſſary for the* 593
Production of Light or Preſervation of Fire, which may be obſerv'd in the burning of all thoſe Bodies that go out when the Air is taken away from them.

Experiment 2.] Put a lighted Candle under the Receiver of the Air-Pump; exhauſt the Receiver, and the Candle will immediately go out.

Plate II. *Fig.* 2. *Experiment* 3.] Take a round Plate of Steel of about 3 Inches Diameter, with an Hole in the Middle to receive the Axis which is to be mov'd *in Vacuo* *, and let it be preſs'd * 567
and fix'd between two round Pieces of Wood by the Help of the Screws *d*, *d*; let Pieces of Flint be faſten'd to the Spring *f*, *f*, ſo that by the Motion of the Axis the Steel Plate may rub nimbly againſt the Flints. As long as there is any Air in the Receiver the Attrition will produce Sparks of Fire; when the Air is drawn out, tho you continue the Attrition, you can perceive no Light; but upon re-admitting the Air, it becomes again ſenſible.

594 We obſerve alſo on the contrary, that *very often the Abſence of Air is neceſſary for Light*, as might be obſerv'd in the Experiments already
* 557 mention'd *. *And* laſtly, That *taking away the*
571 *Air, the ſame Light, which may be ſeen in the open*
595 *Air, is* ſometimes *increaſed.*

* 575 *Experiment* 4.] With the *Phoſphorus* * above-mention'd write or draw Figures upon Paper, and they will ſhine in the dark, as we ſaid before; but the Paper will become much brighter *in Vacuo.*

CHAP. IV.

Of the Dilatation occaſion'd by Heat.

596
* 547 ALL Bodies are dilated by the Action of Fire *; but *that Dilatation* changes as the Heat changes; ſo that it *ſeems to depend rather upon the Motion than the Quantity of the Fire*; for Bodies are expanded as well by rubbing as by applying Fire to them externally.

Experiment 1. *Plate* III. *Fig.* 1.] Take a ſquare Iron Bar about 3 Foot long and $\frac{1}{4}$ of an Inch thick, and having laid it upon a Board between two firm Obſtacles or Standards O, O, between one of the Obſtacles and one End of the Bar, thruſt in an Iron Ruler about 4 or 5 Inches long, (made Wedge-Faſhion, being $\frac{1}{4}$ of an Inch broader at R than at *r*, and divided into equal Parts) as far as it will go; and obſerve the Diviſion that is againſt the End of the Bar, which muſt be a little oblique, that it may the better apply it ſelf to the Ruler.

Then let the Bar be heated, either by Attrition or Fire; then let it again be put between the Standards, and the Ruler thrust in between: As the Ruler will not go in so far as the Division that was observ'd before, it is plain that the Bar is lengthen'd by Heat.

Experiment 2. *Plate* II. *Fig.* 4.] That *Liquids, as well as Solids, are dilated by Heat* may be prov'd in the following Manner. Take a Glass Ball G that has a small Tube E D for its Neck, and fill it with some Liquor up to what Height you please in the Tube, and the Liquor will ascend in the Tube, when you heat the Ball; a small Degree of Heat will produce this Effect, even tho you use Mercury, the densest of all Fluids. The Experiment will be made in the same Manner, but better, if instead of a Ball you use an hollow Cylinder C with the long Tube B A join'd to it; for the whole Liquor will be sooner heated in a Cylinder than in a Ball. 597

If the Tube E D or B A be divided into equal Parts; or the Tube with its Ball or Cylinder be fitted to a Frame on which equal Divisions are mark'd, the Heat may in some Sort be measured by this Machine: For the Liquor rises or subsides in the Tube, as the Heat of the neighbouring Bodies is increas'd or diminish'd. Such Instruments are call'd *Thermometers*, and are of common Use. They do indeed shew a Change in the Heat, but it is uncertain whether they shew the Degree of Heat; that is, it is not known what Relation there is between the Change of Expansion and the Change of Heat, so as to enable us to compare together the Degrees of Heat, by comparing the Degrees of Dilatation. 598 599

If the Ball G or Cylinder C be suddenly heated, the Liquor in the Tube will immediately descend, but immediately after rise. By reason of the sud- 600 den Heat the Glaſs it ſelf grows hot ſooner than the Liquor contain'd in it; and therefore when the Glaſs is dilated by the Heat, the Cavity grows bigger, ſo that the Liquor deſcends; but the Heat being preſently communicated to it, it riſes again by its Expanſion.

From the Expanſion of Bodies it is evident
601 that *the Particles of which Bodies conſiſt, from the Action of the Fire, acquire a repellent Force, by which they endeavour to fly from each other*, and which acts contrary to that Force by which the Parti-
* 31 cles come to each other *. As long as this laſt Force is ſtronger than the other, the Particles cohere more or leſs, according to the different Degree of Heat. When the repellent Force is almoſt equal to the attractive, the Particles, which were before firmly join'd, ſcarcely cohere, yield to any Impreſſion, and are eaſily mov'd one among another; whence we ſee that *a So-*
602 *lid Body is chang'd into a Liquid by Heat*, which may be obſerv'd in all Bodies that are liquified by Heat, and return to their firſt State upon the Diminution of the Heat. It is a Queſtion,
603 *Whether all Fluidity is not owing to Heat?* which *cannot be determin'd*, becauſe we know of no Body that is entirely without Fire in it; it is certain that Heat is not only the Cauſe of Fluidity in Metals, Wax, and ſuch like Bodies, but that ſeveral Bodies, which are commonly reckon'd Fluid, are only ſo by reaſon of their Heat; thus
604 *Water is melted Ice*; for when Part of the Heat of the Water is gone, it grows fix'd.

605 Heat may be ſo increas'd that in ſome Bodies the attracting Force is overcome by the repelling Force; in which Caſe the Particles fly from each other; that is, acquire an elaſtic
* 431 Force, as the Particles of Air have *, which Elaſticity is increaſed even in the Air by Heat.

We

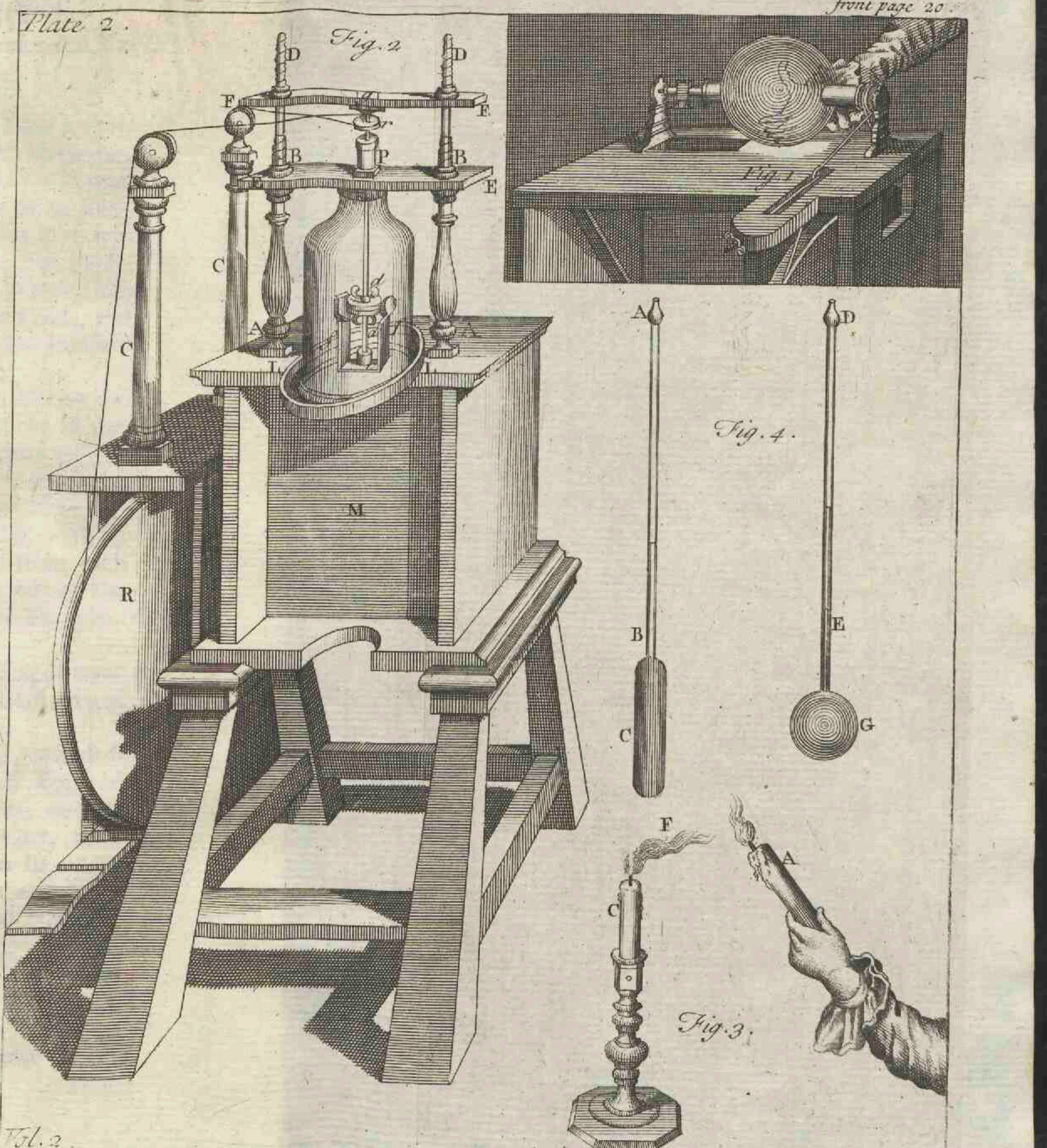
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Fig. 2
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Fig. 1
Fig. 4
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Fig. 3.
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We may obſerve this Effect in Smoke and Vapours.

Experiment 3. *Plate* III. *Fig.* 2.] Take an hollow Braſs Ball E, of about 4 Inches Diameter, with an Handle M; This Ball has a Pipe T with an Hole of hardly the twentieth Part of an Inch. Let this Ball be heated, and the Air in it will expand itſelf * and come out thro' the Pipe; * 597
then, immerging the Ball in cold Water, the Air will be again condens'd by the Cold, and the Water will go into the Ball, by the Preſſure of the Atmoſphere upon its Surface.

If this Ball, thus partly fill'd with Water, be laid upon the Fire, the Moment that the Water is chang'd into Vapours, thoſe Vapours will go out thro' T; but if the Heat be increas'd, ſo as to make the Water boil violently, the Vapours, compreſs'd in the upper Part of the Ball, will, by their Elaſticity, endeavour to recede from each other every Way, and ruſh violently out of the Pipe. Such an Inſtrument is call'd an *Æolipile.* 606

Experiment 4.] The following Experiment 607
ſhews a more ſenſible Effect of the Elaſticity of Vapours.

Plate III. *Fig.* 3.] Take the Ball E, which is alſo of 4 Inches Diameter, made of Braſs or Copper, but thicker than the former, and let it be placed upon a little light Cart, ſuch as is repreſented in the Figure. In its upper Part, it has a ſquare Pipe T. In the middle of this Pipe, there is a Separation, and the hind Part of the Pipe communicates with the Ball. There is an Hole of about $\frac{1}{8}$ of an Inch, in the middle of the Separation of the Pipe, which Pipe is open forwards. This Hole is ſhut up with a long Plate, that goes thro' two Holes in the

Sides of the Pipe, and applies itſelf to the above-mention'd Separation. As the Plate is made Wedge-wiſe, if you ſtrike upon it with a Hammer, it will exactly ſhut the Hole.

Take this Ball off of the Cart, and open the Hole, and, having heated the Ball, immerge it in Water, to let it be in Part fill'd, as in the laſt Experiment. Then, having ſhut the Hole, ſet the Ball again upon the Fire, till the Water boils violently; and then if you make it faſt to the Cart, and open the Hole, the Vapour will fly out violently one Way, and the Cart be carried with the Ball the contrary Way.

608 The Vapour, being very ſtrongly compreſs'd, endeavours to recede equally every Way, and therefore oppoſite Preſſures deſtroy one another; but when the Hole is open'd, the Vapour, which goes out, does not preſs; therefore the Preſſure one Way being taken off, that which acts in a contrary Direction prevails, and the Cart is mov'd along.

609 A Sky-Rocket riſes up into the Air, becauſe the Gun-powder, being ſet on Fire, acquires an Elaſticity, and its Parts endeavour to recede every Way: As the Pipe, or Caſe of it, is open at one End, it is leſs preſs'd that Way, and conſequently at the other End, the Preſſure prevails, and carries up the Rocket.

BOOK III.

PART II.

Concerning the Inflexion, Refraction, and Reflexion of Light.

CHAP. V.

Concerning the Inflexion of the Rays of Light.

HAVING premis'd, in the foregoing Part, what regards Fire in general; let us again farther examine the Properties of Light and the Phænomena arising from them.

The Things obſerv'd concerning Light are very wonderful, yet moſt of them are explain'd by a few Laws of Nature.

Light moves in right Lines *, can be inter- * 581
cepted by an Obſtacle which wholly ſtops ſo much Light as comes upon it, but ſtops no more.

DEFINITION.

Any Light conſider'd according to the Direction 610
of its Motion, if it be all carried in the ſame Direction, is call'd, a Ray of Light.

Such is a Beam of the Sun's Light going thro' an Hole.

Fire, as has been ſaid, is attracted by Bo-
* 549 dies * ; the notable Effects of which Attraction may be obſerv'd in the burning of Bodies ; they
611 are alſo ſenſible in Light ; for *when Light paſſes near Bodies, it is turn'd out of the ſtrait Way* ; which may be diſtinctly perceiv'd by the following Experiment.

Experiment 1. *Plate* III. *Fig.* 4.] Take a little Board T about 6 Inches long, and as high, with an Hollow *c c* in its Surface, in which two Plates of Steel ſlide, each of which has an Edge like a Knife ; the two Edges may be brought together in the middle of the Board, and be join'd together exactly. At the Place where they meet, there is a ſquare Hole in the Board, of almoſt an Inch, that a Beam of Light, let into a dark Room thro' an Hole of a Quarter of an Inch in Diameter, may paſs thro' the ſaid ſquare Hole, ſo as to come to the Plates.

If the Diſtance between the ſaid Edges be of about the 10th Part of an Inch, and the Light be made to paſs between them, the Board being ſet at the Diſtance of 3 Foot from the Window, if the Light falls upon the Paper A, at 5 Foot beyond the Board, there will appear, on each Side of the tranſmitted Beam, a Light like that of the Tail of a Comet ; which proves that the *Light is inflected* as it paſſes by the Edges of the Plates, as is plain from the Figure.

If you bring the Plates nearer (as for Example) within the hundredth Part of an Inch, inſtead of the Light above-mentioned, you will, on each Side of the Light of the Beam upon the Paper, ſee three colour'd Fringes, parallel to the

Edges of the Plates; which will ſtill appear more diſtinct, if the Hole in the Window be made leſs. I ſhall hereafter explain whence theſe Colours ariſe. Now it is enough to deduce from this Experiment, that Light *is attracted* by Bodies that inflect its Rays; for if there was not a Motion towards the Body, the whole Beam would have continu'd in its direct Motion.

But *the Action of Bodies, by which they act upon the Light to attract it, exerts itſelf at a ſenſible Diſtance*; as is plain from the Experiment. 612

Experiment 2. *Plate* III. *Fig.* 4.] Every thing elſe being as in the former Experiment, if the Plates be brought nearer together within $\frac{1}{400}$ Part of an Inch, no Light will appear upon the Paper between the Fringes above-mention'd; ſo that in this Caſe, all the Light, which paſſes between the Edges, is inflected on either Side, ſo as to produce the Fringes above-mention'd. Which plainly ſhews, that Steel acts upon Light at leaſt at the Diſtance of $\frac{1}{800}$ Part of an Inch.

It is alſo proved, that *That Action is increas'd as the Diſtance is diminiſh'd.* 613

Experiment 3. *Plate* III. *Fig.* 4.] Things being ſtill in the ſame Diſpoſition, leſſen the Diſtance between the Plates; and the Fringes will vaniſh ſucceſſively, till the Plates being join'd together, no Light paſſes between them. The Fringes, which vaniſh firſt, are thoſe that are produced by the Rays which are leaſt inflected; and thoſe vaniſh laſt, which are produced by the Rays that are moſt inflected; that is, when the Edges come towards one another, the Shadow between the Fringes, made by each Edge, is continually increas'd, till, at laſt, the whole Light on each Side vaniſhes. Whence it plainly follows, that the

the Rays are more inflected, the nearer they paſs by the Edges; that is, the Attraction is increaſed, as the Diſtance is diminiſh'd.

614 But this Attraction has ſomething particular, for *the Attraction of one Edge is increaſed, as the other is brought near it.* Which is plainly ſeen in this Experiment; for as the Edges are brought towards one another, the Inflection of the Rays continually becomes greater.

CHAP. VI.

Concerning the Refraction of Light and its Laws.

615 ALL *that gives Paſſage to Light, is call'd a* Medium.

Glaſs, Water, and a Vacuum itſelf are Mediums.

When a Ray of Light goes out of one Medium into another, it is often turn'd out of the right Line.

DEFINITION II.

This Inflection is call'd *Refraction.*

616 *In order to produce Refraction, the Mediums muſt be of different Denſities, and the Ray muſt make an oblique Angle with the Surface that ſeparates the Mediums.*

618 *Refraction ariſes from this, that the Rays are more attracted by a denſe, than by a rare Medium*; from which Attraction, that we have prov'd in the foregoing Chapter, all that relates to Refraction may be deduced.

619 Let E F be the Separation of the Mediums [*Plate* IV. *Fig.* 1.] and let X be in the denſer, and Z in the rarer Medium. All the Particles have

* 31 an attractive Force*, and this Force alſo obtains

* 611 in Light. Let the Diſtance, at * which the Particles exert their Action, be that which is comprehended between the Lines E F and G H.

Therefore,

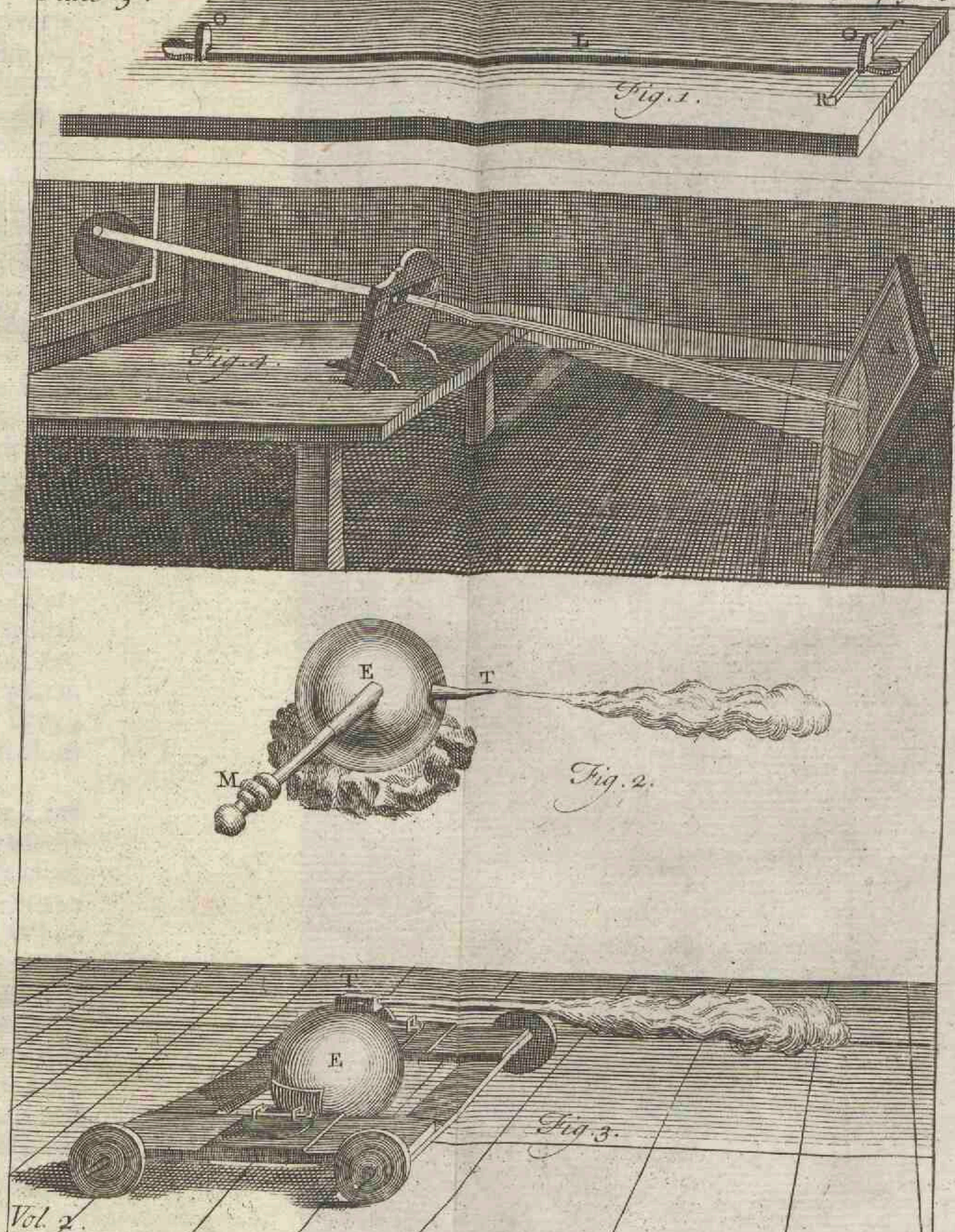
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Fig. 4.
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Fig. 3.

Therefore, the Light, which comes between those Lines, will be attracted by the Medium X.

At the Distance of the Line G H, only the extreme Parts of the Medium X act upon the Light; at a less Distance, both they and other Parts act so as to increase the attracting Force, when the Distance is diminish'd, as has been before observed*. In the denser Medium X, let the Line * 613 I L be supposed at the same Distance from E F as G H is in the Medium Z. Let the Light enter into the Medium X, and it will, on all Sides, be attracted by the Particles of the Medium, whose Distances from the Light are less than the Distance between E F and G H; for the Light is suppos'd to be attracted at that Distance by the Particles of the Medium X.

As long as the Light is between the Lines E F and I L, the attracting Force is the strongest towards I L, because there are more Particles that draw that Way; but as the Number of Particles, that act the contrary Way, increases, that is, as the Distance from E F increases, the Force towards I L is diminish'd, till, in the very Line I L, the Light be equally attracted every Way; which also obtains every where in the Medium X, beyond I L.

Suppose a Ray of Light to come in the Line A *a*, and fall obliquely on the Surface, which divides the Mediums, or rather on the Surface G H, where the Action begins, by which the Light is driven towards the Medium X: When the Ray comes to *a*, it is turn'd out of the right Line, by the Force by which it is attracted by the Medium X; that is, by which it is driven towards it in a Direction perpendicular to its Surface. And, indeed, the Ray of Light is bent out of the right Line in every Point, as long as it is between the Lines G H and I L, between which

which the ſaid Attraction acts; and therefore between thoſe Lines, it deſcribes the Curve *a b*,
* 208 in the ſame Manner that Projectiles move*. Beyond the Line I L, the Action which bends the Ray ceaſes; therefore it goes on then in a right Line, according to the Direction of the Curve in the Point *b*.

The Diſtance, between the Line G H and I L, is very ſmall; therefore, when we conſider Refraction, we take no notice of the bended Part of the Ray, which we look upon as if it was made up of two ſtrait Lines A C, C B, meeting at C, namely, on the Surface which divides the Mediums.

Thro' C draw N C M, perpendicular to the Surface of E F.

Definition III.

620 *The Part* A C *of the ſaid Ray is call'd the incident Ray.*

Definition IV.

621 *The Angle* A C N *is call'd the* Angle of Incidence.

Definition V.

622 *The Part* C B *is call'd the* Refracted Ray.

Definition VI.

623 *The Angle* B C M *is call'd the* Angle of Refraction.

624 In this Caſe, *When Light goes out of a rare into a denſe Medium, the Angle of Refraction is leſs than the Angle of Incidence*, by reaſon of the Inflexion of the Ray; for theſe Angles wou'd be equal, if the Ray A C continu'd to move ſtrait on in the Line C D. The Ray C B does alſo come nearer to the Per-

Perpendicular C M; and therefore *the Refraction is said* to be *made towards the Perpendicular.*

On the contrary, *if the Ray goes out of a denser* 625
into a rarer Medium, it will recede from the Perpendicular, because the denser Medium attracts the Ray in the same Manner, whether it goes out of a rarer into a denser, or out of a denser into a rarer Medium. Therefore if B C be the Ray of Incidence, C A will be the refracted Ray; that is,
Let the Ray come from either Side, and it will move 626
in the same Lines. Therefore, *if there be two Rays,* 627
and one comes out of a denser Medium into a rarer, and the other out of a rarer into a denser, and the Angle of Refraction of the one be equal to the Angle of Incidence of the other, the two remaining Angles of Incidence and Refraction will be equal to each other.

Whence it follows, that *The Direction of the* 628
Ray is not chang'd, if it moves thro' a Medium termined by two Surfaces parallel to each other; for as much as it is turn'd towards any Side at its Entrance, so much exactly is it turn'd the other Way as it goes out of the said Medium.

If a Ray falls perpendicularly on the Surface that 629
separates two Mediums, it will not be turn'd out of the right Line by the Attraction of the denser Medium; because in that Case it acts in the Direction of the Ray.

Plate IV. *Fig.* 2.] To confirm what we have 630
said by Experiments, take a Trough or open Box P, about a Foot long, 4 Inches wide, and of the same Depth. Its two Sides *a b c d, a b c d,* are Planes of Glass parallel to each other, and this Box must be fill'd with Water two Inches and half high.

The Experiments must be made in a dark Place; the Light must be let in thro' a Slit in the moveable round Plate O, which is fix'd to the Wind-

Window-ſhut, and is eaſily turn'd round, that the Slit may be inclin'd at Pleaſure: The Slit is 4 Inches long and $\frac{1}{8}$ Inch wide.

The Light, that is let in, ſtrikes upon the Looking-Glaſs S, and the Slit is ſo inclin'd, and Speculum diſpoſed, that the Beam, that comes thro' the Slit, may be horizontally reflected by the Looking-Glaſs, the Beam being in a vertical Poſition, that it may go thro' a vertical Slit in the Board T, of the ſame Dimenſions as that in the Plate O. This Board is us'd to diminiſh the Breadth of the Beam, which is continually increaſing, by reaſon of the Light that comes from the Sides of the Sun.

Experiment 1.] Things being diſpos'd, as we have ſaid in the Deſcription of the Machine; let the Beam fall perpendicularly on the Surface *a b c d*, and it will paſs perpendicularly thro' the Water and the upper Part of the Trough, and not be turn'd out of the Way at all, either going in or coming out; by which is confirm'd what has been ſaid (N°. 629.)

Experiment 2.] Now let the Beam fall obliquely on the Surface *a b c d*, at *f g*; the upper Part of the Beam will continue its Motion ſtrait along *h*; but the lower Part of it, in the Water, will be bent towards *i*, coming towards the Perpendicular; which confirms (N°. 624.)

Experiment 3.] Every Thing being, as in the former Experiments, the Beam, which, at *i*, goes out of Water into Air, is turn'd out of its Way fromwards the Perpendicular, and in ſuch Manner, as to move in the ſame Direction as the incident Ray that goes into the Water at *g*; for it goes

goes on parallel to the Ray *f b* continued: which confirms (N°. *625*, *626*, and *628*.

In what has been said hitherto, we have only consider'd the Attraction of the denser Medium, because it overpowers; but we must not overlook the Action of the rarer Medium, because it diminishes the Action of the denser, which Action becomes so much the less on the Rays of Light, as the Mediums differ less in Density. Therefore *there is no Refraction where the Densities of Me-* 631
diums are equal; and the Refraction is greatest where the Densities of Mediums differ most.

The Laws of Refraction are deduc'd from the Acceleration which the Attraction generates; therefore this Acceleration must be examin'd.

DEFINITION VII.

The Space, terminated by the Planes G H and 632
I L, is call'd the Space of Attraction.

Plate 4. *Fig.* 1.] The Attraction acts between the Planes represented by these Lines, but no farther *.

* 619.

The Direction of this Action is perpendicular to 633
the Surface that separates the Mediums, and consequently to the Surface I L; *and its Form is unequal at different Distances from the Surface*. But it is equal at equal Distances,* because both Mediums are supposed homogeneous, and alike in all their Parts.

* 619.

The Motion of the Ray A C may be resolved into two other Motions, according to the Directions A O and O C *, of which the first is parallel to the Surface E F, and the second perpendicular to that Surface: The Celerities of which Motions will be respectively proportional to those Lines A O and O C, whilst A C denotes the Celerity of the Ray itself *.

* 192.

* 192.

The

634 *The Motion, according to the Direction* A O, *is not chang'd by the Attraction perpendicular to the Surface* I L, *only the Motion according to* O C *is accelerated.*

635 Keeping the Line A C, that is the Celerity of the Ray, its Inclination may be chang'd, whereby also the Celerity in the Direction O C is also chang'd; which Celerity wholly vanishes, if the Angle A *a* G be very small. In which Case, if after Light has enter'd into a denser Medium, its Motion be resolv'd into two, so that the Direction of the one be perpendicular to the Surface I L, its Celerity must be wholly attributed to the Attraction so often mention'd. For, as it enters into the Space of Attraction, a Motion is generated in that Direction; and, as it goes thro' that Space, in which a new Action does every where act upon the Light in the same Direction, it is continually accelerated. Which Acceleration obtains in every Passage of Light thro' the Space of Attraction; but it is different, according to the different Celerity with which Light comes perpendicular to the Surface which parts the Mediums.

If the Attraction was equable thro' the whole Space of Attraction, the Laws concerning the said Attraction might be determin'd (as was said of the Acceleration of heavy Bodies after N° 130.) by Help of the rectangular Triangle P Q R, (*Plate* IV. *Fig.* 3.) in which the Lines parallel to the Base represent the Celerities, whilst Portions of the Area of the Triangle represent the Spaces gone thro'.

But here we have always the same Space run thro', namely the Breadth of the Space of Attraction, because we only consider the Motion which is perpendicular to the Surface, which separates the Mediums; therefore that Space is always represented by equal Parts of the Area of the Triangle P Q R. Let P *d c* represent such a

 Part

Part when the Celerity is equal to *o*. The Light enters the Space of Attraction in the above-mention'd perpendicular Direction, that is, when an incident Ray makes a very ſmall Angle with the Surface that ſeparates the Mediums; *d c* in that Caſe will denote the Celerity acquir'd by the Attraction, and with which the Light goes out of the Space of Attraction.

But if the Light goes perpendicularly into the Space of Attraction with the Celerity that is expreſs'd by *f g*, it will go out of that Space with the Celerity *h i*, ſuppoſing the Areas P *d c* and *f g i h* equal to one another, as appears from what has been ſaid. The Triangle P *d c*, P *f g*, P *h i* are Similar, and therefore their Areas are to one another, as the Squares of the homologous Sides *d c*, *f g*, *h i*; but the Sum of the Areas P *d c*, P *f g*, is equal to the Area P *h i*; (by reaſon of the equal Areas P *d c* and *f g i h*;) therefore alſo the Sum of the Squares of the Lines *d c* and *f g* is equal to the Square of the Line *h i*; whence it follows, that with the three Lines above-mentioned one may form a rectangular Triangle, whoſe Hypothenuſe will be *h i*.

Therefore, *In a rectangular Triangle, one Side of* 636
which is the Celerity with which Light enters the Space of Attraction perpendicularly, and the other Side the Celerity acquir'd in going thro' that Space, when the Celerity with which the Light enters into it is equal to o; *the Hypothenuſe of the Triangle will be the Celerity with which the Light goes perpendicularly out of the Space of Attraction on the other Side:* Which univerſally obtains, which way ſoever the Attraction is chang'd, in the Space of Attraction, according to the different Diſtance of the Planes that terminate that Space. Which to prove,

Let us ſuppoſe the Space of Attraction to be divided into two Parts, whether equal or unequal, by a Plane parallel to the Surfaces with which it is terminated. Let us ſuppoſe beſides, that the Attraction is not the ſame in thoſe two Parts, but yet that it does not vary in one of them. Theſe Parts are to be conſider'd as two different Spaces of Attraction. Let A (*Plate* IV. *Fig.* 4.) be the Celerity which the Light acquires in going thro' the firſt Part of the Space, when it enters the Space with the Celerity O. Let B be the Celerity acquir'd in going thro' the ſecond Part of the Space, when the ſame Light enters that Part with the Celerity O. It is to be obſerv'd that this Demonſtration relates to the Motion, perpendicular to the Surface, which ſeparates the Mediums.

Let the Light enter the firſt Part of the Space above-mention'd with the Celerity O, it will come to the ſecond with the Celerity A; if therefore a right angled Triangle be form'd with the Sides A and B, the Hypothenuſe E D will expreſs the Celerity with which the Light will go out of
* 636 the Space of Attraction *.

If the Light enters the Space of Attraction with the Celerity F G, let the rectangular Triangle H F G be drawn with the Sides F G and A; the Hypothenuſe H G will be the Celerity, with which the Light goes out of the firſt Part of
* 636 the Space of Attraction *, and enters into the ſecond; and if you draw the rectangular Triangle H G I, whoſe Perpendicular is equal to the Line B, you will have the Hypothenuſe I G to denote the Celerity with which the Light goes out, and continues its Motion after it has run
* 636 thro' the whole Space of Attraction *.

Now we muſt demonſtrate that the Celerity I G is alſo the Hypothenuſe of the rectangular Triangle N M L, whoſe Side M L is equal to the Celerity F G, with which the Light enters the

Space

Space of Attraction; and whose other Side L N is equal to the Line E D, which is the Celerity that the Light acquires in going thro' the whole Breadth of the Space of Attraction, when it has enter'd it with the Celerity O; which being also demonstrated in that Case, in which two different Forces of Attraction act, it is plain that the Proposition of N° 636 is thereby prov'd.

But it is plain from the Consideration of the rectangular Triangles, that the Lines I G, and N M, are equal. The Square of the Line N M is equal to the Squares of the Lines N L and L M or F G: N L is equal to the Line E D, whose Square is equal to the Squares of the Lines E C and C D, or of the Lines A and B, which are equal to F H and H I: therefore the Square of the Hypothenuse N M is equal to the three Squares of the Lines F G, F H, and H I. To which three Squares, the Square of the Lines G I is equal; as having been prov'd equal to the Squares of the Lines H I and H G, which last is equal to the Squares of the Lines H F and F G.

If the Space of Attraction be divided into ever so many Spaces by plain parallel Surfaces, which terminate that Space, and the different Parts have different Forces of Attraction, the same Demonstration will serve; and the Number of Divisions may be made any how *in infinitum*; which Case obtains in the Refraction which Light suffers going out of any Medium into another of different Density*: *to* which *Refraction* 637
therefore *the Rule of* N°. 636 *may be applied.* * 636

Plate IV. *Fig.* 5.] Let Z be the rarer, and X the denser Medium, and let them be separated by the Plane E F; let a Ray of Light A C fall obliquely on the Surface E F; let A C denote the Celerity of the Light in the Medium Z, and let that Line A C be ſettled; that is, let it be always the ſame, whatever the Inclination of the Ray is. With the Center C and the Semidameter C A, draw a Circle; and let N C M be drawn perpendicular to E F; from A, draw A O perpendicular to N C, and A Q to E F.

Let us conceive the Motion along A C reſolv'd into two others, the one along A O, and
* 192 the other along A Q or O C *; the Line O C will denote the Ray's Celerity perpendicular to the Surface E F, which Celerity alone is in-
* 634 creaſed by the Attraction of the Medium *.

Let C P be the Celerity which Light acquires, in paſſing perpendicularly thro' the Space of Attraction of the Medium X; ſuppoſing the Celerity of Light at its Entrance to be O, the Hypothenuſe O P of the rectangular Triangle P C O will be the Celerity of the Ray A C in the Medium X, according to a Direction perpendi-
* 637 cular to the Surface E F *; the Celerity of the Light in the Direction A O or Q C, parallel to
* 634 the Surface E F, is not chang'd *. Therefore let C V be equal to A O or Q C, and V B perpendicular to E F, equal to the Hypothenuſe P O, and draw C B; the Motion along C B is compounded of the Two, and this Line by its Situation determines the Direction, and by its Length
* 190 *the Velocity of the Light in the Medium* X *; which
638 Celerity *is not chang'd by the different Inclination of the Ray* A C. For the Square of the Line C B is equal to the Square of the Line B V or P O, the Square of the Line C V or A O; but the Square of the Line P O is equal to the Squares of the Line P C and C O: Therefore the Square of the Line C B is equal to the three Squares of the Lines P C, C O and A O; which two laſt, if join'd, will give us the Square of the Semidiameter A C or C N; that is, C B is equal

to

to P N, whose Square is also equal to the Squares of the Lines P C and C N, and which undergoes no Change from the different Inclination of the Ray A C.

The Line C B does in T cut the Circle, which is describ'd with the Semidiameter C A; from the Points B and T, draw B S and T R perpendicular to C M; by reason of the Similar Triangles C B S, C T R, B C will be to T C or C A, as B S to T R; which Lines therefore, by reason that B C and C A are settled, will have the same Ratio to one another, whatever be the Angle of Incidence. T R is the Sine of the Angle of Refraction T C R, and B S which is equal to C V, that is equal to A O, is the Sine of the Angle of Incidence A C O.

Therefore, *in every Inclination of the Incident* 639
Ray, there is a settled and constant Ratio between the Sines of the Angles of Incidence and Refraction.

Now since B C and C A which are as the Sines above-mention'd, do also denote the Celerities of the Light in *the* Mediums X and Z, it follows that those *Sines are inversly, as the Celerities in the Mediums.*

If the Medium Z be Air, and X Water, the 640
aforesaid Sines are as 4 to 3; and the Celerity of the Light in Air to its Celerity in Water, as 3 to 4. But if, Z being still taken for Air, X be Glass, the Sines will be as 17 to 11. One Experiment determines this for all Mediums.

The Ratio between the Sines of any Angles is 641
the inverse Ratio of the Secants of the Complements, as it appears in this Figure, supposing a Circle drawn with the Semidiameter C Q or C V; for then A C (which is equal to C T) and C B will be the Secants of the Angle A C Q, and B C V Complements to the Angles of Incidence and Refraction, and inversly, as B S (which is

equal to A O) and T R, which are the Sines of Incidence and Refraction in the greater Circle.

And this Proportion of the Secants gives us a Method of eaſily reducing to Experiment the *Prop.* of N°. 639.

Experiment IV. *Plate* IV. *Fig.* 6.] In this Experiment the Light is to be let into the dark Chamber thro' a Slit, in the ſame Manner as in the former Experiments, and by means of a Looking-Glaſs reflected thro' the vertical Slit in the Board T.

Take a Trough P, nearly of the ſame Size as that which was us'd in the former Experiments, but which has only one End of Glaſs, namely, the little Side *a b c d*. And let it be half fill'd with Water.

The vertical Beam of Light being made to fall obliquely on the Glaſs End of the Trough, the Part of it, which is above the Water, goes directly forwards, and at *h* falls upon one of the long Sides of the Trough; but that Part of the Beam, which is refracted in the Water, goes along *g i*, and ſtrikes againſt the ſame Side of the Trough at *i*. Whatever the Angle be which the Beam makes with the End or Side *a b c d*, the Lines *f h* and *g i* will always be to each other, as 3 to 4; as is very eaſily ſhewn in ſeveral Inclinations, if you have two Scales, each with ſmall Diviſions on them; which Diviſions in the one muſt be to the Diviſions in the other, as 3 to 4: For the greater Line *g i* will always contain as many of the great Diviſions, as the leſſer Line *f h* will contain of the ſmall ones. The Angle, which *f h* makes with the Plane *a b c d*, is the Complement of the Angle of Incidence to

a right

a right Angle, and the Angle made by the Line *g i* with the same Plane is the Complement of the Angle of Refraction to a right Angle; therefore *g h* and *g i* are the Secants of the Complements of the Angles of Incidence and Refraction, which have a constant Ratio to one another, as was to be confirm'd by this Experiment.

642 We have hitherto consider'd a Ray of Light going out of a rarer into a denser Medium, but the same constant Proportion of the Sines mention'd, N°. 639, holds good also in the contrary Motion of the Rays; the Angles A C N, M C B (*Plate* IV. *Fig.* 5.) are not chang'd, whether the Incident Ray be A C or B C*. In that Case, if B C be the Celerity of the incident Ray, C A will be the Celerity of the refracted Ray; for the Motion of the Ray, going out of X into Z, is retarded in the same Manner by the Attraction towards the Medium X, as it is accelerated in the contrary Motion.

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CHAP. VII.

Of the Refraction of Light, when Mediums are separated by a plane Surface.

Definition I.

643 RAys *proceeding from the same Point, as a Center, and continually receding from each other, are said to be* divergent.

Definition II.

644 Those diverge more, *which make a greater Angle with each other.*

Definition III.

645 *The Point, from which the divergent Rays proceed, is call'd the* Radiant Point.

646 *The more the Rays diverge, supposing them at equal Distances from each other, the less is the ra-*
647 *diant Point distant from them; and so on the contrary*, the Rays are often mov'd by *Refraction*, as if they came from a radiant Point, tho they do not really proceed from such a Point; that is, if the Rays should be continued or produced back the Way from whence they come, they would meet in one Point. In that Case also, the Rays are said to be divergent.

Definition IV, and V.

648 Rays *which concur in one Point, or would concur if they were continued, are said to be* convergent;
649 *and those are* more convergent, *which make greater Angles between themselves.*

Definition VI.

650 *The Point of the Concourse of converging Rays, is call'd the* Focus.

Definition VII.

651 *The Point, in which converging Rays, and such as (being intercepted or turned out of the Way before their Concourse) would have concurred, being continued, is called the* imaginary Focus. Which Name is also given to that Point from which those divergent Rays are conceived to flow,
* 647 which do not proceed from the radiant Point *.

652 *The more the Rays converge, supposing their Distance from each other to be the same, the less Distance from them is the Focus, whether real or imaginary.*

If

Plate 4.

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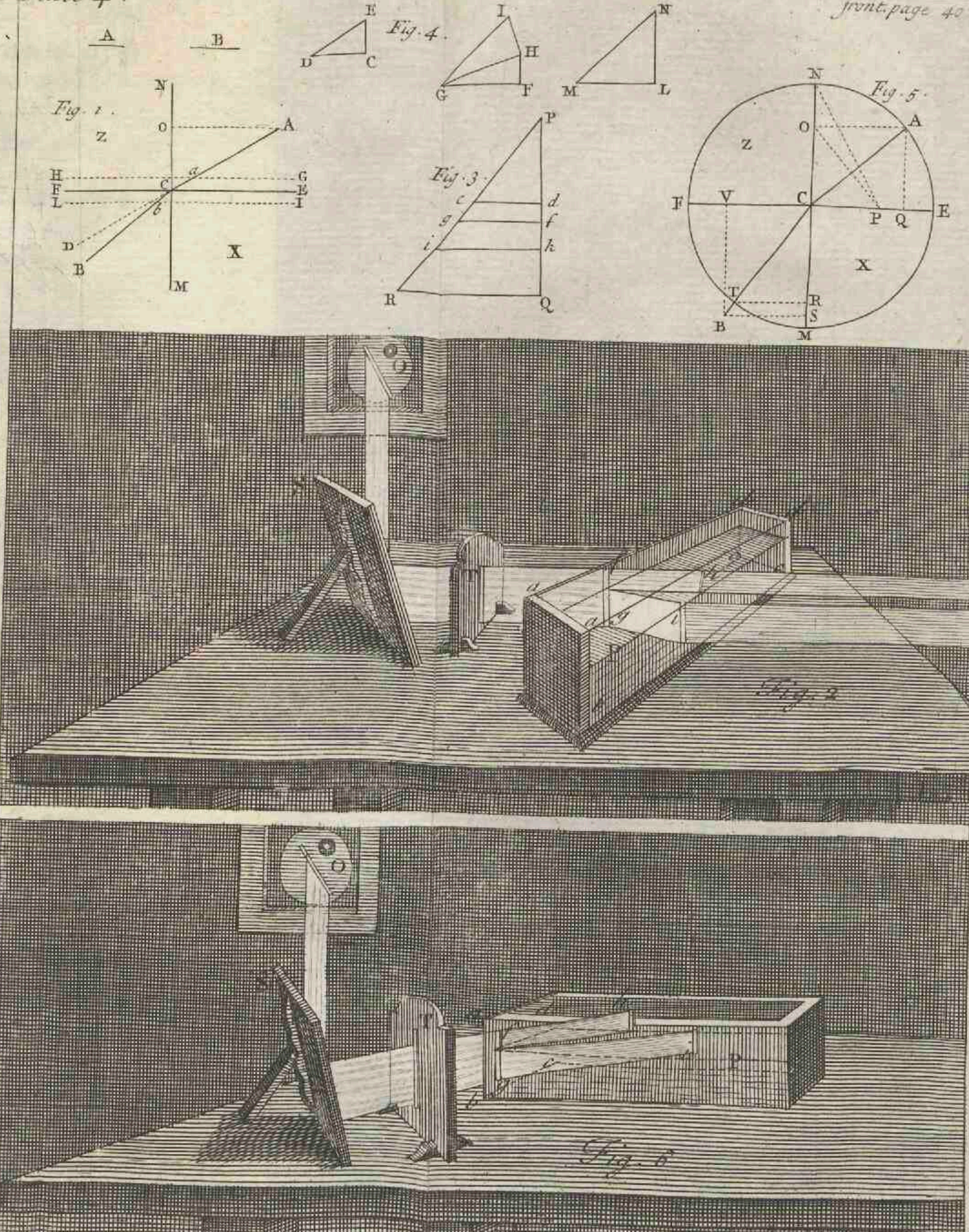

If parallel Rays pass out of any Medium into another of different Density, they will also be parallel after Refraction: Because they are all equally inflected; for, in all this Chapter, we speak of Mediums separated by a Plain Surface. 653

Let X *and* Z *be two Mediums, the last more rare, and the other more dense, separated by the Plane* E S, (*Plate* V. *Fig.* 1.) *from the Point* R C, *let there proceed the divergent Rays* P C, R *o*, R *n*, *and enter into the denser Medium:* Let one of them be R C, perpendicular to the Surface E S; this last is not turn'd out of the Way *, but continues its Motion along C G. The Rays R *o*, R *n*, are refracted towards Perpendiculars, which are conceiv'd to fall upon the Surface E S in the Points *o* and *n* *. *These Rays are moved in the denser Medium, as if they all proceeded from the imaginary Focus r, which is farther distant from the Surface than* R, *if the Rays are not too much scattered*; which yet is not to be understood Mathematically; for, by a Point, we understand a small Space, such as is otherwise call'd a Physical Point. 654

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To demonstrate this Proposition, we must consider, that the Angle R *o* C, is the Complement of the Angle of Incidence to a right Angle; and, that the Angle *r o* C is also the Complement of the Angle of Refraction to a right Angle; and therefore that the Lines R *o*, *r o*, are the Secants of the Complements of the Angles of Incidence and Refraction, supposing the Semidiameter to be *o* C; between which Secants, there is a constant Proportion *. In the small Divergence R *o* and R C, as also *r o* and *r* C, they do not sensibly differ, and, between R C and *r* C, the Ratio is always constant; that is, *r* is fixed as well as R, tho the Inclination of the

* 641

639.

the Ray be chang'd: And therefore R*n* is refracted along *n* A, as if it had proceeded from *r*.

655 *If the Rays are too much dispers'd*, this Demonstration will not serve, and the Place of Concourse *r* cannot be taken for a Point: In this Case *a little Circle must be imagin'd* there, *into which all the Rays concur, which will be the greater, the greater the Angle is that the divergent Rays make.*

656 *If some Rays, proceeding from* R, *are not too much dispersed, but fall very obliquely on the Surface* E S, *they will be refracted, as if they proceeded from a Point not very remote from the Point r:* As is plain from what has been said.

657 *The Rays*, such as A *n*, B *o*, G C, *which come converging from a denser Medium* X *into a rarer* Z, concur sooner than they wou'd do, if they shou'd
* 625 continue their Motion in a denser Medium *, that is, *become more convergent*, and the real Focus is less distant than the imaginary one. In this Figure, the imaginary Focus is *r*, and the
* 625 real Focus R *. This Proposition therefore is properly the Inverse of the Proposition of N°.654.
* 626 and therefore * both are prov'd by the same Experiment.

Experiment 1. *Plate* V. *Fig.* 2.] Thro' the Ball G, which is moveable in the Window-shut, and has an Hole going thro' the Middle of it, let a cylindric Beam of the Sun come into the dark Room, and be reflected horizontally by the Looking-Glass S; let it then go through the Convex Lens of Glass that is fix'd in the Board or Stand T, and the Rays will meet together at R, and beyond R will move as if they proceeded from that Point; which therefore is the radiant Point.

Convex Lenses of Glass are very common; we shall hereafter mention their Properties*, it being needless to do it in this Place: Now we only want a radiant Point, and it is enough to shew how to make it. * 691 697

Take a Trough Box, P, whose Side *a b c d* is of Glass, and let it be fill'd with Water: The Rays, which diverge from the Point R, become less diverging when they go into the Water.

658 *When convergent Rays*, as H D, I *p*, L *q* (*Plate* V. *Fig.* 1.) having their imaginary Focus at *f*, *go from a rarer Medium* Z *into a denser* X, *they become less convergent* *, and concur in the Focus F, which is more distant from the Surface E S *, as appears by applying here the Demonstration given in N°. 654. * 624 * 652

659 *Rays proceeding from the Point* F, *and going out of a denser Medium into a rarer, become more diverging*, and move as if they came from *f*, which Proposition is the Inverse of the foregoing, and is confirm'd by the same Experiment *. * 626

Experiment 2. *Plate* V. *Fig.* 3.] Take the same Box B, as was used in the former Experiment; but here let in two Beams of the Sun into the dark Room thro' two Holes in the moveable Plate in the Window-shut; let them be both reflected horizontally, and transmitted thro' similar convex Lenses; thereby the Rays of the Beams will become convergent, having their Focus's at the same Distance; but if the converging Rays are made to run into the Water in the Box thro' the Side *a b c d*, they will be collected at a greater Distance; which will plainly appear by comparing together the Situation of the Points F in the Air, and *f* in the Water.

CHAP.

CHAP. VIII.

Concerning the Refraction of Light, when a ſpherical Surface ſeparates the Mediums.

Plate VI. *Fig.* 1.] LET X and Z be Mediums differing in Denſity, the laſt the rarer, and the firſt the denſer; let them be ſeparated by the ſpherical Surface E S, whoſe Center is C, and whoſe Convexity is towards the rarer Medium.

660 To begin, by examining the moſt ſimple Caſe; *Let us ſuppoſe parallel Rays*, as B O and A *n*, *going out of a rarer into a denſer Medium, and falling upon a convex Surface*, ſuch as we have juſt deſcrib'd; let one of them be B O, which, being continu'd, goes thro' the Center, and falls perpendicularly upon the Surface E S; and there-

* 629 fore is not turn'd out of the right Line *. All *the Rays, which are not too diſtant* from that Ray, come nearer to it by the Refraction of the denſer Medium, and *are collected into one Point* F: As for Example; Let A *n* be a Ray which is refracted along *n* F; thro' the Point *n* draw to the Center C the Semidiameter C *n*, and let it be continu'd to *p*; as this Line is perpendicular to the Surface which ſeparates the Mediums, the Angle of Incidence is A *n p*, which is equal to the Angle *n* C O; the Angle of Refraction is C *n* F. If the Arc *n* O be a very ſmall one, theſe Angles are as their Sines, whoſe Ratio is

* 639 conſtant *. Therefore theſe Angles *n* C O and C *n* F are increas'd and diminiſh'd in the ſame Ratio, as long as their Difference, which the Angle *n* F O, which conſequently follows the Proprotion of the Arc *n* O, which is the Meaſure of the Angle *n* C O; as long as the Arc *n* O

does

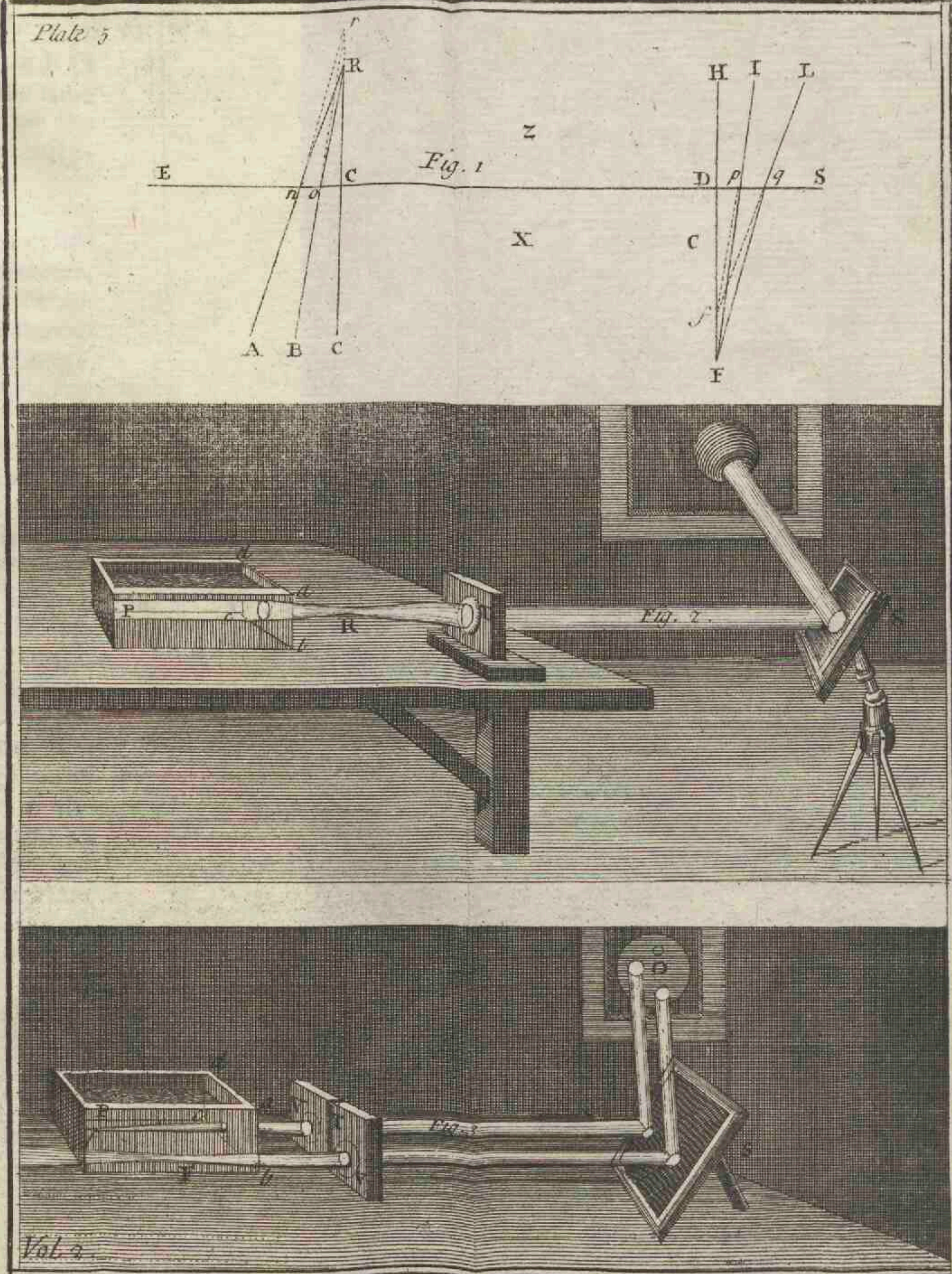
Plate 5
r
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Fig. 1
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Fig. 2
Fig. 3
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does not exceed 15 Degrees, the Angle *n* F O is increaſed and diminiſhed ſenſibly in the ſame Ratio, as the ſaid Arc; and therefore all the Rays, between A *n* and B O, do by their Refraction meet ſenſibly in the Point F.

Experiment 1. *Plate* VI. *Fig*. 2.] Let a cylindric Beam of the Sun, of an Inch in Diameter, made up of innumerable parallel Rays (which are ſo on Account of the Sun's immenſe Diſtance) be let into the dark Room, as in the firſt Experiment of the foregoing Chapter, and be reflected horizontally by the Looking-Glaſs S.

Fill with Water the Trough P, which is about 3 Inches high, and as wide, and one Foot long. Let it have a Glaſs V made faſt in one of its Sides: This Glaſs muſt be a Portion of a Sphere, thin, and every where of the ſame Thickneſs, ſuch as the Cryſtal of a Pocket-Watch.

The Convex Part of the Glaſs V muſt be outwards, that the Water next to it in the Trough may put on a ſpherical Surface. If the Rays above mention'd go into the Trough thro' this Glaſs, becauſe the Glaſs is thin, and has its Surfaces parallel, there is no ſenſible Change in the Motion of the Light by the Refraction of the Glaſs, and the Light enters into the Water in the ſame Manner, as if there was no Glaſs. Let the Trough be ſo diſpos'd, that one of the Rays may paſs thro' the Center of the ſpherical Surface, and the others will come nearer and nearer to it, and at laſt concur with it at F.

Plate VI. *Fig*. 3] Again let X be the denſer Medium, and Z the rarer, and let them be ſeparated by the ſpherical Surface E S, whoſe Center is at C, and whoſe Convexity is towards the rarer Medium: *From the radiant Point* R *let Rays pro-* 661

ceed,

ceed, and enter into the denſer Medium thro' the Surface above-mention'd; ſo that of thoſe Rays, that which is expreſs'd by R O, being continued, may paſs thro' the Center; this Ray is not refracted as it goes into the Water, and all the reſt of the Rays come towards it by the Refraction, *and when they are not too divergent are collected into one Point* as F, in the ſame Manner as was ſaid of parallel Rays; with this Difference, that the Focus F in that Caſe is more diſtant. The ſame Demonſtration will alſo ſerve here, as relates to parallel Rays, which is built upon this Foundation, that the Angle of the Incidence increaſes in the ſame Ratio as the Arc *n* O, which does alſo obtain here, when the ſaid Arc does not exceed 15 Degrees. Let R*n* be a Ray of Light, and from the Center C thro' *n* draw C *n p*: The Angle R *n p* will be the Angle of Incidence; let it be divided into two Parts by the Line *nq*, parallel to the Line R O C; the Part *p n q* is equal to the Angle *n* C O, which is meaſur'd by the Arc *n* O, and which therefore follows the ſame Proportion as that Arc; and which alſo the Angle *n* R O (if it be very ſmall) does follow, and is equal to the ſecond Part of the Angle of Incidence, which alſo does wholly increaſe and diminiſh in the ſame Ratio, as the Arc *n* O; for the Ratio which holds in reſpect of every Part, taken ſingly, will alſo hold in reſpect of the Whole.

662 The ſame Demonſtration may be applied to any diverging or converging Rays, which in any Caſe are refracted in paſſing thro' a ſpherical Surface; and which (as appears by this Demonſtration) when they diverge but little, have their Focus real, or imaginary, or run parallel. It is enough to have obſerv'd this in general.

The

The Focus F *of the Rays, that come from* R, *goes farther off when* R *is brought nearer; and so on the contrary.* For the radiant Point being brought nearer, if the Point *n* remains the same, the Angle of Incidence is increas'd; and as it increases, so does also the Angle of Refraction F *n* C, and *n* F intersects R C at a greater Distance.

Experiment 2. *Plate* VI. *Fig.* 4.] This Experiment differs from the foregoing only in this, that a Cylindric Beam of the Sun, reflected horizontally, must be transmitted thro' the Convex Lens in the Board T, as was done in the Experiments of the foregoing Chapters, to form the radiant Point R, from which the Rays, going forward, diverging, are collected in the Water at a greater Distance, than if they had been parallel.

As you move the Board T, the Point R also changes its Place: If this Point is farther off from the Surface that separates the Mediums, F falls nearer to it: On the contrary, if R be nearer, F is farther off.

The radiant Point may be brought so near to the 664
Surface above-mention'd, that the Focus will recede to an infinite Distance; that is, *that the refracted Rays will run parallel.*

Experiment 3. *Plate* VI. *Fig.* 5.] Things being dispos'd as in the former Experiment; by removing the Board T, let R be brought nearer to the Trough; and it may easily be so dispos'd, as to make the refracted Rays become parallel.

Experiment 4. *Plate* VII. *Fig.* 1.] Now if the 665
Experiment be repeated, *bringing nearer* to the Trough *the radiant Point* R, *the refracted Rays will become divergent; but they will diverge less than*

666 *the incident Rays. If the Rays, which out of a rarer enter into a denſer Medium thro' a convex Surface, be converging and directed towards the Center of that ſpherical Surface, they will ſuffer no Re-*
* 629 *fraction *. But if they be directed towards another*
667 *Point*, ſince they are refracted towards the Per-
* 624 pendicular*, they will be ſo inflected, that the Focus of theſe converging Rays will always be between the Center of the Surface which ſeparates the Mediums (to which all the Perpendiculars are directed) and the Point to which the incident Rays tend. *That is, if the imaginary Focus of the incident Rays be at a leſs Diſtance than the Center, the refracted Rays will be leſs converging: But if this imaginary Focus be beyond the Center, the refracted Rays will be more converging.*

Experiment 5. *Plate* VII. *Fig.* 2.] Every Thing being in the ſame Manner, as in the former Experiments, it is eaſy to confirm theſe Propoſitions by Experiments; for the Board T may be ſo diſpos'd, that the convergent Rays ſhall enter the Water, ſo as to have their imaginary Focus at any Diſtance in it.

668 From what has been ſaid hitherto it is eaſy to determine what happens *in a contrary Motion*
* 626 *of the Rays**; that is, the Motion of the Rays from a denſer into a rarer Medium, *the convex Surface remaining towards the rarer Medium.*

Parallel Rays, after Refraction, concur in a
* 644 *Focus *:*

669 *The Rays that come from a radiant Point meet*
* 661 alſo *in a* Point or *Focus* *, and as that Point is brought near, the Focus goes farther off; and
* 663 ſo the reverſe on the contrary*.

670 *The radiant Point may be ſo placed, as that* the Focus ſhall fly out to an infinite Diſtance; that
* 660 is, *the Rays will become parallel*.*

If

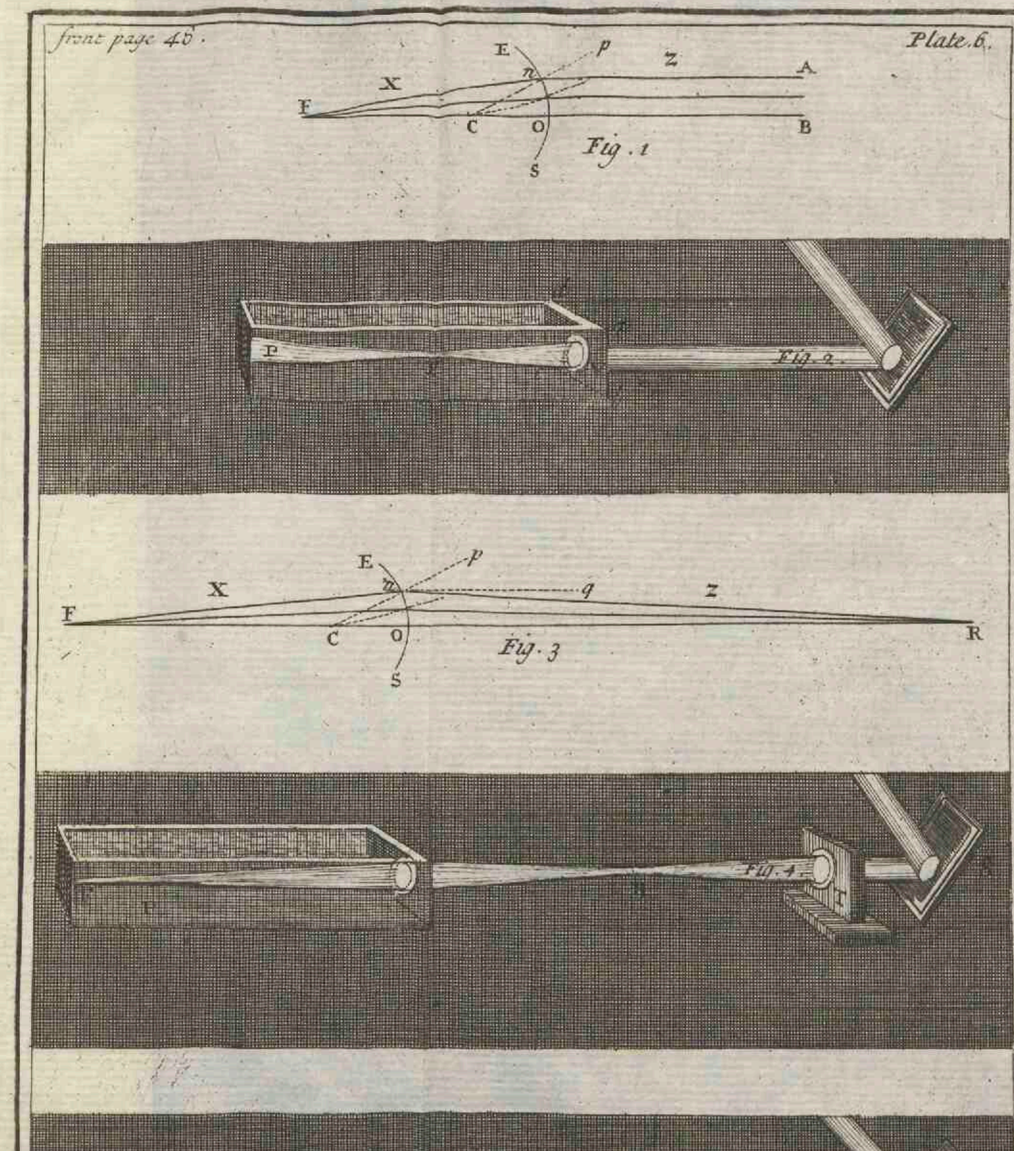
front page 48.
Plate 6.
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Fig. 1
Fig. 2
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Fig. 3
Fig. 4
Fig. 5
P

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the incident Rays. If the Rays, which out of a rarer, pass into a denser Medium thro' a convex Surface, be converging and directed towards the Center of that spherical Surface, they will suffer no Refraction*. But if they be directed to another Point, then they are refracted towards the Perpendicular*; this will easily be inferred, that the Focus of these converging Rays will always be between the Center of the Surface, which separates the Mediums (to which all the Perpendiculars are directed) and the Point to which the incident Rays tend. That is, If the imaginary Focus of the incident Rays be at a less Distance than the Center, the refracted Rays will be less converging; and if the imaginary Focus is beyond the Center, the refracted Rays will be more converging.

Experiment, Plate VII. fig. 2.] Every Thing being in the same Manner, as in the former Experiment, it is easy to confirm this Proposition by Experiment; for the Board [illegible] may be so placed, that the convergent Rays shall enter the Water, so as to have their imaginary Focus at any Distance [illegible].

[illegible] it is easy to [illegible] what happens in a concave Surface [illegible] by the Motion of the Rays from a denser into a rarer Medium, the concave Surface [illegible] towards the rarer Medium.

Parallel Rays, after Refraction, concur in a Focal Point*.

669 The Rays which come from a radiant Point, have also a Focal Point*; and as that Point is brought nearer, the Focus goes farther off; and so the reverse the contrary*.

The radiant Point may be so placed, as that the Focus shall be at an infinite Distance; that is, the Rays will become parallel*.

If the radiant Point be brought nearer, the refracted Rays will diverge; they *will diverge less than the incident Rays, if the radiant Point be more distant from the Surface than the Center**. 671

* 667

But *if the radiant Point be between the Surface and the Center, the refracted Rays will be more divergent **. 672

* 667

If the Rays are convergent, they become more convergent in every Case, which follows from the Refraction being made fromwards the Perpendicular*, and which may be also deduc'd from N°. 665. 673

* 625

Plate VII. *Fig.* 3.] *Let us* again *suppose the Rays to go out of the rarer Medium* Z *into the denser* X, *and that the Hollow or Concave of the spherical Surface* E S, *which separates the Mediums, is towards the rarer Medium.* If the Rays be *parallel*, as B O, A *n*, B O, which goes thro' the Center C of the Surface E S, will not be refracted; but A *n* is refracted towards the Perpendicular C *p* along *n* G *, and, being continued towards Z, intersects B C O at *f*, which is also true in respect of the *Rays between* B O and A *n**; those Rays therefore *become divergent*, having their imaginary Focus *f* in the rarer Medium. 674

* 624

* 662

Experiment 6. *Plate* VII. *Fig.* 4.] This Experiment differs from the first of this Chapter, only in this, that the Glass V has its Concavity towards the Air, the Trough P being in all other Respects the same; in this Case the Rays of the cylindric Beam diverge in the Water.

If Rays come from a radiant Point in C B, *which is beyond* C (*Plate* VII. *Fig.* 3.) the Angle of Incidence A *n* C is diminish'd, and therefore also the Angle of Refraction G *n p* grows less; that is, *the refracted Rays become more diverging*, and the imagi- 675

* 646 imaginary Focus *f* comes nearer to C *; till by the radiant Point coming nearer, at length it coincides with the imaginary Focus at C; for in
* 629 that Case the Rays undergo no Refraction*.

676 If the radiant Point comes nearer between C and O, the imaginary Focus is farther from O than the radiant Point, for it is always between that Point and C, by reason of the Angles of Re-
* 624 fraction being less than those of Incidence*.

Experiment 7.] Things being, as in the former Experiment; if you use the Board, with the Convex Lens in it, to form a radiant Point, the Experiments proving these Propositions may be easily made.

677 *If the Rays are converging, and the Point of Concourse be in the denser Mediums, near the Surface which separates the Medium, the refracted Rays* will also *converge*, but *less than the incident Rays.*

678 If the imaginary Focus of the incident Rays recedes more and more from O, that is, *if they converge less, the refracted Rays will also converge less; until, by the receding of the imaginary Focus, the Rays become parallel.*

679 *If the imaginary Focus recedes yet farther, the refracted Rays become divergent.*

Experiment 8. *Plate* VII. *Fig.* 5.] Here the Board must be so plac'd in respect of the Trough, that the Rays may enter the Water converging; and the Phænomena above-mention'd may be seen, according as you remove the said Board.

680 Rays which *from a denser go into a rarer Medium, the concave Surface being towards this last,* are almost subject to the same Laws.

* 678 *Parallel Rays by Refraction become divergent*.*
626 681 *If they proceed from a radiant Point, they become more divergent*.*
* 677

And

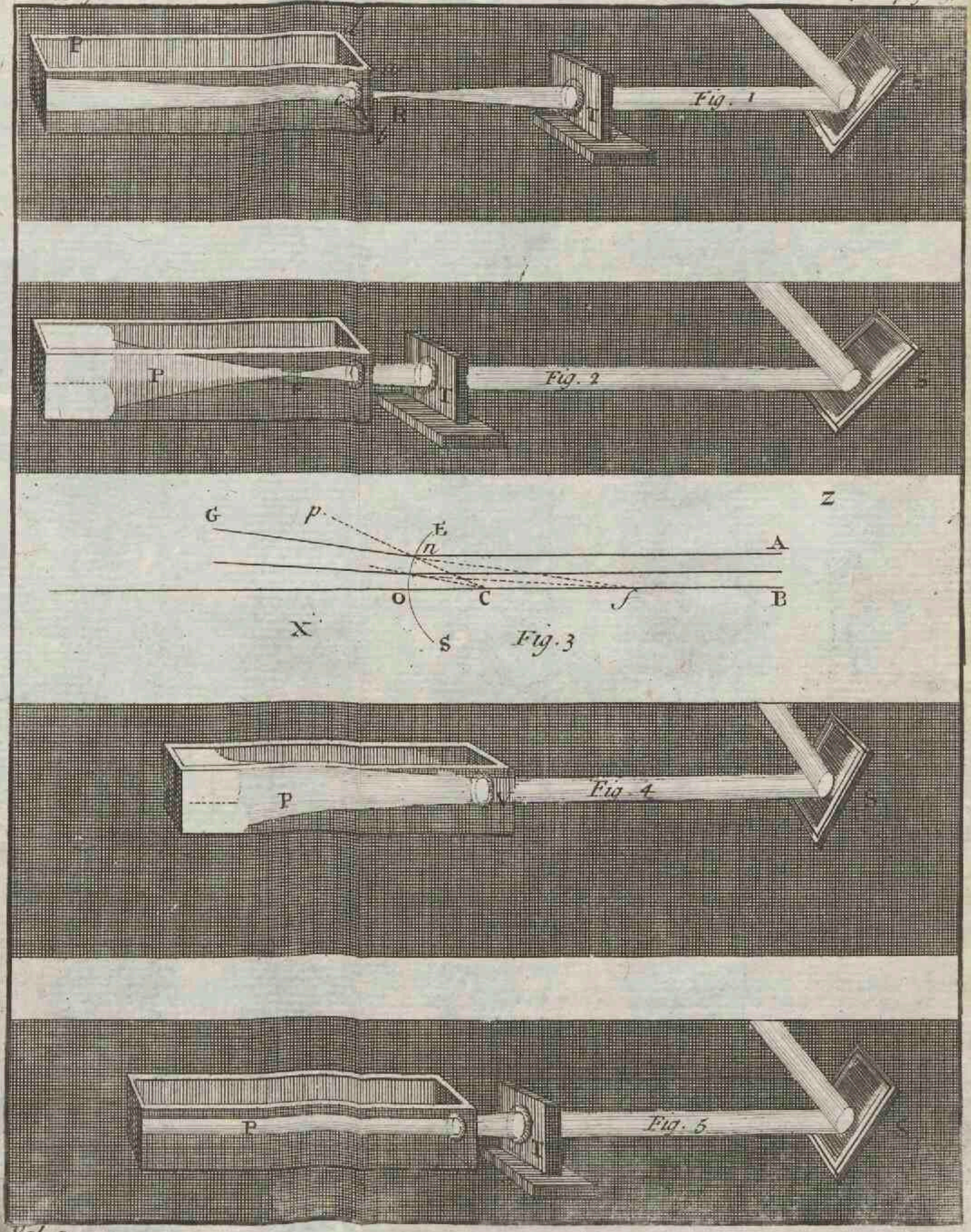
P
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Fig. 1
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Fig. 3
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Fig. 4
P
Fig. 5

And they diverge still more and more, as the radiant Point is brought nearer *. 682
* 678

Converging Rays, which tend to the Center of the spherical Surface, undergo no Change *. 683
* 629

If they converge more or less, the imaginary Focus of the incident Rays is always between the Center of the Surface, which separates the Mediums, 684 685 *and the Focus of the refracted Rays,* * *which may recede* in infinitum, *so as to make the refracted Rays become parallel* *. * 675, 676
* 674

We have hitherto consider'd such Rays as are but little inclin'd to the Surface which separates the Mediums; for we have mention'd such incident Rays as diverge but little, and one of which is perpendicular to the Surface that separates the Mediums. *The same Propositions hold* 686 *good in oblique Rays*, yet *in that Case all the Rays are inflected*, which does not happen so in direct ones; for the Ray which is perpendicular to the Surface is not inflected. Oblique Rays also undergo a greater Refraction, that is, *they are more inflected either to or from each other*, 687 than direct ones, supposing the Circumstances the same.

Plate VIII. *Fig.* 1.] Let Z be a rarer, and X a denser Medium, E S the Surface separating the Mediums, and having its Center at C; and the parallel Rays A *n*, B *m* will come together at F. The Rays that proceed from the radiant Point R will concur at F.

Plate VIII. *Fig.* 2.] If the Surface be turn'd so as to have its Concavity towards the rarer Medium, the parallel Rays A *n* and B *m* will have their imaginary Focus at *f*; but its Distance from the Surface E S, as also that of the above-mention'd Foci F and *f* in the *Figure* 1. is less, than if the Rays were direct.

688 *All the Points of a lucid Body are radiant Points, and have each their particular Focus*, which ſerves to explain the following Experiment, made to confirm what has been ſaid of the oblique Rays.

Experiment 9. Plate VIII. *Fig.* 3.] Take the Trough P mention'd in the firſt Experiment, and fill it with Water; let the Glaſs V be all cover'd, but a circular Part in the Middle of about half an Inch; have in the Trough a moveable white Plane T. If the Candle A be ſet at the Diſtance of 3 or 4 Foot from the Trough, let the Plane T be mov'd backward and forward in the Water, and when it is come to the Diſtance of the Foci of the Flame A, that Flame will appear exactly repreſented on that Plane, all the Foci forming a Picture. And this holds good, whether the Rays from the Candle fall obliquely or directly upon the Glaſs V, only that when the Rays are oblique (the Diſtance of the Candle A remaining the ſame) the Diſtance of the Plane T from V muſt be leſs. In this Caſe alſo the Candle and the Glaſs V will not be in the ſame right Line as the Repreſentation of it, as it happens when the Rays are direct, by which the Propoſition of N°. 686. is confirm'd.

689 *The Candle is repreſented inverted*, becauſe the Rays, which proceed from different Points, interſect one another as they go thro' V, as may be plainly ſeen by looking at the firſt Figure. For which Reaſon, if there are two Candles, as A and B, the Repreſentation of the laſt will be at *b*, and that of the firſt at *a*.

690 *All the Changes that happen in Light*, which we have taken Notice of in this Chapter, *are ſo much the more ſenſible, as the Surface ſeparating the Mediums is* more curve; that is, *a Part of a leſſer Sphere*.

CHAP.

CHAP. IX.

Concerning the Motion of Light thro' a more dense Medium. Where we shall take notice of the Properties of Lenses.

THE Use of Glasses is common, they are 691
more dense than Air, and the Rays out of Air pass thro' the Glass into Air again. According to the several Surfaces that terminate the Glass, Light undergoes different Changes as it moves in it; which to determine, the Glasses, or any Mediums encompass'd with a rarer Medium, and terminated with different Surfaces, must be examin'd. *If we consider only plane and spherical Surfaces, there are six Sorts.*

The Medium may be plane or flat on both Sides. 2. Plane on the one Side and convex on the other. 3. Convex on both Sides. 4. Plane on one Side and concave on the other. 5. Concave on both Sides. 6. *Lastly*, It may be terminated with a concave Surface on one Side, and a convex one on the other.

DEFINITION I.

If the Glass be made use of, and is not very 692
thick, Glasses, whose Figure is mention'd in the last five Cases, are call'd *Lenses of Glass*.

In the second and third Case, a Lens is said to be convex; and if we distinguish those two Cases, in the second it is call'd *plano*-convex. And so in the fourth Case, it is said to be *plano*-concave; tho both this Case, and the fifth, is generally referr'd to concave Lenses. But a *concavo*-convex Lens is referr'd to the concave or convex Lenses, according as the one or the other Surface is predominant; and that is said to be predominant which is moſt curve; that is, which is a Portion of a leſs Sphere.

DEFINITION II.

693 *In every Lens, or Medium, terminated in any Manner above deſcribed, a right Line, which is perpendicular to the two Surfaces, is call'd the* Axis. When both Surfaces are ſpherical, the Axes goes thro' both their Centers; but if one of them be plane, it falls perpendicularly upon that, and goes thro the Center of the other.

694 In the Paſſage of Light thro' a Medium, terminated by two plane Surfaces, *the Direction of*
* 628 *the Rays is not changed* *; which is the Caſe *in plane Glaſſes.*

695 *It is the Property of all Sorts of convex Lenſes, that the Rays in their Paſſage thro' them are inflected towards one another; ſo much the more, as*
696 *the Convexity is greater: And ſo concave ones, that the Rays are deflected from one another, according as the Concavity is greater.* For the Direction of
* 694 the Rays thro' a plane Glaſs is not changed; * but, by inflecting one or both Surfaces, another Direction is given to the Rays: There are more inflected towards the Axis of the Lens, by reaſon of the Convexity of the Surface of the Glaſs, and, by making the Surface concave, they are deflected from the Axis; as is plain in every Caſe, by comparing the Inflection in the plane Surface that is perpendicular to the Axis, with the Inflection in the ſpherical Surface at any Diſtance from the Axis. And the Difference of their Inflexions, that is, the Change of the Direction of the Rays, increaſes, as their Diſtance from the Axes does; and it is to be obſerv'd in every Direction of the Rays, as well in oblique Rays, as in direct: but *the Changes are greater in oblique Rays*, becauſe the Angles of Incidence are greater. From which
697 we deduce the following Properties of Lenſes.

That

That *parallel Rays, by passing thro' a convex Lens, concur in a Focus.* 698

That *diverging Rays either diverge less, or run parallel, or lastly, converge; in which Case, the radiant Point receding, the Focus comes nearer, and so on the contrary:* But this is the Case, when the radiant Point is farther distant from the Lens than the Focus of parallel Rays. 699

Lastly, That *converging Rays converge more, when the Light emerges out of the Lens.* 700

The same Things are observable in oblique Rays; concerning which it is to be noted, that the Distances of the Foci of the emerging Rays, are less than in the direct, and the other Changes more sensible.* 701

* 697

All these same Things may be deduced from examining the double Refraction in the Entrance and Emersion of Light. And this double Refraction is visible in every Case, by the following Experiments; by which the aforesaid Properties of convex Lenses are confirm'd.

Plate VIII. *Fig.* 4.] Take several Boxes like P, with Water in them, and thro' which Light is transmitted thro' the Glasses V and V, which are placed in the opposite Sides of the Box, and are distant from one another about one Inch. These Glasses are thin; in the Box which represents a convex Lens, on each Side there is placed one, like that of the first Experiment of the former Chapter, which are so disposed as to have their Convexities without the Box. When a *plano*-convex Lens is to be represented, on one Side there is a plane Glass. A *concave*-convex Lens is represented by two spherical Glasses, that are Portions of different Spheres, and the Convexity of the Portion of the greater Sphere, must be turn'd towards the Inside of the Box. 702

Whilst the Light passes thro' these Boxes, the Changes of the Light are visible to the Eye in its Entrance into, and Emerſion out of a denſer Medium, and by the Aſſiſtance of theſe, all Things, relating to convex Lenſes, are clearly demonſtrable.

Experiment 1.] *Ex. gr.* Let P be one of the fore-mentioned Boxes, with the ſpherical Glaſſes V, V, the Convexities being placed outwards; let it be fill'd with Water; in a dark Room let a cylindric Beam of the Sun be horizontally reflected from the Looking-Glaſs S; let this Beam enter the Box; the parallel Rays, of which it is form'd, will be inflected towards one another, and will converge; at their Emerſion on the other Side, they will converge more, and concur in F. Experiments may be made of the incident Rays, which diverge or converge, by uſing the Board with the convex Lens, as in the Experiments of the former Chapter.

Every Point of a lucid Body, as was ſaid be-
*688 fore, is a radiant Point, * and being placed at a
due Diſtance from a convex Lens, every one has
*698 its Focus. *

Experiment 2.] Let a lighted Candle be removed from a convex Lens beyond the Focus of parallel Rays; at the oppoſite Part of the Lens, upon a white Plane, by the Foci of the Points of the Flame, it will be repreſented; and this Repreſentation will be inverted, by reaſon of the Interſection of the Rays in their Paſſage thro' the Glaſs.

703 *Convex Lenſes are alſo burning Glaſſes*, becauſe
*698 they collect the Rays of * the Sun, which, upon the Account of the immenſe Diſtance of the Sun, are eſteem'd as parallel. But Rays united in a Focus, (by reaſon that the Fire, that was before diſperſed, is now collected, and by reaſon

Plate 8.

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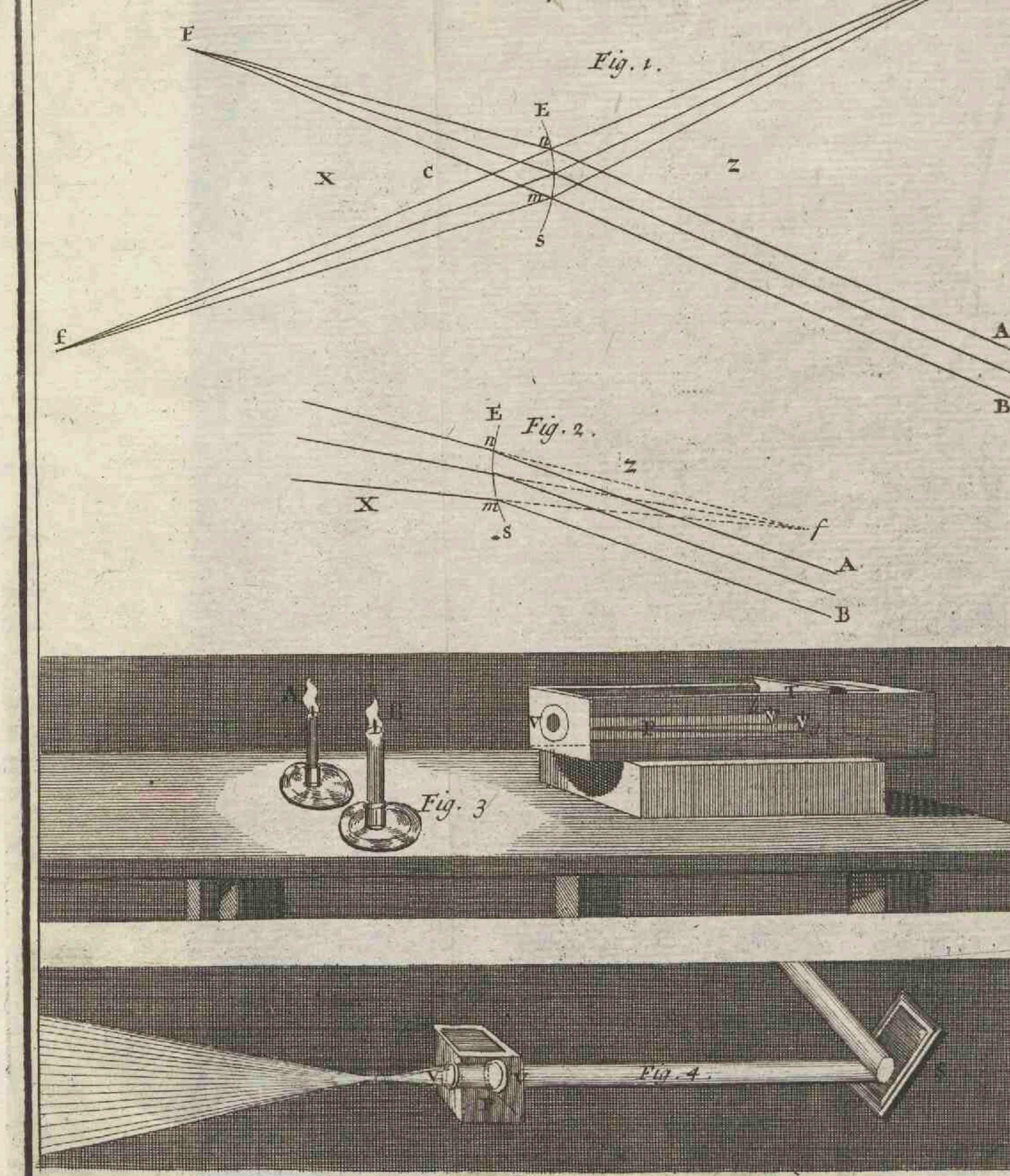

ſon of the Motion of the Fire according to various Directions,) do burn vehemently.

Experiment 3.] Take a convex Lens of any Magnitude, let it be ſo expoſed to the Rays of the Sun, that the Axis of the Lens may be in the Direction of the Rays; if any combuſtible Body be placed in the Focus of the Sun's Rays, it will burn.

When, by reaſon of the Magnitude of the Lens, the Rays are not exactly enough collected, before they come to the Focus, they muſt be tranſmitted thro' another convex Lens that is leſs, by which they will be reduced into a ſmaller Compaſs, ſo as to burn more violently.

As for concave Lenſes, and their Properties, they may be eaſily deduced from * what has * 696
been ſaid.

Parallel Rays become diverging, by paſſing thro' 704
a concave Lens.

Diverging Rays diverge the more. 705

Converging Rays either converge the leſs, or be- 706
come parallel, or (as it happens in ſuch as converge leſs) *go out from the Lens diverging.*

All which Things happen to oblique as well 707
as direct Rays, but more ſenſibly in the firſt. * * 697

Plate IX. *Fig.* 1.] Boxes, to repreſent the Ef- 708
fects of concave Lenſes, are made in the ſame Manner as thoſe that repreſent the Effects of convex ones.* The Difference is only in the Poſi- * 702
tion of the Glaſſes: In the firſt Box the Concavities of the two ſpherical Glaſſes V, V, are outwards. In the ſecond, inſtead of one of thoſe Glaſſes, you have a plane Glaſs. In the third. you have two ſpherical Glaſſes, but Sections of different Spheres; the Section of the greater Sphere has its Convexity outwards, and the other its Convexity inwards.

Expe-

Experiment 4.] Parallel Rays of the Sun, reflected horizontally in a dark Chamber by the Looking-Glaſs S, muſt be tranſmitted thro' the Box P, which is full of Water, and repreſents a Lens concave on both Sides: As they go into the Box they will begin to diverge, and as they go out they will diverge more.

The remaining Experiments, relating to concave Lenſes, are made in the ſame Manner, as has been ſaid, in reſpect of convex Lenſes.

CHAP. X.

Of Viſion; where we ſhall ſpeak of the Make of the Eye.

THE Properties and Laws of the Refraction of Light, that we have explain'd, are of wonderful Uſe in repreſenting Objects to our Mind.

By theſe Laws, the Objects are beautifully painted in their proper Colours in the Bottom of the Eye; and this Picture, as I ſhall ſay here-
*716 after, * is the Occaſion of the Ideas which are excited in our Minds concerning the Things that we ſee.

How this Picture is form'd in the Eye, cannot be explain'd, without examining a new Property of Light; namely, its Diviſibility, which is paſt our Comprehenſion.

DEFINITION.

709 *A Body that is not lucid, and intercepts the Light, is ſaid to be* opaque.

710 *Several* among all the opaque *Bodies*, when exactly poliſh'd (except perfectly black Bodies, if

 there

there are any ſuch) have the Property of dividing Light; for they *reflect the Light, ſo that the Rays from every Point*, being ſtruck back, are divided, and *recede every Way*, ſo that *all the ſingle Points of the Body become as it were radiant Points*, from which Light goes every Way.

Whence we deduce a Method of painting Ob- 711
jects upon a white Plane; for all the Points of the enlighten'd Body, from which the Rays come upon a convex Lens, have their Focus of the other Side of the Lens.* The Foci of diſtant * 699
Objects, tho not exactly, are ſenſibly at the ſame Diſtance from the Lens; thoſe Objects may by theſe Foci be repreſented in the ſame Place; which Repreſentation is inverted, (by reaſon of the Interſection of the Rays as they go thro' the Glaſs,) and ſenſible in a dark Place, in which Light comes in no Way but thro' the Lens, and only that Light by which the Objects are repreſented.

This will do wherever the Lens is placed, and in Reſpect of all the Points of Objects, enlighten'd by Rays of Light, from which right Lines without Interruption may be drawn to the Lens; in this Manner the above-mention'd Diviſibility in Light may be proved, and the Aptneſs that Bodies, that reflect Light, have to divide it.

Experiment 1. *Plate* IX. *Fig.* 2.] Make an Hole in a dark Place, over-againſt ſeveral Objects that are at leaſt 50 Foot off or farther. Let the Hole be V, and let it have a convex Lens in it that collects parallel Rays at the Diſtance of about 4 or 5 Feet; if a white Plane be placed behind the Lens a little farther from it than that Diſtance, all the Objects above-mention'd will be painted upon it in very beautiful Colours. It is to be obſerv'd, that the Lens muſt be placed in a Poa Poſition parallel to the Plane; and that by moving the Lens or the Plane, the Diſtance muſt be found at which the Objects are repreſented moſt exactly.

This Repreſentation of Objects has great Affinity with that by which the Objects, that we ſee, are repreſented in the Bottom of the Eye, as will appear from the Make of the Eye.

712 The Figure of the Eye, when taken out of the Head, is nearly ſpherical; only the Fore-part is ſomething more convex than the reſt.

The Section of the Eye is repreſented *Plate* IX. *Fig.* 3.

The Part A A, which is moſt convex, is tranſparent, and call'd the *Tunica Cornea.*

The whole Covering of the Eye, except the *Cornea*, is call'd the *Sclerotica*, B A A B.

That Part of the *Sclerotica*, which is next to the *Cornea*, is call'd *the Adnata*, or *White of the Eye*.

Behind the *Cornea*, on the Inſide, is a Coat call'd the *Uvea*, which has in its Middle an Hole *pp*, call'd the *Pupil.*

The Uvea is made up of concentric circular Fibres, interſected at right Angles by ſtrait Fibres. If the firſt are ſwell'd, the laſt are relax'd, and the Pupil is leſſened or contracted; and a contrary Motion of the Fibres increaſes or widens it.

In the Middle of the Eye, but nearer the Fore-part, there is a tranſparent ſoft Body C C, like a convex Lens, whoſt Hind-part is more convex than the Fore-part. It is call'd *the Cryſtalline Humour*. Its Axis coincides with the Axis of the Eye, that goes thro' the Centers of the Pupil and the whole Eye.

This cryſtalline Humour is ſuſtain'd by ſmall Fibres or Threads, which are fix'd to all the Points of its Circumference, and likewiſe to the

Inside of the Eye: They are inflected in the Form of an Arc, and every one of them is a Muscle; they are call'd the *Ligamenta Ciliaria*, and two of them are represented by *l* C, *l* C. They all cohere to one another, and, together with the Crystalline, make a Separation in the Eye, and divide it into two Cavities, one forwards *p p*, and the other backwards S S.

The Cavity, that is forwards, is fill'd with a Liquor like Water, call'd the *Aqueous Humour*.

The hind Cavity is fill'd with a transparent Humour, nearly of the same Density as the Aqueous Humour, but not so fluid, call the *Vitreous Humour*.

The hind Surface of the Eye within is lined with a Coat call'd the *Choroides*, which is again cover'd with a thin Membrane call'd the *Retina*.

At the back Part of the Bulb of the Eye, a little on one side, is the Optic Nerve N N so join'd to the Eye, that the Eye itself is, as it were, an Expansion of the Optic Nerve; for the expanded Coats of the Nerve form the Choroides and Sclerotica, and the Fibres, which make up the Retina, concurring, make the Marrow of the Nerve.

The Eye is moved in the Head by several Muscles inserted in the Sclerotica; but we shall not treat of them here: As we only consider the Eye with respect to the Motion of Light, we purposely forbear to take Notice of any Thing else.

Rays that proceed from any Point, and enter the 731
Eye thro' the Pupil, go out of a rarer into a denser Medium thro' a spherical Surface; and therefore *if that Point be at a due Distance from the Eye*, the Rays *after Refraction will converge*; * in the same * 661
Manner as in the Experiment of N°. 663. (*Plate* VI. *Fig.* 4.) in which the Glass V represents the transparent Cornea of the Eye, whilst the Water

in the Trough is instead of the aqueous Humour; and therefore, *supposing only the Cornea and the*
714 *aqueous Humour, there will be in the Eye an in-*
*710, *verted Picture of the Objects.* *
711

Experiment 2. Plate IX. *Fig.* 4.] Let P be the Trough above-mention'd full of Water, and set in a dark Place, which has an Hole about half an Inch wide, so dispos'd towards enlighten'd Objects at a certain Distance, that one may see them thro' the Hole; let the Glass V of the Trough be applied to this Hole, and upon the white Plane T you will have an inverted Picture of the Objects: By moving the Plane backwards and forwards, you will find the Place where the Picture is most distinct.

If the abovemention'd Picture, which we have imitated in this Experiment, was to be made in the Eye, it would be at too great a Distance from the Cornea, and beyond the Bottom of the Eye; and therefore this Distance is diminish'd
715 *by Help of the Crystalline Humour*, which is denser, but encompass'd with rarer Mediums; for the Rays, converging in the aqueous Humour, pass thro' the crystalline into the vitreous Humour; that is, out of a rare Medium thro' a denser, (which is terminated by two spherical convex Surfaces) into a rare Medium again; by
*700 which Motion the Rays converge still more; * and therefore they concur sooner, and *the Picture above-mentioned falls within the Eye.*

716 *The Objects which*, as we have explain'd, *are represented in the Bottom of the Eye, are painted upon the Retina; and by the Motion of Light the small Fibres, of which the Retina is made up, are agitated; by which Agitation, the* Ideas *of the Objects, painted in the Eye, are excited in the Mind.* The Connexion between the *Ideas* and the Motions by which they

they are excited, is unknown to us, * as we said * 502
before: In determining the Causes of Sensations, we can go no farther than the Agitation of the Nerves.

The more exact the Picture above described is, the 717
more distinct will the Objects appear. When the 718
Rays, coming from the same Point, are not exactly united upon the Retina, its Picture is not a Point, but a Spot, which is confounded with the Pictures of the neighbouring Points; in which Case the *Vision is confused.*

But when, *according to the different Distance of* 719
the radiant Point, its Focus is brought nearer, or removed farther off, * *it is necessary that there should* * 663
be a Change in the Eye, lest the Place, in which the Picture is exact, should fall short of, or beyond the Retina, and so *the Vision should be confused.*

But it is very difficult to determine what this Change is, and Philosophers are divided in their Opinions about it: I shall only observe in general, that *it is not very probable that the Figure of*
the whole Eye is changed, in order to put back or 720
bring forward the Retina; and therefore we must expect to find this Change within the Eye.

For if the Figure of the Eye was changed, as this Change must be equally necessary in all Animals, the Eyes of all Animals would undergo the same Changes; for the same natural Effects cannot have different Causes. Now in the Whale the Sclerotica is too hard to be subject to any Alteration of Figure. Besides, if there was such a Change in the whole Eye, it would arise from the external Pressure of the Muscles, which would be different in different Positions of the Eye, and only regular in one Situation of it.

If now we examine the Eye within, it will appear necessary that there should be a Change in the Crystalline; which by changing its Place

or

or Figure in the Eye, will produce the desired Effect; for the Rays that fall upon the Retina, before they are united, will be made to unite just upon the Retina, if the Crystalline becomes
* 695 more convex, * or if (its Figure remaining the same) it be brought forwards towards the Cornea.

721 That *the Position of the Crystalline Humour is easily changed, and* that *it is brought nearer to, or farther from the Retina,* its Axis remaining the same, is plain, because the ciliary Ligaments are muscular: When these Muscles are swell'd, and become shorter, the Hollow which their Inflection makes at C*l*, C*l*, becomes less; by which means the vitreous Humour is compress'd, and therefore it presses upon the Crystalline, and pushes it forwards farther from the Retina; which is necessary when we look at near Ob-
* 663 jects.*

699 From an Experiment, that we shall hereafter
753 mention, it has been demonstrated, that there is another Change in the Eye that acts contrary to this; and we shall shew what is the Occasion of it. The second Change is also to be re-
622 ferr'd to the Crystalline; which (*when it is drawn by the ciliary Ligaments, to make it recede from the Bottom of the Eye*) *becomes also flatter, and therefore it must recede farther than if its Figure was unchangeable*; that is, the Change becomes more sensible; which we shall shew to
* 730 be of Use.*

These Changes in the Eye have their Limits, for which Reason also *Objects appear only distinct*
724 *within certain Limits, which are different Distances*
725 *according to the Difference of People's Eyes; and very often in the same Man, both Eyes have not the same Limits*; which is almost of the same Use, as if the Limits of both Eyes were more distinct from one

one another: For one may see an Object distinctly enough with only one Eye. In some Persons also the nearest Limit of one Eye is farther off than the farthest of the other: In which Case near Objects and distant Objects are seen distinctly, but the intermediate ones appear confused.

The Picture in the Bottom of the Eye, as has 726
been said, * is inverted; whence a Question a- * 714
rises, why we see Objects erect? To which we answer by asking another Question; Whether it is more easy to conceive the Connexion between an Idea in the Mind, and an erect Figure, than an inverted one? We confess, that we have no Notion of that Connexion in either Case: But Experience teaches us, that there is a Connexion between an inverted Picture in the Eye, and the Idea of an erect Object; and further than this we do not know.

If we look at the same Object with both Eyes, 727
it will appear single; but this happens only when the Object is painted in correspondent Points of each Retina; which probably happens from the meeting of the Optic Nerves. For it is observ'd in all Animals, which see the same Object with both Eyes, that the Optic Nerves meet and separate again before they go to the Brain; but in Animals which see different Objects with each Eye, the Optic Nerves go separately from the Eyes to the Brain.

Only one Point at a Time can be seen distinctly, 728
namely, that which is represented in the Axis of the Eye; if we look at one Point with both Eyes, we must so direct the Eyes, that their Axes continued shall meet in that Point; which happens when we have our Eyes intent upon any Point.

By this Direction of the Axes we judge of the Diſtance of Objects; for the Situation of the Eyes alter according as the Axes make a different Angle, which Angle depends upon the Diſtance of the Object: Whence it happens, that without perceiving when we do it, by Uſe we get a Habit of judging of the Diſtance of
729 Objects *by the Direction of the Axes*; which is ſenſible to us, becauſe it depends upon the Motion of the Eye, that we feel. Therefore we may ſee the Uſe of having two Eyes placed at a certain Diſtance from one another; *as long as this Diſtance of the Eyes bears a ſenſible Proportion to the Diſtance of the Objects, we can judge of it pretty certainly.*

730 *We can alſo judge of leſſer Diſtances with one*
*721 *Eye alone*; becauſe in the Variation of a ſmall
723 Diſtance, the Change in the Eye is ſenſible.*

731 *In great Diſtances*, if we look at known Objects, *we judge from the apparent Magnitude and the Colour.*

732 *It is impoſſible to judge of very great Diſtances, except the ſame Objects be ſeen from different Places.*

733 *The apparent Magnitude of an Object depends* upon the Bigneſs of the Picture in the Bottom of the Eye, which Picture depends *upon the Angle under which an Object is ſeen*, that is, the Angle which is form'd by Lines drawn from the Extremities of the Object to the Eye.

734 *This* apparent *Magnitude* is to be diſtinguiſh'd from the Magnitude *which our Mind attributes to the Object that we ſee*, which laſt is founded upon the Judgment, whoſe Foundation is not in the Appearance alone. Every Body knows that the Object appears the leſs according as it is more diſtant; whence it happens, that, *according to the greater Diſtance of the Object*, if it be known, the apparent Magnitude of the Object *is increas'd*

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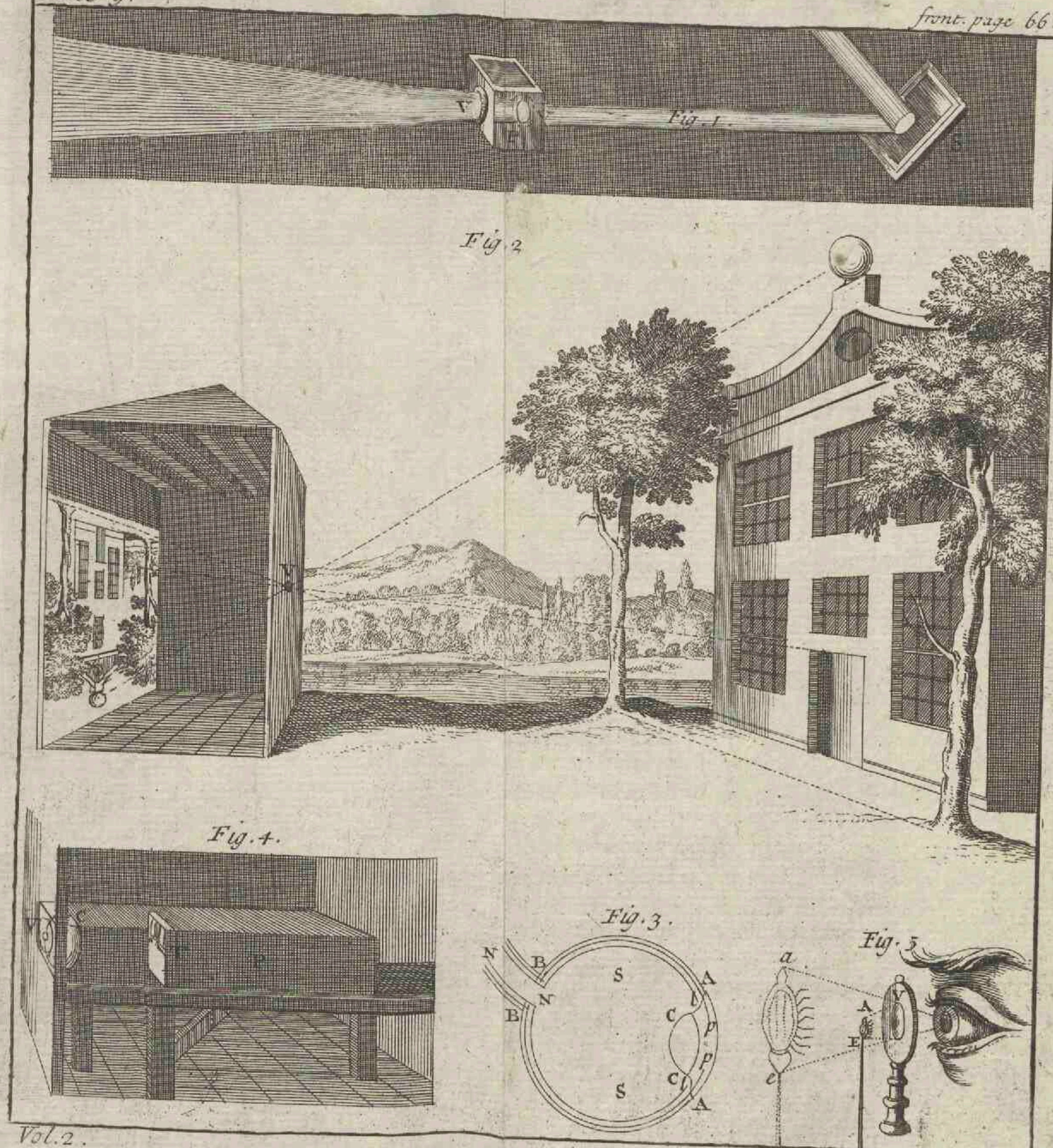

in the Judgment that our Mind makes of it, which we do without any Attention to it. Therefore the same Object at the same Distance appears of a different Magnitude, if we judge differently of the Distance.

We have a remarkable Example of this in re- 735
spect of the Sun and Moon, which appear greater when near the Horizon, than at a greater Height; tho, as is known to Astronomers, the Picture of the Sun in the Bottom of the Eye is the same in both Cases, and that of the Moon is less when it appears nearer the Horizon; we cannot judge of the Distance in either Case, * but it appears * 732
greater near the Horizon, by reason of the Interposition of the Fields and Part of the Heavens. If we see the Bodies above-mention'd thro' a Tube, this apparent Distance vanishes, as also the Magnitude which is deduc'd from it. From our Childhood upwards, and so continually, we join the Idea of Distance with the Increase of apparent Magnitude, (which is necessary for making a true Judgment concerning the Magnitude) whereby the Ideas are so closely join'd, that they cannot be separated, not even in those Cases, in which we know that they lead us into Error. Logicians teach us, how many Errors are to be attributed to Ideas so join'd.

CHAP. XI.

Of Vision thro' Glasses, and how to correct some Defects of the Eyes.

AN Object is visible, because all its Points 736
are as it were radiant Points; * therefore * 713
a *Point appears in that Place from whence diverging* 714
Rays are emitted. 715

737 *If Rays inflected any how enter the Eye diverging, the visible Point will be in the imaginary Focus of the Rays*; for the Rays enter the Eye exactly in the same Manner that Rays would do that came directly from that Focus; and to have them unite upon the Retina, the same Situation of the Crystalline is requisite; so that, in respect to a Spectator, it is no Matter whether those Rays, after Refraction, or these directly enter the Eye; and there will be the same Motion in the Eye, when
* 719, 730 it fits itself for distinct Visions.*

738 *A Point appears the more enlightened, the greater Number of Rays coming from it enter the Eye.*

739 *When Objects are seen thro' a plane Glass terminated with parallel Surfaces, they appear to be nearer than when seen with the naked Eye.* Let A (*Plate* X. *Fig.* 1.) be a visible Point; the Rays, going from it and entring the Eye, are between A *b* and A *b*; these, being refracted in the Glass V V, move along *b c*, *b c*, and go out thro' *c d*, *c d*,
* 628 which are parallel to the Lines A *b*, A *b*: * now because *b c*, *b c*, are refracted towards the Perpen-
* 624 dicular, * *c d*, *c d*, fall between *b* A and *b* A; that is, they intersect at *a*, which is nearer than A; therefore the imaginary Focus of the Rays which enter the Eye is at *a*, in which the Point A ap-
* 737 pears to be.*

740 *That Point* also *appears to be more enlightened, when seen thro' the Glass above-mentioned.* For all the Rays between A *b* and A *b* enter the Pupil between *d* and *d*; but as the Lines A *b*, A *b*, are parallel to the Lines *c d*, *c d*, and these are between those, A *b* and A *b* being continued would fall beyond *d* and *d*; therefore if the Glass was taken away, the Rays, which now enter the Pupil, would take up a greater Space, and therefore would not all enter the Eye.

Plate

Plate X. *Fig.* 2.] *The apparent Magnitude of an Object is increased by the Interposition of a plane Glass*; the Object A E is seen by the naked Eye under the Angle A *d* E; but if you use the Glass V V, by reason of the Refraction thro' A *b c d* and E *b c d*, it will be seen under the Angle *c d c*, which is greater than the last. *But yet the Object is not greater in Proportion to the increased apparent Magnitude*; * for it appears to be at a less Distance.* 741 742 * 734 * 739

The Increase of apparent Magnitude is so much the greater, as is the Difference of the Angles A *d* E and *c d c*; whose Difference *increases* as the Intersections of the Lines A *d* with *b c*, and E *d* with *b c*, come nearer to the Points *b* and *b*; which obtains *as the Object is brought* nearer to the Glass; and therefore it is the greatest of all, when the Object touches the Glass; which shews that Objects, even in the Glass itself, must appear magnified. 743

And in general, *the Eye being placed in a rarer Medium, the Object that is seen in a denser Medium appears bigger, and is also brought nearer by the Refraction.** This is every Day confirm'd by Experience, when we look at Objects in the Water. 744 * 659

Let there be *a Point* A *seen thro' a convex Lens* V V, (*Plate* X. *Fig.* 3.) and the Rays A *b*, A *b*, at *c d*, *c d*, will go out more diverging, as if they came from *a*; * therefore that Point *appears to be at a greater Distance.* *It appears also more enlightened*; for the Rays come nearer to each other as they go thro' the Glass, * and are also reduced into a less Space, wherefore a greater Number of them must enter the Pupil. 745 * 699 * 737 746 * 695

The apparent Magnitude of an Object is also increased; that is, the *Object seen thro' a convex Glass* is seen under a great Angle, which ap- 747

pears from a Sight of the Figure; the Object A E, seen with the naked Eye, is seen under the Angle A *d* E, (*Plate* X. *Fig* 4. and 5.) but now it is seen under the Angle *c d c*, which is greater; (in *Fig.* 4.) the Rays A *b*, E *b*, which are convergent, converge more as they go out of the
* 700 Lens; * or diverging (as in *Fig.* 5.) they come
* 699 to the Eye converging.* Therefore the Object *appears magnified*, both from the Appearance of
* 745 it being farther, * and its Magnitude being in-
* 734 creas'd; * and therefore *the Magnitude, that we*
748 *attribute to an Object, does not follow the same Proportion as the apparent Magnitude*; for which Reason we shall not delay Time in Demonstrations about it: But we shall observe in general,

749 That *the Angle, under which an Object is seen thro' a convex Glass, diminishes as the Eye recedes from the Glass; whilst the Object is not more distant from the Glass than the Point in which parallel Rays are collected: But if the Object is farther off, the apparent Magnitude is increased as the Eye recedes.*

750 After the same Manner, *if the Eye be between the Glass and the Focus of parallel Rays, the Angle abovemention'd is diminished as the Object is farther removed; the Eye being placed at a greater Distance, the same Angle is increased as the Object is farther removed*; in which last Case the Object may be so far removed, as not to be visible beyond the
* 754 Glass, as will be said anon.*

Also in those Cases in which Objects are visible, they do not always appear distinctly.

751 For, *that a Point may appear distinct, it is required that the Rays that proceed from a Point should*
* 736 *enter the Eye diverging,* * *and that the imaginary*
* 727 *Focus of those Rays, in respect of the Spectator,*
724 *should be within the Limits of distinct Vision.**

752 If the Object be removed beyond the Focus of parallel Rays, the Rays flowing from a Point of

of the Object, enter the Eye converging; *which *699
Caſe is impoſſible to the naked Eye: In this the Viſion is always confuſed, and the Eye diſpoſes itſelf ſo as to have the Viſion the leaſt confuſed that may be; from this Diſpoſition we judge of the Diſtance, as we do in every Caſe in which we judge of it with only one Eye.* *730

753 But this Diſtance does not always appear to be the ſame; whence may be deduced what is ſaid of the Change of the Figure of the Cryſtalline.* For if, ſuppoſing the Cryſtalline moveable, *722
its Figure be unchangeable, in every Situation of the Object and the Eye, in which the Rays, coming converging from a Point, enter the Eye, there will be the leaſt Confuſion, if the Cryſtalline comes back towards the Retina as far as may be; ſo that in every Caſe there would be the ſame Diſpoſition of the Eye, and the ſame Judgment concerning the Diſtance; which, as has been ſaid, is contrary to Experience: But if it becomes flatter as it recedes from the Retina, there will be Changes in the Eye, which agree with the ſeveral Judgments made of the Diſtance in different Situations of the Object and the Eye.

754 *If in the laſt Caſe, in which Rays, coming from a Point converge, the Eye be ſo removed, that the Rays unite before they come to the Eye*, in all the Points in which the Rays concur, there will be radiant Points; which are the Foci of all the Points of the Object, by which the Object is repreſented inverted upon a white Plane; * and which are *711
viſible Points in reſpect of the Eye, to which the Rays can come after their Interſection.* In *736
that Caſe *the Object appears inverted*, becauſe we don't ſee the Object itſelf, but its Repreſentation behind the Glaſs, which we have ſaid to be inverted.* *711

755 We have ſaid that the Caſe is impoſſible to the naked Eye, in which the Rays, coming from a Point, enter the Eye converging; and therefore ſuch Viſion is always confuſed, becauſe the Conſtruction of the Eye cannot adapt itſelf to an impoſſible Caſe: Yet ſometimes, but rarely, even in that Caſe, the Objects are ſeen diſtinctly; which, as it is occaſioned by ſuch a Defect of the Eye as takes away all diſtinct Viſion from the naked Eye, I did not think proper to take Notice of ſuch Exceptions of the general Rule.

756 *The Fault of the Eyes of a great many old Men* is, that they can ſee none but diſtant Objects diſtinctly, thoſe that are near appearing confuſed to them; which Defect *is corrected by the Interpoſition of a convex Lens.* The Rays, which flow from a Point which is near, concur beyond the Retina; paſſing thro' a convex Glaſs, they will diverge leſs as they enter the Eye, and ſo concur ſooner in the Eye; that is, come to the Eye as if they flow'd from a remote Point, ſuch as is ſeen diſtinctly by an old Man.

757 *Thro' a concave Lens Objects appear to be nearer, leſs enlighten'd, and leſs.*

Plate X. *Fig.* 6.] The Rays A*b*, A*b*, and all that are between, going thro' a concave Lens
* 705 become more diverging, * and enter the Eye as
* 652 if they came from a Point *a*, which is leſs diſtant,*
* 737 where the Point A appears to be.*

By making the Rays to diverge more, they are carried farther aſunder; and therefore fewer of them enter the Eye, which diminiſhes the
* 738 Illumination of the Point ſeen.*

Plate X. *Fig.* 7.] The apparent Magnitude is alſo diminiſh'd, becauſe the Rays A *b*, E*b*, by which we ſee the Extremities of the Object,
* 706 come to the Eye leſs converging, * and therefore the Angle *c d c*, under which the Object is ſeen beyond

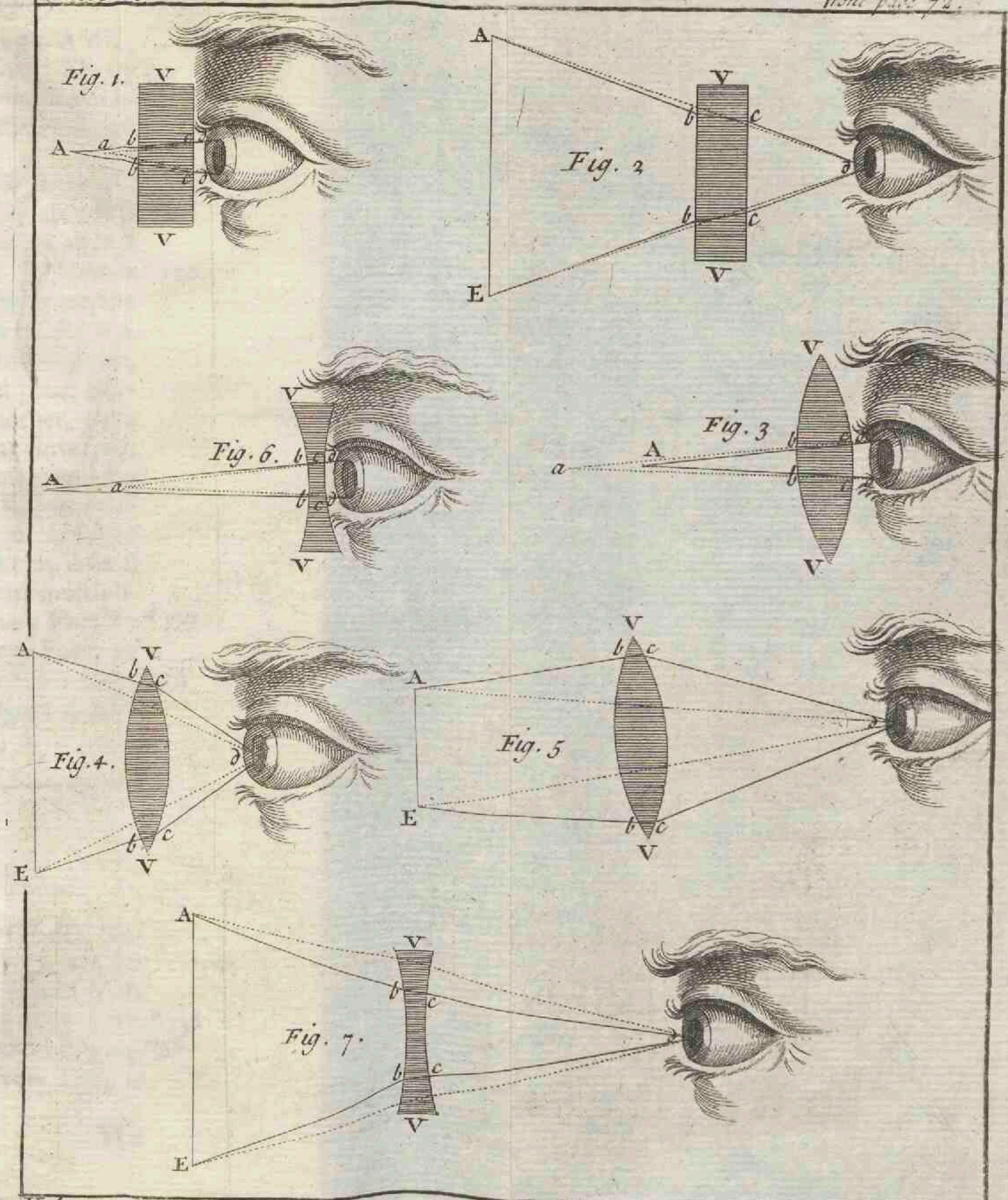
Fig. 1.
Fig. 2
Fig. 3
Fig. 4.
Fig. 5
Fig. 6.
Fig. 7.

beyond the Lens, is leſs than the Angle A *d* E, under which it is ſeen by the naked Eye: Therefore upon account of the Diminution, both of the Diſtance and the Angle above-mention'd, the Object appears diminiſh'd.* * 734

A concave Lens is of Uſe to thoſe who ſee no Ob- 758
jects diſtinctly, but ſuch as are near; ſuch are call'd Myopes; thro' this Lens remote Points appear to be near, * and the Rays, which did concur * 757
before they came to the Retina, now enter the Eye more diverging, and meet upon the Retina.

There are Glaſſes that have one Surface plane, and the other Side is made of ſeveral plane Surfaces that make Angles one with another, (like a Diamond) thro' theſe the Rays that flow from one Point ſuffer different Refractions; and by every Surface are made to enter the Eye in a different Direction, as if they came from different Points: That is, the ſame Point forms ſeveral imaginary Foci; and therefore appears multiplied; for it is ſeen in ſeveral imaginary Foci *: * 737
which as it happens in reſpect of every Point of the Object, *thro'* ſuch *a Lens, which is a Poly-* 759
hedron (or multiplying Glaſs) *the Object appears multiplied.*

CHAP. XII.

Of Microſcopes and Teleſcopes.

WE have ſhewn of what Uſe Glaſſes, terminated with ſpherical Surfaces, are for correcting the Defects of the Eyes of old Men and of the Short-ſighted *. How they ſerve * 756
for diſcovering the ſmalleſt Objects, and bringing 758
the moſt diſtant (as it were) to the very Eye, is what we are now to conſider.

We

We have ſaid that the convex Glaſſes magnify
* 747 the Objects*; which magnifying depends upon the Refraction of the Rays as they go thro' a convex Lens; whence it follows, that it is increaſed, if, in the ſame Circumſtances, the Refraction be increaſed; which Effect may be produc'd, by augmenting the Convexity of the Lens; which will be the more convex, as the Surfaces that terminate it are Segments of a leſs Sphere; which can only be had in very ſmall Glaſſes.

DEFINITION I.

760 Such ſmall Lenſes are call'd *Microſcopes.*

761 *By a Microſcope ſmall Objects are vaſtly magnified*; by which means, Things, which wou'd be inviſible to the naked Eye, are very diſtinctly ſeen.

DEFINITION II.

762 *The Space ſeen thro' the Microſcope, that is, the Circle in which Objects are viſible thro' the Microſcope, is call'd the* Field of the Microſcope.

Experiment 1. *Plate* IX. *Fig.* 5.] If we look at the ſmall Object A E thro' the Microſcope V,
* 745 it will appear magnified at *a e* *.
747 There are alſo compounded Microſcopes, made up of two or three Lenſes; what Foundation they depend upon, will be ſufficiently ſhewn by explaining one of thoſe which is made up of two Lenſes.

Plate XI. *Fig.* 2.] Take a ſmall Lens that is very convex, as V V, and let the Object A E be plac'd at ſuch a Diſtance from it, that all its
* 710 Points ſhall have their Force beyond the Lens;
699 let the Object be brought ſo near, that the Foci
* 699 may be remov'd to *a e* *, and you will there have the Repreſentation of the Object, very much enlarg'd,

enlarg'd, which will be ſenſible if you receive it there upon a white Plane *. * 711

Experiment 2. *Plate* XI. *Fig.* 1.] The Lens abovemention'd muſt be made laſt in the End of a Tube at V; and the other End of the Tube, which is wider, muſt be cover'd with a very thin Paper C C; the Object A E muſt be ſo plac'd, that the Foci of the Points of that Object ſhall be juſt at the Diſtance of the Paper: If then the Object be well enlighten'd, you will have its Repreſentation inverted, viſible thro' the Paper at *a e*. By moving the Object, you will have the true Poſition that brings the Repreſentation upon the Paper to be diſtinct.

Plate XI. *Fig.* 2.] All the Points of the Repreſentation *a e* are radiant Points, and therefore viſible*; which, being ſeen thro' a large Micro- * 736
ſcrope V V, ſhews the large Repreſentation *a e* 754
at a e*; that is, the Rays coming from the Ob- * 761
ject A E, after the Refractions thro' both the Lenſes V V, V V, will enter the Eye, as if they came from an Object at *a e*.

Therefore *thro'* ſuch *a compounded Microſcope* 763
the Object appears inverted, and much more magnified than thro' a ſingle Microſcope.

Definition III, and IV.

In this Microſcope the ſmalleſt Lens, which is 764
next to one Object, is called the Object-Glaſs, *and the other the* Eye Glaſs.

This laſt ought not to be too ſmall; for the Points of the Repreſentation *a b*, tho they be radiant Points, do not emit Light every Way; only the Rays, which paſs thro' the Object-Glaſs, inteſect one another in the ſeveral Points of the Repreſentation *a b*; which Repreſentation therefore will not be viſible, unleſs the Rays that go thro' the Object-Glaſs do alſo go thro' the Eye-Glaſs.

765 Glaſs. *The Field* therefore (or the Space that the Microſcope can take in) *depends upon the Magnitude of this Lens.*

The Eye alſo muſt be ſo plac'd, that all the Rays that come to the Eye-Glaſs, going thro' it, ſhall come to the Eye; which is done by placing the Eye at *d*, *the Point in which all the Rays, which come from the Center of the Object-Glaſs, and paſs thro' the Eye-Glaſs, are collected.*

Objects appear bright enough thro' Microſcopes, becauſe they are very near the Glaſs; and ſo the ſame Number of Rays paſs thro' a ſmall Lens as wou'd not paſs at a greater Diſtance, unleſs thro' a great Hole: *Yet often, where Objects are the moſt magnified, they muſt be enlighten'd by*
767 *Rays collected thro' a convex Lens and thrown upon them.*

The Aſtronomical Teleſcope much reſembles the compound Microſcope.

Definition III.

768 *Inſtruments, fitted to ſee diſtinct Objects, are call'd* Teleſcopes.

769 That which we now treat of is call'd the *Aſtronomical* Teleſcope, becauſe it is not ſo fit for ſeeing Objects upon Earth; for it repreſents them inverted: But Aſtronomers do not much regard the Poſition of the Appearance of the Object.

This Teleſcope conſiſts of two convex Lenſes, the one an Object-Glaſs, which is plac'd next to the Object, and the other an Eye-Glaſs, plac'd next to the Eye. By Help of the firſt, diſtant Objects are repreſented at a certain Diſtance be-
* 711 hind the Lens *, as near Objects are in the compound Microſcope. If this Repreſentation be obſerv'd thro' an Eye-Glaſs, it will appear enlarg'd and inverted, as we have ſaid concerning the Microſcope.

It is plain also, that in this Case, as well as in 770
the Microscope, the *Field depends upon the Breadth of the Eye-Glass*; as also, that *the Place of the Eye* 771
must be determined in the same Manner for the Telescope as for the Microscope *: For the Astronomic * 766
Telescope differs from the compounded Microscope only in this, that in the Microscope the Lenses are more convex, and therefore less proper for looking at distant Objects, especially in respect of Object-Glasses. In the Microscope, the Object-Glass is more convex than the Eye-Glass; but the contrary obtains in the Telescope.

Telescopes cannot be too long for observing the Stars: But, if they are above 20 Foot long, they are of no Use for seeing Objects upon Earth; because of the constant Trembling of the Air, which is too sensible in Glasses that magnify very much.

A short *Astronomic Telescope will serve to see Ob-* 772
jects upon Earth, by adding to it two convex Lenses, which are also call'd Eye-Glasses; the three Eye-Glasses are alike, and less convex than in the Astronomic Telescope, the Object-Glass remaining the same.

Plate XI. *Fig.* 3.] Take an Object-Glass V V, 773
which represents a distant Object at *e a*; then take besides three Eye-Glasses D D, D D, D D; the first must be so plac'd, that the Rays, coming from the Point of the Representation *e a*, shall become parallel when they have pass'd the Lens *; * 699
in that Case the Rays, which come from the middle Point of the Object-Glass, will be collected at G; the Second Lens must be so plac'd, that these Rays which are collected at G (where they intersect one another, and move as if they came from that Point) may go out parallel after they have pass'd thro' it *; which being perform'd, * 669
the Rays coming from the Object-Glass to *e*, and

and there interſecting and forming that Point of the Repreſentation of the Object, being refracted thro' the firſt Lens, paſs by G parallel to one another; thro' the Second Lens they are refracted
* 698 in the Direction D e, and collected at e *, ſo as to make it the Point of a new Repreſentation. In the ſame Manner the Point of a new Repreſentation corresponds to the Point a of the ſecond Repreſentation; which being alſo true concerning the intermediate Points, there will be found an erect Repreſentation of the Object at a e.

Experiment 3. *Plate* XI. *Fig.* 4.] Let three little Boards D, D, D, with Eye-Glaſſes in them, that collect parallel Rays at the Diſtance of about 5 Inches be moveable upon a Plane between two Rulers, in ſuch Manner that the three Glaſſes may be in the ſame Line as the Hole V, thro' which alone the Light enters into the Room, and in which there is an Object-Glaſs, which is fix'd in a ſhort Tube, in order to exclude all the ſide Light.

This Object Lens is ſuch as is able, at the Diſtance of 3 Feet from V, to repreſent diſtant Objects inverted at F; which Repreſentation will be viſible, if you let the Rays fall upon a
* 711 white Plane in that Place *. Five Inches farther from F, you muſt place the firſt Eye-Glaſs, and 10 Inches from that, you muſt place the Second; at *f*, which is five Inches from it, you will have an erect Repreſentation of the ſame Objects, which will alſo be viſible, if receiv'd upon a white Plane.

774 *Plate* XI. *Fig.* 3.] If the Repreſentation a e be ſeen thro' a third Eye-Glaſs, ſuppoſing the Eye at *o*, in which the parallel Rays a D and a E are collected, *the Object appears magnified, brought near, and erect*; for it is ſeen under the Angle

D *o* D,

D*o*D, when with the naked Eye it wou'd appear under a very ſmall Angle; it will alſo appear near, becauſe, tho it be ſeen beyond a e, yet the Diſtance, at which it appears, has no ſenſible Relation to the Diſtance of a very diſtant Object.

Experiment 4. *Plate* XI. *Fig*. 4.] Suppoſing every Thing as in the foregoing Experiment; let there be a third Eye-Glaſs plac'd 10 Inches from the Second, and 5 Inches from that a little Board, or Eye-Stop, with an Hole O; if the Eye be plac'd at O, the Object, as has been ſaid, will appear erect, magnified, and near. If the Board O be diſplac'd, that is, be brought nearer or remov'd farther off, the Field of the Teleſcope is diminiſh'd; becauſe there is but one Situation of the Eye, in which all the Rays which paſs thro' the Eye-Glaſſes can come to the Eye.

We are to take notice, that the Eye-Glaſſes, made Uſe of here, are not convex enough in reſpect of the Object Glaſs V; but they are beſt for making the 3d Experiment.

All the Points of the Object do alſo *appear more* 775
enlighten'd: For the Rays which, coming from any Point of the ſeveral Points of the Object Glaſs, do interſect one another in a Point of the Repreſentation, by reaſon of the ſmall Diſtance of the Eye-Glaſs from that Repreſentation, are but little diſpers'd before they come to the Eye; ſo that they all go into it. And therefore the Illumination, given by the Teleſcope, is to that which is given by the naked Eye, as the Surface of the Object Glaſs, thro' which the Rays paſs, to the Surface of the Pupil.* *738

One may alſo *with two Lenſes make Teleſcopes,* 776
which ſhall ſhew Objects erect, enlighten'd, and magnified. Theſe muſt be ſhorter; for if they be above one Foot long, they become almoſt uſeleſs,

becauſe

becauſe their Field will be ſo ſmall; that is, they will take in ſo little of an Object.

Plate XI. *Fig.* 5.] Let V V be an Object-Glaſs, the inverted Repreſentation of a diſtant
* 711 Object will be at *e a**: The Rays are ſo intercepted by the concave Lens D D, that ſuch of them, as come from the Center of the Lens V V, are inflected as if they proceeded from the Point
* 705 *f**; by the ſame Refraction in the Rays which
* 706 concurr'd at *a*, become diverging*; having their imaginary Focus at a; which alſo happens in reſpect to all the Points of the Repreſentation *e a*, and, inſtead of it, you have an imaginary Repreſentation which is erect at a e; that is, the Rays enter the Eye as if they came from the Object plac'd at a e.

777 The Rays, in all reſpects, go out diverging from the Eye-Glaſs; and therefore *the Eye muſt be brought as near as poſſible to the Eye-Glaſs.*

778 *In this Teleſcope, the Field depends upon the Bigneſs of the Object Glaſs*; for the Rays, which from a Point come obliquely to the Center of this Lens, very often do not enter the Eye; whilſt other Rays from the ſame Point, which paſs thro' the Lens near its Circumference, do come to the Eye.

CHAP. XIII.

Of the Reflexion of Light.

WE have ſhewn that Light is reflected from opaque Bodies, and that every Point
* 710 reflects it every Way *. The Occaſion of this is the Inequality of the Surfaces, which are made up of an innumerable Quantity of ſmall Planes, which, in all ſenſible Points, are directed

every

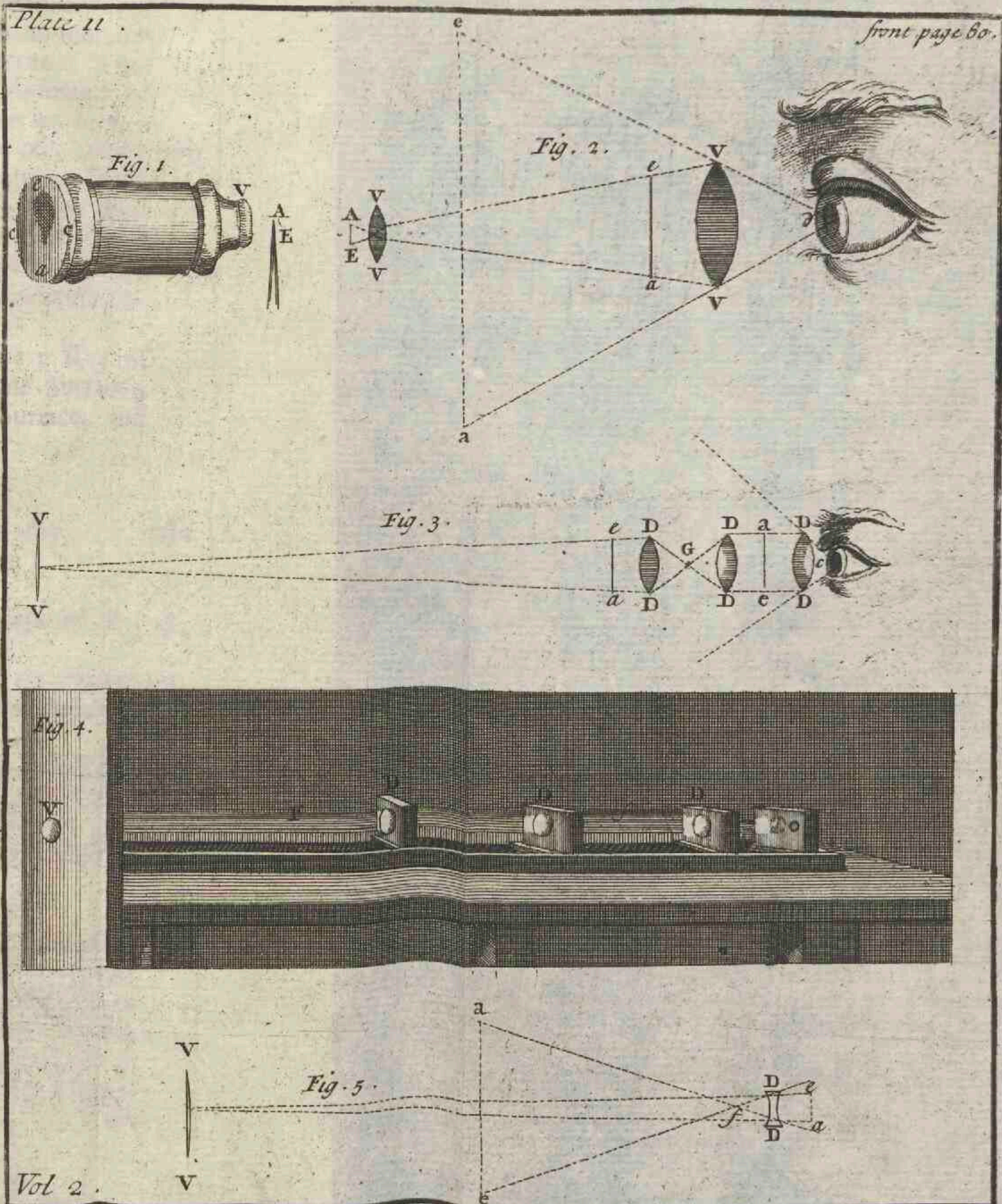
Plate 11
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Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
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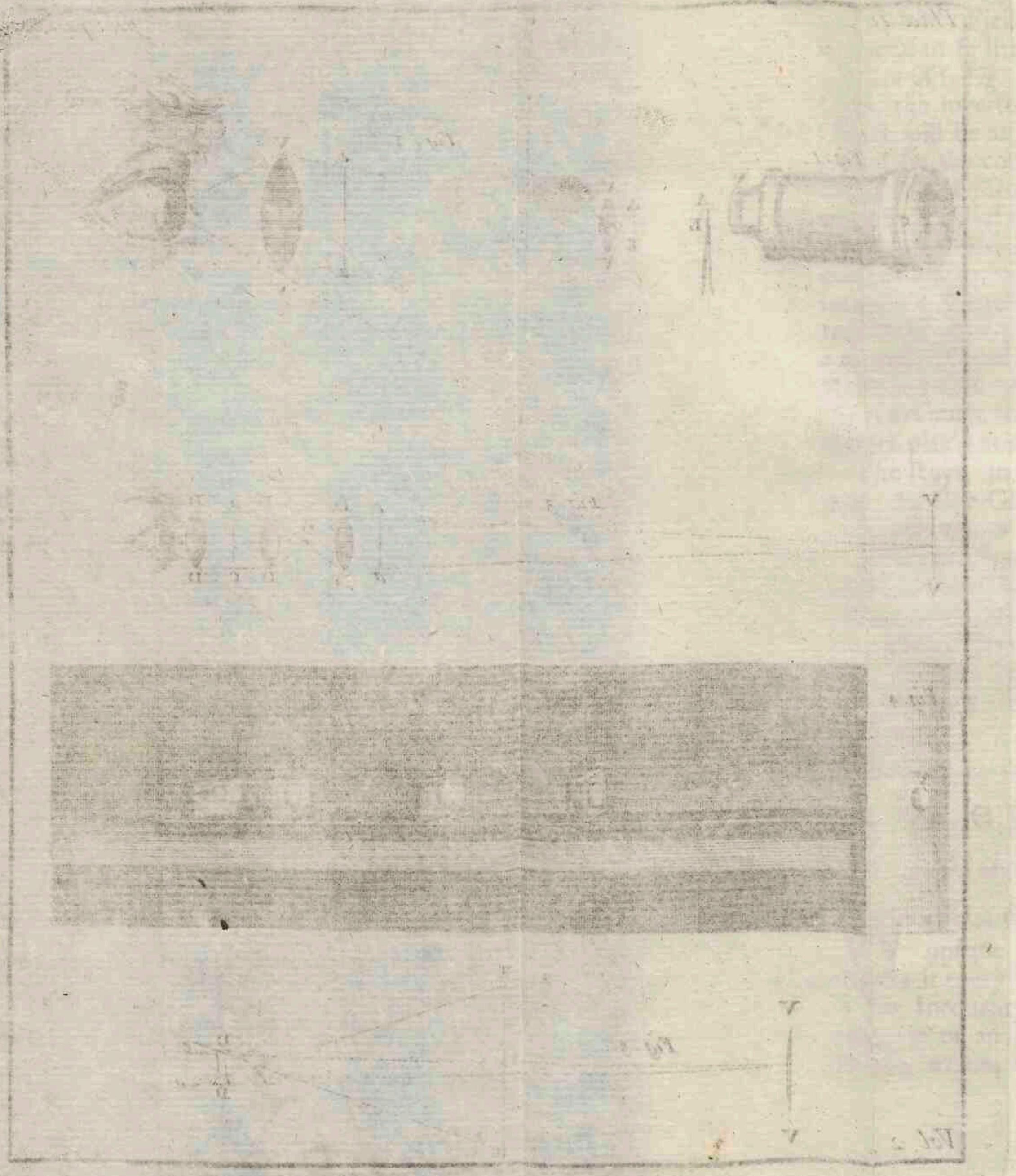

every Way; which will be easily conceiv'd, if we imagine a Surface cover'd with an innumerable Quantity of small Hemispheres. That this is true, we deduce from the Reflexion of Light from a polish'd Surface; that is, from a Surface whose Inequalities are taken off; which 779
in all its Points reflects the Light only one Way, which holds in Curve as well as in plane Surfaces: Nay, from Surfaces that are not at all polish'd, the Light is mostly reflected that Way, and it would be all reflected if they were polish'd, as daily Experience shews.

Plate XII. *Fig.* 2.] Let A C be a Ray of Light coming obliquely upon a plane Surface; let C O be perpendicular to this Surface, and the Rays be reflected along C B.

Definition I.

The Ray C B is call'd the *reflected Ray.* 780

Definition II.

The Angle O C B is call'd the *Angle of Re-* 781
flexion.

The reflected Ray, together with the incident 782
Ray, in the same Plane which is perpendicular to the reflecting Plane.

For *the Action of this Plane, by which the Light* 783
is reflected, is directed perpendicularly to a Plane, which is suppos'd like in all Points.

The Angle of Reflexion is equal to the Angle of 784
Incidence.

Experiment 1. *Plate* XII. *Fig.* 1.] Take a plane Looking-glass S, which may be set in any Position by Means of a Ball and Socket join'd to the Foot that sustains it; thro' a Hole, in the Plate of Metal L, that is in the Window, let in a Sun Beam of about a Quarter of an Inch Diameter into the Room; the Glafs muft be fo difpofed that the Beam may come thro' an oblique cylindric Cavity (of the fame Bignefs as the Beam) made in a little upright Board T: If you turn this Board Side for Side, the reflected Ray will go thro' the fame Cavity. This holds good, whatever the Inclination of the Cavity be, as may be demonftrated by ufing different Boards.

By which Experiment N°. 779. is prov'd, as well as N°. 784.

785 *Plate* XII. *Fig.* 2.] *If the reflected Ray becomes the incident Ray*; that is, if the Light comes along the Line B C, it will return in the Line C A, that is, the firft *that was the incident Ray will become the reflected Ray*; as appears from the Equality of the Angles B C O, O C A.

From this Equality of the Angles of Incidence and Reflexion, we farther deduce, that

786 *the Light, after it has fallen upon a Body, recedes from it with the fame Force that it came upon it.* Let the Motion along A C be refolv'd into two

* 192 Motions along A O and O C *, fuppofing A O parallel to the reflecting Plane, and O C perpendicular to it. Let A O be continued; the Motion in that Direction is not alter'd from the Action of the Plane: Therefore let A O and O B be equal; if the Light recedes from the Plane with the fame Force, with which it came upon it, the Motion occafion'd by the Repulfion is reprefented by C O, and in that Cafe

* 190 the reflected Ray goes thro' B *; that is, the Angle O C B is equal to the Angle O C A, which agrees with the Experiment.

787 As to the Reflexion of Light, it is to be obferv'd, that *Light does not run againft the folid Part of Bodies, when it is reflected by them*; *but that it is reflected in thofe Places, where it cou'd very freely pafs.*

pass. I ſhall prove this by ſeveral Experiments, by which many other wonderful Properties of Reflexion are diſcover'd.

It is a common Experiment obſerv'd by every 788
Body, that when Light is mov'd thro' any Medium, as for Example, Glaſs, Water or Air, it does not undergo a ſenſible and regular Reflexion; but that it is reflected there, where two Mediums of different Denſity are ſeparated; ſo it is reflected in the Surface of Water or Glaſs.

Cou'd Light in ſuch Quantity ſtrike againſt the Particles, juſt where the Mediums are ſeparated, whereas it moves thro' both the Mediums for a great Space without ſtriking againſt any ſuch Particles; Are there more of thoſe Particles
near the Surface than elſewhere? *Light* alſo *is more* 789
abundantly reflected in a denſer Medium, when it comes againſt the Surface of a rarer; than when on the contrary, moving in a rarer Medium, it ſtrikes againſt the Surface of a denſer.

Experiment 2. *Plate* XII. *Fig.* 3.] In a dark Place in which the Light enters thro' an Hole in the Plane L, let there be placed a triangular Priſm of Glaſs A B; let the Light enter the Priſm thro' one Side; if it comes to the next Side making an Angle of Incidence greater than 40 Degrees, it is wholly reflected, and does not at all penetrate into the Air; but Light moving in Air is never wholly reflected by the Glaſs.

But if the Reflexion be made by the ſtriking of Light againſt the ſolid Parts of Bodies, there muſt be more ſuch Parts in Air than in Glaſs; for if Light was reflected from the Glaſs itſelf into the Air, the Light would never come to the Separation of the Mediums; that the Light can alſo go out of Glaſs in the very Places, where it is reflected, is prov'd by following Experiments.

periments. Therefore in the Neighbourhood of the Glaſs there muſt be ſo many Parts in the Air, that there may be no Way for the Paſſage of the Light, to cauſe it to be wholly reflected into the Glaſs; but it is plain that there are no ſuch Parts, becauſe Light comes thro' the Air in all Directions quite to the Glaſs. Even in the ſame Place of the Surface which ſeparates the Glaſs and Air, the Light which comes from one Side is reflected, whilſt that which comes from the other Side is tranſmitted. Which clearly proves that the Light is reflected in the very Place where it can go thro'.

790 *Experiment* 3. *Plate* XII. *Fig.* 3.] Every Thing being as in the former Experiment, if the Obliquity of the Light be chang'd, Part of it will paſs thro' into the Air.

Who wou'd conceive that Light, which paſſes from Glaſs into Air, and does not run againſt the ſolid Parts, ſhou'd all of it (by a little increaſing the Obliquity) run againſt thoſe Parts; when in each Medium, as has been already ſaid, there are Pores and Paſſages in all Directions?

791 *Experiment* 4. *Plate* XII. *Fig.* 3.] Take a Glaſs triangular Priſm AB, moveable about its Axis; which is made ſo by fixing braſs Plates to its Ends, with braſs Wires perpendicularly fix'd to them: The Priſm muſt be ſo laid upon the Trough P, as that the ſaid Wires may bear upon the Brims of it, which are made a little hollow to receive them, yet ſo as to let them turn, that the Priſm may move freely about its Axis: Let it be ſo plac'd as to reflect the Light in the ſame Manner, as in the ſecond Experiment. Let the Trough be fill'd with Water up to the Priſm; then the Light, which, ſtriking againſt the

the Air, was wholly reflected, now running against the Water, does partly enter into it, and is only reflected in part.

Which Experiment does not at all agree with a Reflexion made by a Stroke upon the solid Parts.

In the third Part of this Book we shall also shew, that thin Plates, which reflect Light, will transmit it, if they become thicker*. * 894

The fourth Experiment also proves that *the* 792
reflecting Power is so much greater, as the Mediums, which are separated by a reflecting Surface, differ more in Density; for Glass and Air differ more in Density than Glass and Water.

In this Experiment we also see that *Reflection* 793
is made by the same Power by which the Rays are refracted, which produces different Effects in different Circumstances.

A Ray, which goes out of a denser into a rarer Medium, by the Attraction of the former, is made to recede from the Perpendicular *; if * 625
the Obliquity of the incident Ray be increas'd, the Obliquity of the refracted Ray will also increase, till it comes at last to move in the very Surface which parts the Mediums. And this obtains, when the Sine of the Angle of Incidence is to the whole Sine, as the Sine of Incidence, in the denser Medium, is to the Sine of Refraction in the rarer; for in that Case the Angle of Refraction is a right one. If the Obliquity of the incident Ray be more increas'd, it is plain that the Ray cannot penetrate into the rarer Medium: This is the Case in which the Light is wholly reflected; which Reflexion depends upon that Attraction by which the Rays are refracted. For when the Ray is mov'd thro' the Space of Attraction, it is bent towards the denser Medium *; if it be in the denser Medi- * 618
um,

um, and ſo bent, that, before it has gone thro' the whole Space of Attraction, the Tangent to the Curve be parallel to the Surface that ſeparates the Mediums, the Curve, being continued, turns back again; and therefore the Ray is reflected by the Attraction of the denſer Medium, and this Continuation of the Curve is ſimilar and equal to the firſt Part, and makes the Angle of Reflexion equal to the Angle of Incidence; becauſe the Light returns thro' the ſame Part of the Sphere of Attraction; and the ſame attracting Force acts upon the Light in correſpondent Points of the two Parts of the Curve. Thus a Projectile, in its Aſcent and Deſcent, deſcribes ſimilar Curves.

Yet that *all Reflexion does not depend upon that*
794 *Attraction, in the ſame Manner*, is evident; for in that Caſe, in which the Refraction is made, Part of the Light is reflected; for the Light does not wholly penetrate out of the rarer into a denſer Medium; for even in that Caſe, in which the Attraction is the moſt oppos'd to the Reflexion that is poſſible, yet ſome Rays are reflected.

Yet it cannot be doubted but that, *in every*
795 *Caſe, Reflexion has Relation to the refracting Power.*
796 *Where Light paſſes without Refraction, there it is*
* 617, 788. *not reflected**; *but where the Refraction is greateſt,*
* 631, 792. *there the Reflexion is alſo ſtrongeſt**; which is true, not only when Light, moving in a denſer Medium, ſtrikes againſt a rarer, as in the fourth Experiment; but the ſame Thing is obſerv'd, when Light ſtrikes againſt the denſer Medium: Thus ſuppoſing the Light to move in Air, the Surface of Glaſs reflects more ſtrongly than that of Water; and that of a Diamond yet more ſtrongly. If Glaſs and a Diamond be immers'd in Water; the refracting Power is leſs in the Separation of thoſe Bodies with Water, than where thoſe

thoſe Bodies touch the Air*. Theſe Bodies alſo reflect Light leſs ſtrongly in Water than in Air. From this Relation of the reflecting and refracting Powers, we deduce, that *Light is driven back at a certain Diſtance from the Bodies*, in the ſame Manner that the refracting Power does alſo act at ſome Diſtance from the Body: This Propoſition is confirm'd from what has been demonſtrated concerning Reflexion, which does not depend upon a Stroke made againſt the ſolid Parts of Bodies; and this is fully made out, if we conſider, *that poliſh'd Bodies reflect the Light regularly* (which we obſerve in Looking-Glaſſes) *tho there be a great many Scratches in their Surfaces:* For as they are poliſh'd with the Powder of *Emery* and *Putty*, tho their Parts are very ſmall, yet they leave very great Scratches on the Surface in Reſpect of the Particles of Light; whence in the Surface itſelf the Reflexion muſt needs be irregular; but if we conceive the Reflexion to be made at ſome Diſtance from the Surface, the Irregularities are diminiſh'd, and almoſt wholly taken off, as is eaſily underſtood by any one that conſiders it with Attention.

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CHAP. XIV.

Of Plane Mirrors.

Plate XII. *Fig.* 4.] LET *b c* be the Surface of a Plane Mirror or Looking-Glaſs; A a radiant Point. *Let the Plane of the Glaſs be continued, and from the Radiant* A *let a Perpendicular* A C *fall upon it; if this Line be continued, and* C *a be made equal to* C A, *a will be the imaginary Focus of the reflected Rays that proceed from* A. Let A *b* be the incident Ray; *b f* the reflected Ray; which continue beyond the Glaſs; 799

the Angles of Incidence and Reflexion are equal
*784 to one another *, their Complements alſo, which are the Angles A *b* C, *f b d* are equal; to this is equal its oppoſite and vertical *a b* C: The Triangles A *b* C, *a b* C, which are rectangular, have the Side C *b* common, and the Angles C *b a*, C *b* A, equal; therefore they agree in all Reſpects, and C A and C *a* are equal to one another: Which Demonſtration may be applied to all other Rays which flow from A, in whatever Plane, perpendicular to the Glaſs, they be conceiv'd to be. Therefore wherever the Eye is, if the reflected Rays come to it, they will enter the Eye as if they came from *a*; and the Point A will appear in that Place *; but *the Appearance of that Point*
*737 *will have the ſame Poſition in Reſpect of the Mirror,*
800 *behind it, as a radiant Point has before it.*

If this be applied to all the Points of the Ob-
801 ject, it will appear, that *the Object will appear behind the Glaſs in the ſame Poſition that it has before the Glaſs.*

CHAP. XV.

Of Spherical Mirrors.

802 EVERY ſpherical Surface may be conſider'd, as made of innumerable ſmall Planes; and a Plane, which touches the Sphere in any Point, is as it were a Continuation of ſuch a ſmall Plane.

803 Spherical Mirrors are either *Concave* or *Convex*.

The firſt are made of Part of an hollow Sphere poliſh'd.

The ſecond are Parts of Spheres poliſh'd on the Outſide.

A

A Ray coming upon any spherical Mirror, together with its reflected Ray, is in a Plane, which, being continued, goes thro' the Center of the Sphere *, for such a Plane is perpendicular to the Surface of the Sphere. *A Line which is drawn thro' the Center of the Sphere and Point of Incidence, being continued makes equal Angles with the incident and reflected Rays* *; for that Line is perpendicular to the Surface, and those Angles are Angles of Incidence and Reflexion: Therefore *the Ray that goes thro' the Center, or which, being continued, wou'd go thro' the Center, when reflected returns upon itself.* 804 * 782 804 * 784 806

Plate XII. *Fig.* 5.] Let *b c* be a Portion of the convex Mirror; A a radiant Point; let A *b*, A *d*, A *c*, be incident Rays; the reflected Rays will be *b f*, *d g*, *c h*; *if from the radiant Point* A, *a Tangent be drawn to the Mirror*, the reflected Ray will be a Continuation of the incident, or rather *the Reflexion of the Rays terminated in the Point of Contact.* 807

If b f, *d g*, *c h*, *the Rays that are reflected from the convex Mirror, be continued*, with all the intermediate ones, by their Intersections they will form the Curve *a a*, which all these Rays touch, and the neighbouring Rays intersect in the Periphery of the Curve; so that they always enter the Eye as if they came from a Point of the Periphery; *in which* therefore *the Point* A *does* always *appear* *, as long as the reflected Rays can come to the Eye, and the Eye is mov'd in a Plane which goes thro' the Center of the Sphere; but when the Eye is mov'd out of that Plane the radiant appears in another Curve, because there are such Curves in every Plane, which may be conceiv'd to pass thro' A and C. 808 * 737

Since all these Curves, and each of them wholly are behind the Glass, *all the Objects* also *appear behind the Surface of the Glass.* 809

810 *The Objects* likewife *appear erect.* For if the Point A be mov'd about the Mirror, the whole Curve *a a* is carried with the fame Motion; which proves (in Refpect to the erect inverfe Situation) that the Points of the Reprefentation have the fame Relation to each other, as the Points of the Object itfelf.

As the Point A is farther remov'd from the Glafs, the whole Curve does alfo recede by a contrary Motion; but fuppofing A at an infinite Diftance, that Point of the Curve, which is the fartheft remov'd from the Surface, will be diftant from a Quarter of the Diameter; whence it
811 follows, that *the Objects appear diminifh'd*, becaufe all the Reprefentations are compris'd in fmall Limits.

812 *If the Eye be mov'd, the Appearance of the Object is alfo mov'd, and its Figure chang'd:* For all the Points are mov'd in their own Curves, and that unequally, according to the different Situation of the Eye in Refpect of each Curve; whence of Neceffity the Figure muft be chang'd.

Experiment 1. *Plate* XII. *Fig.* 6.] If any one fees his Face in a fpherical convex Mirror, ftanding at A, he will fee his Face at *a* erect, diminifh'd and unlike; by the Motion of the Eye one may obferve the other Things mention'd in Refpect to fix'd Objects.

813 *Let b d* (*Plate* XIII. *Fig.* 1.] be *a concave Mirror*, and a Portion of a Sphere whofe Center is C; *let parallel Rays fall upon the Surface of the Mirror*, one of which, C*d*, is fuppos'd to pafs thro' the Center; this Ray by Reflexion returns upon
* 806 itfelf*, and the Rays next to it, being reflected, become converging, and concur with it in the Focus F, which is the middle Point between *d* and C. Let A*b* be a Ray very little diftant from C*d*; draw

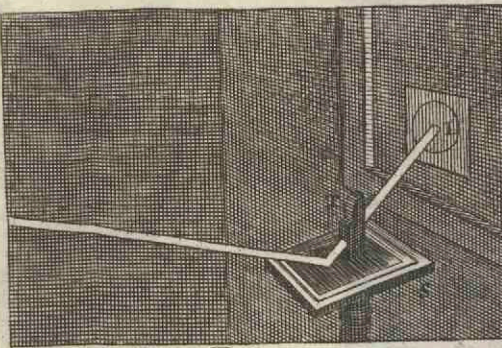

Fig. 1.

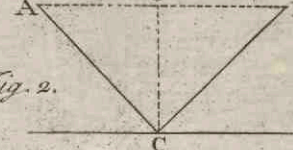

Fig. 2.

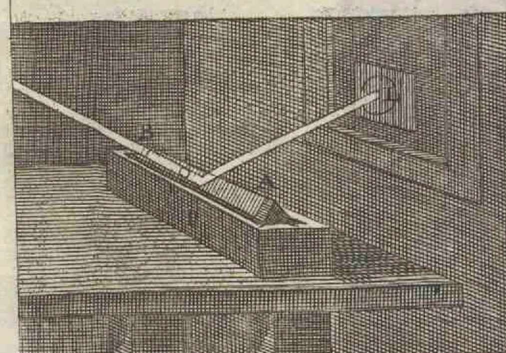

Fig. 3.

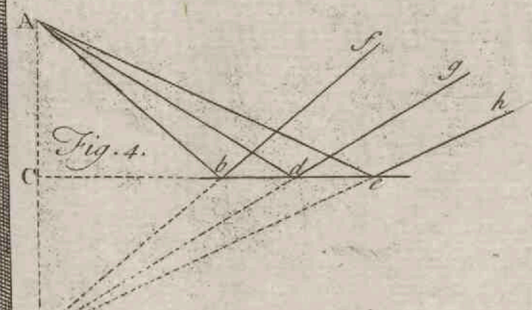

Fig. 4.

Fig. 6.

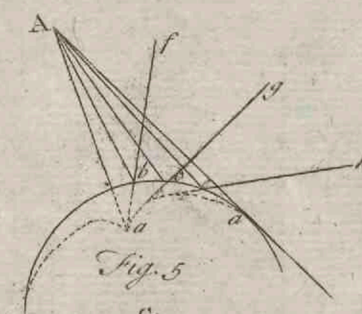

Fig. 5

the Semidiameter C *b*; the Angle of Incidence will be A *b* C, to which the Angle of Reflexion C *b* F* is equal, as alſo the alternate Angle *805
b C F; therefore *b* F C is an Iſoſceles Triangle, and the Sides F C and F *b* are equal; becauſe *b d* is very ſmall, F *d* and F *b* do not ſenſibly differ; therefore F C and F *d* are equal; which Demonſtration will ſerve for all the Rays that are but very little diſtant from C *d*.

If parallel Rays are farther diſtant from C *d*, they do not meet at F; yet they will all come together into a little Circle, if the Diameter of the Mirror does not exceed the fifth or ſixth Part of the Diameter of the Sphere of which it is a Portion.

Burning Mirrors are made upon this Founda- 814
tion, which collect the Sun's parallel Rays into a Focus.

Experiment 2. *Plate* XIII. *Fig.* 2.] Let there be a concave Mirror S, made of Metal, or of Glaſs quickſilver'd behind; let it ſtand upon the wooden Foot P, whoſe upper Part is bor'd ſo as to receive a Cylinder of Wood made faſt to a tranſverſe Piece A A, which ſerves for turning the Glaſs round with a horizontal Motion; and the Mirror itſelf muſt move upon two Ends of an Axis between the Pillars A B, A B, ſo as to be inclin'd in any Angle, and the Screws B, B, will make it faſt in any Poſition.

Having expos'd the Burning-Glaſs to the Sun-Beams in ſuch a Manner, that the Ray, which comes upon the Middle of the Glaſs, is perpendicular to its Surface; ſince all the others are parallel to it, they are collected in a Focus, at a Quarter of a Diameter's Diſtance from the Glaſs, and there burn violently.

If the Diameter of the Surface of the Mirror (as it is in mine) be of about 15 Inches, and the Focus is 18 Inches diftant from it, Wood will immediately be in a Flame, and thin Plates of Lead prefently melt.

If we confider the Rays that are at fome Diftance from C *d*, and parallel to it, thofe of them that are neareft one another being reflected, will interfect before they come to C *d*, and
815 in that Cafe, that is, *where parallel incident Rays fall obliquely on the Glafs, being a little difpers'd by Reflexion, they are collected in a Point.*

816 *If the Focus, in which parallel Rays are collected by a concave Mirror, becomes the radiant Point*, the Rays, which are but little difperfed, are refle-
* 813 cted parallel to one another*.

785
817 From thefe Properties of a concave Mirror we deduce the Method of reprefenting Objects in a dark Place, much like what was before fhewn in Refpect of a Convex Lens*.

* 711 *Plate* XIII. *Fig.* 3.] Let there be an Hole F thro' the Wall; let a b be a concave Mirror, fo plac'd as to collect the parallel Rays that are perpendicular to the Wall at F: The Rays, com-
* 816 ing from F in that Direction, are reflected *, and fuch are the Rays, which, being reflected from the external Objects, interfect one another at F.

Let A F be Rays coming from a Point of a diftant Object; thefe Rays are by the Mirror reflected perpendicularly to the Wall; and becaufe Rays coming from a diftant Point, and paffing thro' a fmall Hole, may be looked upon as parallel, thefe Rays will, after Reflexion, be collected into one Point at *a*, at the Diftance of
* 815 the Wall*, that is in its Surface; where therefore the Point will be reprefented. In the fame Manner the Rays which come from a Point

thro'

thro' B F, are collected at *b*; which, as it is true with Regard to all the Points of an Object, will give the Repreſentation of it upon the Wall; and if the Wall be white, and the Object enlighten'd by the Rays of the Sun, the Picture will appear in very lively Colours.

Experiment 3. *Plate* XIII. *Fig.* 4.] In a dark Place cover the Backſide of the Window-ſhut with white Paper, an Hole being made in the Middle of it little more than half an Inch Diameter, ſo as to anſwer to an Hole behind it in the Window-ſhut, over-againſt which, at a Diſtance no leſs than of 50 Foot, there are ſeveral Objects enlighten'd by the Sun: Let a concave Mirror whoſe Surface is 15 Inches wide, and which collects parallel Rays at the Diſtance of 18 Inches, be placed at that Diſtance from the Window, in ſuch Manner, that a Line paſſing thro' the Center of the Hole, and the Center of the Surface of the Mirror, be perpendicular to the Plane of the Paper and the Surface of the Glaſs. Then the Objects will be repreſented upon the Paper in a Circle concentric with the Hole, and whoſe Diameter is equal to the Diameter of the Mirror. You muſt join to the Hole, on the Outſide of the Room, an hollow, truncated Cone, to exclude the Light which does not come from the Objects to be repreſented.

Let *be* (*Plate* XIII. *Fig.* 5.) *be a concave Mir-* 818
ror; C the Center of its Concavity; A *a radiant Point farther diſtant than* C *the Center of the Glaſs*; A*b*, A*d*, A*e* incident *Rays*, whoſe *reflected* ones *bf*, *dg*, *eh*, with their intermediate ones *by their mutual Interſections form the Curve aa*, *which they touch*; therefore *the Point* A *appears in that Curve**; and if the Eye be mov'd in the * 808
Plane of the Curve, the Appearance will change

Place

Place in that Curve. But in all the Planes which may be conceived to paſs thro' C A, there is ſuch a Curve, and they all concur in the Line
819 C A, namely, at the Point *a*. *Therefore in that Point a, the reflected Rays are the moſt abundantly collected*, which therefore is call'd the Focus of
* 785 the Rays coming from A. On the contrary, A will be the Focus, ſuppoſing the Radiant at *a**.

In this Figure there is only Part of the Curve drawn, which is produced by one Part of the Line A C; ſuch another Part muſt be conceiv'd on the other Side, and both join in the Focus of the radiant Point.

820 *As the radiant Point recedes, the Curve comes nearer the Mirror.*

821 As the Radiant comes forward, the Curve recedes from the Mirror, and moves towards the Radiant, till they concur *at the Center* C; in which, *if the Radiant be plac'd, all the reflected*
* 806 *Rays will coincide with the incident* *, and the whole Curve will, as it were, be ſwallow'd up in the Center.

822 *If the Radiant* is yet brought nearer to the Mirror, ſo as to *be between the Center and the Glaſs, the Curve will* recede farther, and *be* then *beyond the Center*; and in the Curve, that Point will recede moſt of all, in which all the Curves concur which are conceiv'd in ſeveral Planes, that is, the Focus of the radiant Point: And that Focus
823 will be at an infinite Diſtance *when the Radiant is diſtant from the Mirror juſt the fourth Part of the*
* 813 *Diameter of the Sphere.** Then alſo *the Curve is*
816 *extended in infinitum, and the two Parts* which concur in the Focus of the Radiant *are ſeparated*; this ſeparated Part is ſeen at a a: (*Plate* XIII. *Fig.* 6.) *If the Radiant be brought ſtill nearer, the*
824 *Curve Parts decline from one another*, becauſe the Rays, ſuch as A *b*, and thoſe nearer it, being reflected,

flected, do not touch the Curve, but become divergent; that is, those reflected Rays, being continued beyond the Glass, will intersect one another, *and form a new Curve behind the Glass, which has two Legs*, one of which is seen at *a a*; they concur in the Line C A continued, namely, at *a*, and, receding from the Glass, are stretched out *in infinitum*. And there is also, on each Side of the radiant Point, a Point in the Surface as *d*, which separates the Rays that form the Curves *a a* and a a; and the Ray A *d*, being reflected in *d g*, touches neither of the Curves, if it be infinitely continued toward each Part *g*, *g*, tho it is continually coming nearer to each Curve. If the whole Sphere was compleated, in Respect of the opposite Part of the Sphere, the Radiant would be beyond the Center, and the reflected Rays would form the Curve which we have mention'd before, * by which the separated Legs, as a a, * 818
would be join'd. These Things thus premised, we proceed to explain the Phænomena of concave Mirrors.

If the Mirror be enlightened by a lucid Body, the 825
Rays which come from all the Points of the Object, being reflected, will form Curves, but *are chiefly collected in the Foci of these Points*; * therefore *if* * 819
these Foci are in the Surface of a white Plane, there 826
will be upon it a Representation of the lucid Body, as in the second *Experiment* of *Chap.* IX. And that Representation will be *inverted*; for the Line, which joins the radiant Point with its Focus, goes thro' the Center of the Sphere;* in which there- * 819
fore all such Lines intersect one another; and this Intersection is between the radiant Point and the Focus, * in which the Point is represented. * 818

But as the lucid Body is brought nearer to the Mirror, the Appearance recedes farther, * *and* in * 820
this Case *becomes bigger*.

Experi-

Experiment 4.] Hold a lighted Candle between the Mirror and the Center of the Sphere of which it is a Portion; yet ſo that it may be more diſtant from the Mirror than that Center: If then there be a white Plane perpendicular to the Line that paſſes thro' the Candle and the Center of the Mirror, and this Plane be held beyond the Center, you will have upon it an inverted Repreſentation of the Candle; the proper Place will be found by moving the Plane forwards and backwards; as likewiſe by this Proportion, *viz.* As the Difference of the Diſtances of the Candle, from the Center of the Sphere and from the Mirror, is to the fourth Part of the Diameter of the Sphere, ſo is the Diſtance of the Candle from the Glaſs, to the Diſtance requir'd. As the Candle is brought nearer to the Speculum, the Plane muſt be mov'd farther off, and the Repreſentation will grow bigger.

827 *Plate* XIII. *Fig.* 5.] *Objects, placed beyond the Center, appear between the Glaſs and the Center*, for
* 818 all the Points appear in a Curve as at *a a*; * *the*
828 *Images of the objects will alſo be diminiſh'd and inverted:* for they are reduced into a narrow Space; and as the Point A moves downwards, its Repreſentation will be carried upwards; for the Line *a a* keeps the ſame Situation in reſpect of A C *a*, as it is carried round the Center C.

Experiment 5. *Plate* XIII. *Fig.* 7.] Leſt the Repreſentation of the Object ſhou'd be leſs vivid, the Mirror is to be included in a Box. If you have a Mirror, whoſe Surface is about 8 Inches wide, and which is a Portion of a Sphere of one Foot and a half in Diameter; ſhut it up in a Box P, in whoſe Fore-Part there is an Hole of of about 6 Inches Diameter, and from which the Glaſs is diſtant above 6 or 7 Inches; and let this Opening be turn'd from the Light. Now if any Perſon, as A, beholds himſelf at the Diſtance of about 2 Foot from the Glaſs; his Face will appear inverted in the Box towards the Hole; and if the Beholder comes nearer, he will ſee a Head coming out of the Hole.

The Repreſentation of a Point, placed in the Center of a Sphere, 829 *coincides with the radiant Point itſelf, and is as it were ſwallowed up by it**. * 821

If the Eye be plac'd in that Center, no Object can 830 *be ſeen by it*; for then only the Rays, that flow from the Eye, will be reflected to it*. * 806

If the Object be between the Center and the Point, 831 *in which parallel Rays are collected after Reflexion, the Object will alſo appear without the Glaſs, at a greater Diſtance from the Glaſs than the Object itſelf**; *the Repreſentation is inverted,* which is pro- * 822 ved in the ſame Manner as in N°. 828; *and magnified,* becauſe it is farther remov'd from the Center, than the Object itſelf is diſtant from it; for the Repreſentation recedes from the Center *in infinitum*; whilſt the Object goes thro' the fourth Part of the Diameter of the Sphere.

If the Object be leſs diſtant from the Mirror than 832 *the fourth Part of the Diameter of the Sphere, according to the different Situation of the Eye, the Object appears either before or behind the Glaſs.*

Plate XIII. *Fig.* 6.] If the Eye be ſo plac'd, that thoſe Rays may come to it which form the Curve *a a*, as towards *f*, it will ſee the Appearance of the Objects towards the Glaſs * magni- * 824 fied; becauſe the Curves, as *a a*, which belong to ſeveral Points, are diverging.

If thoſe Rays come to the Eye which form 833 the Curve *a a*, the Object will appear without the Glaſs: And *in both Caſes the Repreſentation is* *erect*; for as the Point A aſcends or deſcends, the Curves *a a* and a a, in which it is repreſented, are agitated with the ſame Motion.

834 *If the Eye be* in the Point, in which the reflected Rays, that belong to each Curve, interſect one another, *as in* O, *the Appearance of the Object will be double.*

It is plain in every Caſe of the Appearance, that the Points have not the ſame Relation to one another, as the Points of the Object; and
835 therefore that a *Concave Mirror never repreſents the Objects exactly*: But the moſt irregular Repreſentation of all is that which is in ſuch Lines, as a a.

836 There are alſo cylindric Mirrors convex and concave; theſe in one Reſpect are plane, and in another Reſpect ſpherical; and therefore the Repreſentation of the Objects is very irregular; which Irregularity, ſince it depends upon a regular Figure, may be ſo determin'd, that Pictures may be drawn, which, tho truly irregular, will in ſuch a Glaſs appear regular by Reflection, in a determinate Situation of the Eye.

CHAP. XVI.

Of the Magic Lantern.

THERE are ſeveral Machines made by the Combination of Mirrors and Lenſes, which afford uſeful and pleaſant Appearances; whoſe Explanation may be eaſily deduc'd from what has been ſaid.

Among many other I ſhall only chuſe to explain one, in which Figures, that are painted upon ſmall Pieces of Glaſs, are repreſented monſtrouſly large upon a white Plane. This is a Phæno-

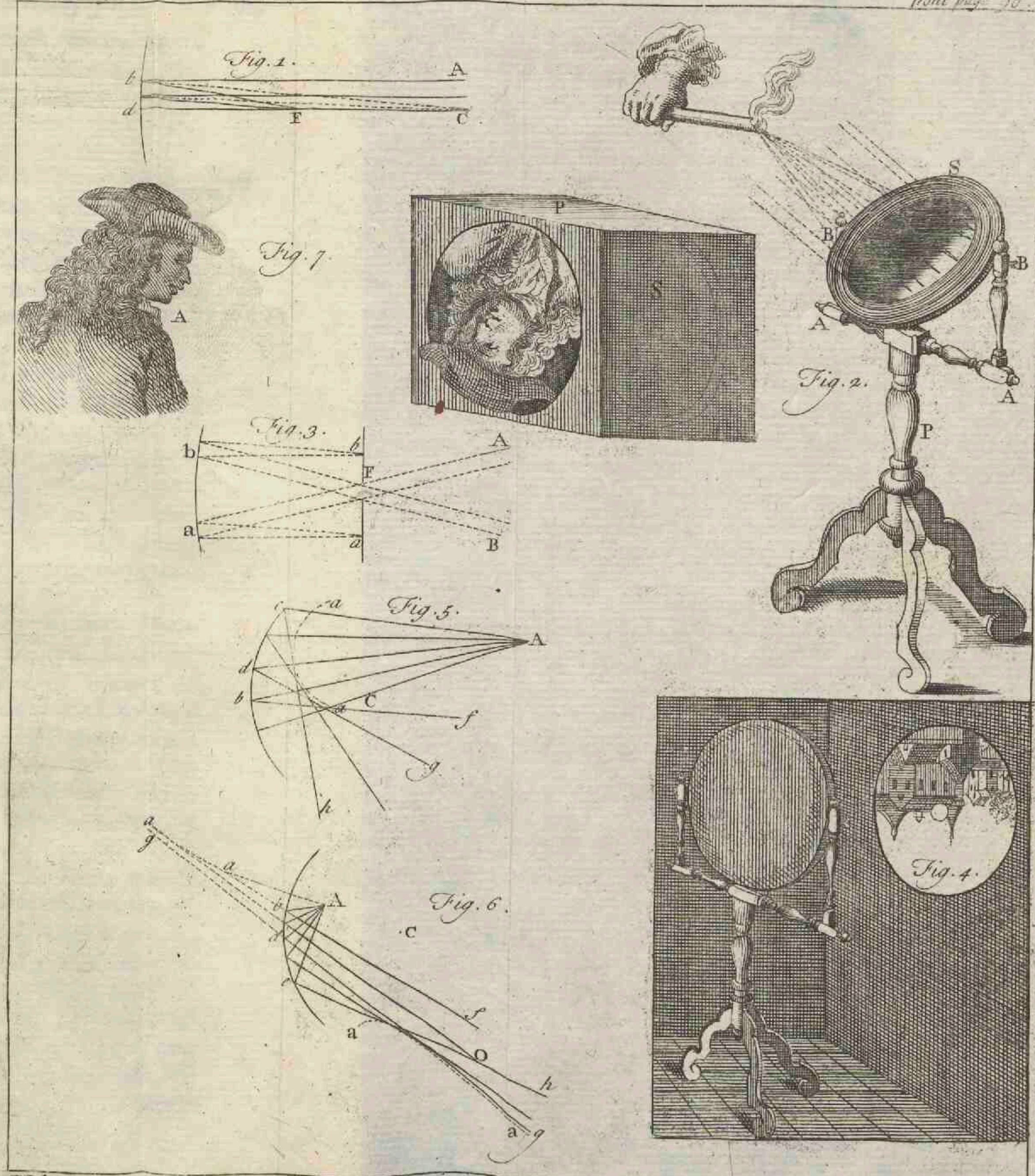
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.

Phænomenon wonderful enough to deſerve a particular Explanation. The Inſtrument that performs this is call'd a *Magic Lantern*, which Optic Writers have not altogether paſs'd by, but yet have not ſufficiently explain'd.

Plate XIV. *Fig*. 1.] Let there be a wooden 837
Box about a Foot and an half long, 14 Inches high, and as wide; there muſt be a concave Mirror S, of 8 Inches Diameter, and a Portion of a Sphere of 18 Inches: This Mirror is fix'd to a Foot which moves upon Rulers, along the Length of the Box.

There is alſo in this Box a Lamp L, ſuſtain'd by a wooden Foot which is moveable long-wiſe between two Rulers, in the Side of the Box. The Pipe of the Lamp ſtands forward in ſuch Manner, that the Center of the Flame is over-againſt the Center of the Surface of the Mirror; this Flame is made up of four little Flames, which, by touching one another, make one ſquare Flame, two Inches wide.

In the Top, or upper Plane of the Box, there is an oblong Hole, which has a Cover that ſlides to two Grooves, or between two Rulers or Ledges: Thro' this Cover paſſes the Chimney C, which (as you ſee in the third Figure) ſtands up about one half Foot above the Box. The Chimney is moveable with the Cover, whilſt the Opening remains ſhut; that the Chimney may be always over the Lamp.

In one of the little Sides of the Box, which is overagainſt the Mirror, there muſt be a round Hole about 5 Inches wide; which muſt have in it a Convex Lens of Glaſs of the ſame Bigneſs V, convex on both Sides, which are Portions of a Sphere of one Foot Diameter: The Axis of this Glaſs, being continued to the Surface of the Mirror, will be perpendicular to it, and fall upon its Center, as likewiſe to the Plane of the Flame, thro' whoſe middle Point it alſo paſſes.

This Hole is ſhut and open'd by a Plane moveable in a Groove, which is mov'd by a Cylinder that ſtands out of the Box at E.

To this Hole without the Box anſwers the Tube T, whoſe Length and Diameter is of about 6 Inches, at the End of which there is a Ring, in which the ſecond Tube *t* moves, of about 4 Inches Diameter, and 5 or 6 Inches long.

In the leſſer Tube there are two Lenſes; the firſt in that End which is thruſt into the Tube T, and it is of the ſame Convexity as the Glaſs V, and three Inches and a half Diameter. The ſecond Lens is three Inches from the firſt, and flatter, being terminated by Portions of a Sphere of four Foot Diameter. Between theſe Lenſes, at the Diſtance of about one Inch from the ſecond, there is plac'd a wooden circular Stop, or Aperture, which ſhuts up all the Tube, except an Hole of an Inch and a Quarter Diameter in the Middle of the Wood.

The Objects, that are to be repreſented, are to be painted upon a flat thin Piece of Glaſs, which muſt be mov'd without the Box overagainſt the Glaſs V, between it and the Tube T, the Picture being in an inverted Poſition. If theſe Pictures are round, they may be of 5 Inches Diameter: That they may be moved eaſily, they are put into flat Boards, three in one Board. The Picture alſo may be painted upon long Glaſſes, which may be ſucceſſively made to ſlide before the Glaſs V.

Plate IV. *Fig.* 3.] This whole Box ſtands upon a Frame or Foot, made ſo that it may be fix'd at different Heights. There are flat Pieces of Wood fix'd to the Box, at Bottom, which ſlide in Grooves in the Frame; each of them has a

Slit

Slit in it; so that the Box may be made fast at any desir'd Height, by the Help of Screws join'd to the Frame, and moveable in the Slits.

The whole Machine is placed at the Distance of 15, 20, or 30 Feet from a white Plane, which Distance must be different according to the Bigness of the Plane; for this Distance may be equal to the Length of the Plane: The Box must be just at such an Height that the Tubes, in the Side of the Box, may be exactly opposite to the Middle of the Plane.

The Lamp being lighted, the Box must be shut, and the Figures which are painted upon the Glass will be represented upon a white Plane. By moving backwards and forwards the Tube that has the two Lenses in it, you will find the proper Position of the Glasses requir'd to give a distinct Representation. As for the Disposition of the several Parts of the Machine, which immediately serve for exhibiting this Appearance, we shall here more particularly explain.

Plate XIV. *Fig.* 2.] The Parts in this *Figure* 838
are shewn separately; S S is the Mirror, *l l* the Flame which consists of four Flames in the Line *l l*; V V is the Glass V of the first Figure; O O is a Picture painted upon a flat thin Piece of Glass; *a a* the biggest Lens; *d d* the flattest Lens; *b b* the wooden Stop between the Lenses; *f* the Aperture or Hole in the Middle of the wooden Circle.

These Things being dispos'd as has been already explain'd, and as may be seen in the Figure, the Rays which proceed from a Point of the Picture O O, by going thro' the Lens *a a*, become less diverging, and fall upon the Lens *d d*, as if they came from a Point more remote *; * 669
from this Lens they go out more converging *, * 699
and are collected upon the Surface of the white

 Plane,

Plane, where they exhibit the Point of the Pi-
* 711 cture that is painted on the Glaſs *. This Picture is illuminated both by the Rays that proceed from the Flame *l l*, and by the Rays reflected by the Mirror S S.

839 For the Perfection of this Machine it is requir'd, 1*ſt*, That the Figure O O be enlighten'd as much as poſſible; 2*dly*, That it be equally enlighten'd in all its Points; 3*dly*, That all the Light, by which every Point of the Picture is enlighten'd, go thro' the Lenſes *a a* and *d d* to the white Plane, and ſerve to make the Repreſentation; 4*thly*, That no other Light but that go out of the Box, leſt the Repreſentation ſhou'd be leſs lively, by reaſon of extraneous Light.

The firſt Requiſite depends upon the Bigneſs of the Flame and of the Mirror, and of its Concavity; the more concave it is, the nearer it is to be brought to the Flame, and then the more Rays will be intercepted and reflected; yet Care muſt be taken that the Mirror (which may be made of very good Glaſs) be not too much heated.

When the Flame and Mirror are ſo contriv'd, that the Picture is the moſt enlighten'd that it can poſſibly be, and every where equally enlighten'd, the Flame and Mirror muſt be ſo plac'd, that the inverted Image of the Flame
* 826 ſhall fall juſt upon the Picture*. Now, as the Repreſentation of the Flame can be increas'd
* 826 and diminiſh'd *, the Mirror and Flame muſt be ſo diſpos'd, that the Repreſentation of the Flame ſhall cover the whole Picture upon the Glaſs, but ſo as not to exceed it: For then the Picture is as much enlighten'd by the reflected Light as it can be, and all its Points are equally illuminated; the direct Light alſo does pretty near

near equally fall upon all the Points of the Picture; this Light wou'd indeed be increas'd by bringing the Flame nearer; but the reflected Light wou'd be diminiſhed, and the Diminution of this laſt wou'd be greater than the Increaſe of the other.

The Glaſs V V ſerves to inflect the Light, by which the Picture O O is illuminated, before it comes to the Picture; by which Inflection all the Light comes to the Lens *a a*, and ſerves for the Repreſentation on the white Plane.

All the Light, that is of Uſe for this Repreſentation, goes thro' the Hole *f*; and the Rays, coming from different Points, interſect one another there; wherefore the Picture upon the Glaſs, which is placed inverted, is repreſented erect upon the white Plane; by the Ring *b b* all the Rays, which do not ſerve to form the Repreſentation, are intercepted, leſt they ſhou'd enter the Room, and make the Picture leſs diſtinct. This Ring or Aperture alſo intercepts thoſe Rays by which one Point is more enlighten'd than another, whereby the Light, which (from what has been ſaid) is equally enough diffus'd, is yet made more equal. But unleſs the Stop or Aperture *b b* be juſt where the Rays interſect, it does a great deal of Miſchief.

BOOK III.

PART III.

Of Opacity and Colours.

CHAP. XVII.

Of the Opacity of Bodies.

DEFINITION.

840 BODIES *that transmit the Light are call'd* Transparent. Such are
615 all Mediums, except a *Vacuum*.
841 *There is no Body whose smallest Parts are not transparent:* No one who is used to Microscopes will doubt of this. There are some Parts of Metals, which, tho very small, do not transmit the Light; But if they be dissolv'd in *Menstruums*; that is, if they be divided into much less Parts, they become transparent. One may also prove by a very easy Experiment, that Light can go thro' several opaque Bodies.

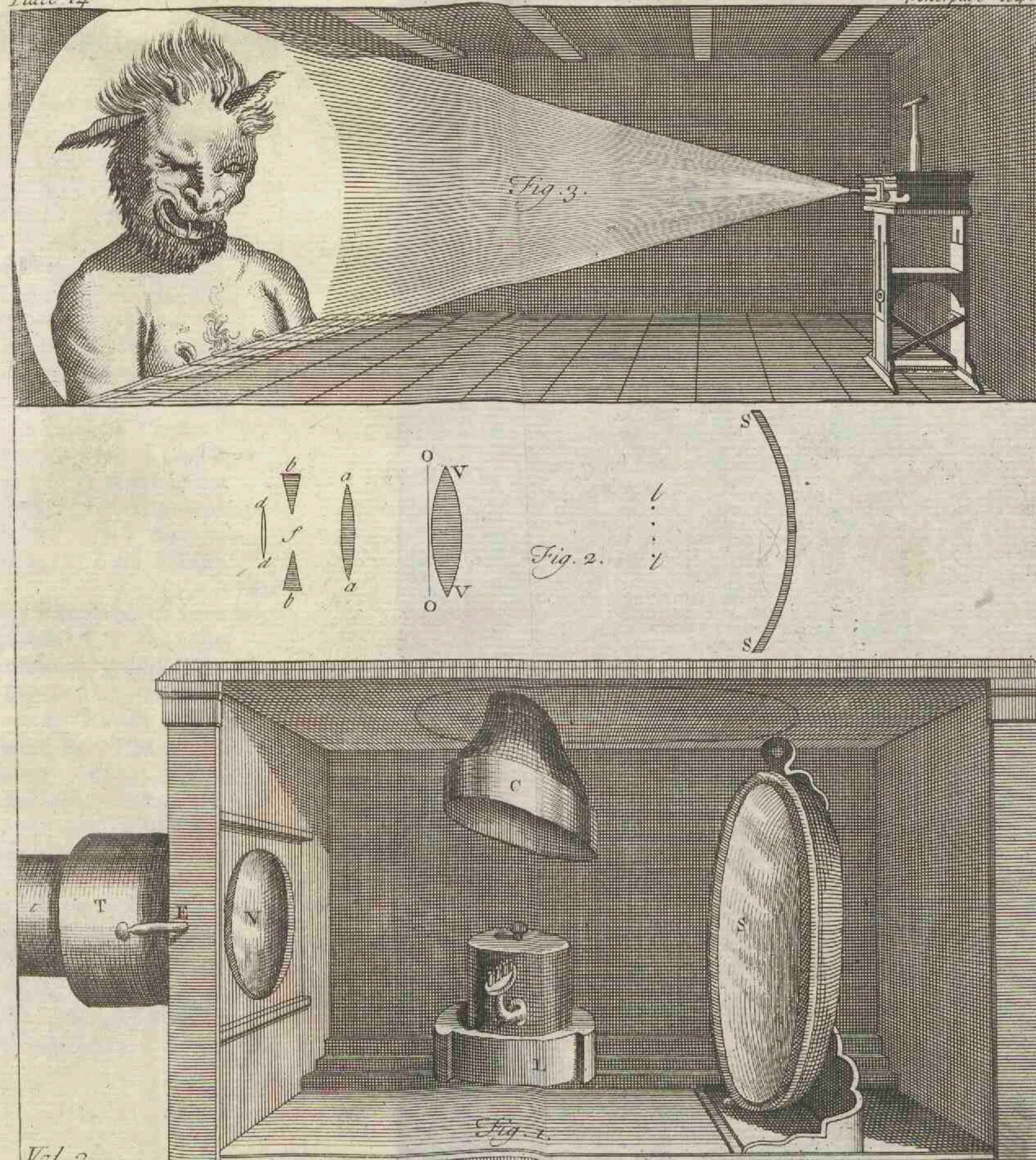
Fig. 3.
Fig. 2.
b
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Fig. 1.
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Experiment 1.] In a dark Room, in which
the Sun's Light comes in thro' an Hole, let that
Hole be cover'd with a thin Plate of an opaque
Body, and the Light will go thro' it; a Piece
of Wood, of the Thickneſs of the tenth Part of
an Inch, does not intercept all the Light. But
the perfect Tranſparency of Parts in opaque Bo-
dies is not prov'd by this Experiment, for that
Tranſparency is only in very ſmall Parts.

Opacity does not (as is commonly imagin'd) 842
happen in Bodies, becauſe the Way, thro' which the
Light might paſs, is ſtopp'd by Particles of Matter;
for Light paſſes thro' all the ſmalleſt Parts of
Bodies; neither is ſuch an Interception of Light
of any Uſe to cauſe Opacity: It is requir'd for
Opacity that the Light ſhou'd be reflected and
deflected from a right Line, for which there is
only requir'd the Separation of two Medi-
ums *. * 631

Let us conceive a Body, conſiſting of very 796
ſmall Parts, perfectly tranſparent (ſuch as are the
Particles of which Bodies conſiſt *) and ſepa- * 841
rated from one another by Pores; and that thoſe
Interſtices are either void, or fill'd with a Me-
dium whoſe Denſity is different from that of the
Particles; if Light enters ſuch a Body, it will
every Moment fall upon a Surface dividing Me-
diums differing in Denſity; therefore it will un-
dergo innumerable Reflections and Refractions
in that Body *, ſo as not to be able to get thro' * 631
it. Therefore we ſee that *Opacity depends upon* 796
the Pores; for *if you fill the Pores with a Medium* 843
of the ſame Denſity as the Particles of the Bodies
themſelves, the Light will undergo no Reflection
or Refraction in the Body, but paſs directly
thro' *, and *the Body will be tranſparent.* * 841

631

Tho 697

Tho we cannot make Experiments, whereby to fill the Pores of the Body with a Medium exactly of the ſame Denſity as the Particles, yet the following Experiments will clearly enough prove Sir *Iſaac Newton*'s Doctrine concerning Opacity.

Experiment 2.] Paper becomes more tranſparent, when moiſten'd with Water; for it fills the Pores, and differs leſs in Denſity from the Particles than Air does. Oil has the ſame Effect.

Experiment 3.] Take a Piece of Glaſs two Inches thick; and take ſeveral Plates of the ſame Sort of Glaſs laid upon one another, yet ſo as not to be quite two Inches thick; and you will find that theſe will be leſs tranſparent than the ſolid Piece, becauſe of the Air between the Plates, which does not get into the ſolid Piece where all the Parts cohere.

Experiment 4.] Take twelve Plates of the ſame Glaſs, as near as may be of the ſame Thickneſs; let ſix and ſix of them be laid together; if you take the leaſt tranſparent of thoſe two Particles, and, having dipp'd it in Water, take it out again, it will become more tranſparent than the other; becauſe the Water, which in that Caſe fills the Interſtices between the Planes, differs leſs in Denſity from the Glaſs than Air does.

What has been ſaid of Opacity is farther confirm'd, and put out of all Doubt by innumerable
844 Experiments, by which *Bodies perfectly tranſparent become opaque, by the Separation of their Parts*, without the Intervention of any opaque Body.

Experi-

Experiment 5.] Let any perfectly tranſparent Liquid, that may be chang'd into Froth, be ſhak'd, till it be full of Bubbles; it will immediately become opaque, by reaſon of the Interſtices that are fill'd with Air.

Experiment 6.] Turpentine and Water are tranſparent Bodies, but, when mix'd, they become opaque.

Experiment 7.] Water and Oyl, by being mix'd together, become opaque, tho, ſingly, they are tranſparent.

Experiment 8.] Tho Glaſs be tranſparent, yet if it be reduced to Powder it becomes opaque; as it alſo does when it is crack'd.

We clearly ſee in all theſe Caſes that Opacity is produc'd, becauſe there is a Medium of different Denſity between the tranſparent Parts; which may alſo be obſerv'd in the Clouds, which are opaque on account of the Air interpos'd between the Particles of the Water.

If we add to this what is ſaid in the 22d Chapter following, concerning the Colours of thin Plates, we ſhall have new Experiments, by which alone it is fully prov'd that Bodies intercept the Light, becauſe they conſiſt of very thin Particles, encompaſs'd with a Medium differing from them in Denſity.

Some opaque Bodies reflect a little Light, and the reſt of the Light, by innumerable Diviſions which it undergoes in the Reflections and Refractions above-mention'd, is extinguiſh'd in the Body; ſuch are black *Bodies*; if there were any Bodies *perfectly black*, they *wou'd reflect no* 845
Light; for all Bodies, when no Light falls upon them,

them, and therefore they reflect no Rays, appear black.

Other opaque Bodies appear to have various Colours; some transparent Bodies are also ting'd with Colours: And whence those arise we are now to examine.

CHAP. XVIII.

Concerning the different Refrangibility of the Sun's Rays.

BODIES appear differently colour'd, tho' they be enlighten'd by the same Rays of the Sun which are reflected by them. Besides these there are several Phænomena of Light, relating to Colours, not to be overlook'd.

846 In these we are to observe three Things. 1*st*, The Rays are to be examin'd. 2*dly*, Their Reflection is to be observ'd. 3*dly*, We are to enquire into the Constitution of the Surfaces of Bodies differently colour'd.

847 As to the Rays, the first Property, to be taken Notice of here, is, that *in the same Circumstance all Sorts of Rays do not undergo the same Refraction.*

DEFINITION I.

848 *The Rays, which undergo this different Refraction, are said to have a* different Refrangibility, and *those are said to be* most refrangible, *which are most inflected by Refraction.*

DEFINITION II.

849 *Those Rays are said to be* Homogeneous, *which do not differ from one another in Refrangibility.*

DEFI-

Definition III.

And those are call'd Heterogeneous, *which, under the same Circumstances, are not equally inflected by Refraction.* 850

Plate XV. *Fig.* 1.] Between A B and C D let there be a Sun Beam made up of an innumerable Quantity of parallel Rays; these are not equally refracted; for if they fall obliquely on the Surface B D of the denser Medium, some of them are refracted between B E and D G, and are mov'd according to that Direction in the denser Medium; others are more inflected, and direct their Motion between B F and D H according to the Direction of those Lines; and indeed no Direction can be conceiv'd between the Mediums, along which the Rays do not move in every Point between B and D: So that the least Beam whatever is, by Refraction, divided into an innumerable Quantity of Rays; because every Sun-Beam, however small, is heterogeneous, and consists of an innumerable Quantity of Rays refrangible in all Degrees of Refrangibility.

The above-mention'd parallel Rays falling 851
upon a plane Surface, by Refraction, are mov'd between B E and D H; which Lines diverge from each other, and, being continued, are more and more separated; so that the Rays above-mention'd are dispers'd by Refraction. In N°. 653. *We have consider'd the Rays as homogeneal,* as also every where *in the Foregoing Part*; the Difference of Refrangibility is small enough in the Rays of the Sun, not to have been worth observing in the foregoing Propositions. Besides, we were first to examine what happens in homogeneal Rays; and what must be chang'd in the Propositions, upon account of the different Refrangibility, will easily appear.

That

582 That this Refrangibility of the Rays may be made visible, the above-mention'd Divergence must be increas'd; which will be perform'd, if the Rays above-mention'd fall upon the Surface E H, which terminates a denser Medium, and separates it from the rarer Medium, and which makes any Angle with the Surface B D, and is so inclin'd to it, that the Rays, which are more refrangible, fall more obliquely upon it than those that are less refrangible; so that the former, going into a rarer Medium, are more turn'd out of the Way, and diverge more from the others upon a double Account, that is, both upon the Account of a greater Refrangibility, and of a greater Inclination. The Rays between B E and D G, which are the least refrangible, being refracted a second Time, continue their Motion between E I and G L, the others between F M and H N: In which Case, if these Rays fall upon a Plane at the Distance of 15 or 20 Foot, those that are most refrangible will be separated from those that are least refrangible, and the whole intermediate Space is enlighten'd with Rays endow'd with a mean Refrangibility.

Experiment 1. *Plate* XV. *Fig.* 2.] Let there be an Hole in the Plate of a Metal in the Window-shut, of about a Quarter of an Inch, thro' which a Sun-Beam enters the darken'd Room: Let this Beam fall upon a triangular Prism of Glass A A, in such Manner, that it may be wholly reflected by the lower Surface (see the *Exper.* of N°. 789.) By the two Refractions which the Light undergoes, Rays that are differently refrangible do not diverge, and, being reflected, come upon a second Prism B B, which is likewise of Glass, and triangular, in the same Manner, as if they had come directly from the Sun.

These

Theſe two Priſms are moveable about their Axes, as we before explain'd *; the firſt A A is laid upon a Piece of Wood faſten'd to it, yet ſo as not to hinder it from turning about its Axis; this Piece of Wood is faſten'd to a Three-legg'd Staff with a Ball and Socket, ſuch as is us'd in practical Geometry. The ſecond Priſm B B is laid on a Frame or Stand S, in whoſe oppoſite Sides there are ſeveral Slits that anſwer one another; by theſe the Priſm is ſuſtain'd at different Heights, but always horizontally, the End of the Axis being plac'd in correſpondent Slits. * 197

The Light, that comes to the Priſm B B, moves perpendicular to its Axis, and paſſes thro', as is demonſtrated in *Fig.* 1. in which B D and E H repreſent the Sides of the Priſm; the Light is alſo equally inclin'd to each Side; which will happen by moving the Priſm about its Axis; for the Light of the Sun (as you move the Priſm) will aſcend, and then deſcend again; and the Situation requir'd is that in which the Light is higheſt of all: Now both the Priſms are to be ſo diſpos'd, that in this Caſe the Light may go horizontally out of the Priſm B B. This horizontal Beam, at the Diſtance of 15 or 20 Foot, muſt fall upon the Board T which is cover'd with white Paper, and has ſuch a Foot, that upon it, it may be rais'd and fix'd at different Heights. The Rays come diverging to the Paper, and upon it form the Oblong Image R V, terminated at the Sides by parallel Lines, but ſemicircular at R and V.

If the Rays of the Sun, that go thro' the round Hole, fall upon a Plane at a certain Diſtance, they will form a bright round Spot, ſo much the greater, as the Plane is more diſtant from the Hole; which ariſes from the Rays that come

come from the Sides of the Sun, which making an Angle with those that come from its Center to the Hole, and intersecting them in the Hole, gives the Image of the Sun upon the Plane.

If the Rays did not go thro' the Prism B B, and fall upon the Plane at the Distance of the Board T, the Image of the Sun wou'd have its Diameter equal to the Breadth of the Image V R; which Breadth is not alter'd by the Re-
853 fraction, because the Rays enter the Prism perpendicular to its Axis, and, in Respect of the Breadth of the Image, are not inclin'd to it. But as, in another Respect, the Image of the Sun is *oblong*, it follows plainly from thence, that all the Rays have not undergone the same Refraction; for homogeneous Rays, tho refracted, will give a round *Image of the Sun.* The least refrangible Rays go to R, and the most refrangible to V; and the whole Image R V is terminated with Semicircles at R and V, because the whole Image *consists of Circular Images.* Now between R and V there are innumerable Quantities of circular Images, made by Rays of all possible Refrangibilities; otherwise the Image R V wou'd not be terminated with rectilinear Sides.

854 In most Experiments, we have said that the Light is let into the darkened Room thro' a Slit or an Hole, which we leave to the Contrivance of the Workman; our Method was the following.

Plate XV. *Fig.* 3.] We made an Hole 4 Inches square in the Window-shut, which on three Sides had Ledges of Wood A B, B C, C D, so rabbetted, as to make Grooves to keep in the square flat Piece of Wood Q L, which is six Inches long, and six Inches wide. It may be drawn out, and

and ſeveral Sorts of them ſerve for ſeveral Experiments. That which we uſe in the following *Experiment* has a Hollow and a Hole in the Middle behind to contain a convex Lens, which is the Object Glaſs of a Teleſcope of 16 or 20 Foot; the round Hole in the Middle mark'd *f* is above half an Inch in Diameter, thro' which the Rays of the Sun, paſſing thro' the Glaſs, enter the Room. In the Fore-part alſo the Board Q is hollow'd, but not in the Middle; this Hollow contains the braſs round Plate L, which towards its Circumference has an Hole at *f*, which Hole is equal to the Hole in the Board Q itſelf, and agrees with it. Together with L there is another concentric Plate, which is leſs, and moveable about the Center; this Plate has ſeveral unequal Holes, which ſucceſſively come to *f* as the *Plate* is turn'd round; ſo that you may at Pleaſure let the Light enter a dark Place thro' a bigger or a leſſer Hole; which in many Experiments, that are made without the Lens above-mention'd, is of good Uſe. The *Pin m*, join'd with the Plate, ſerves to turn it by.

Experiment 2.] Let in a Sun-Beam thro' the Lens above-mention'd, thro' an Hole a Quarter of an Inch wide, into the darken'd Room; by the Rays thus let in, at the Diſtance where parallel Rays are collected, the Sun is very exactly repreſented, and its Image terminated with exactly deſcrib'd Bounds. For the Rays that come from the ſeveral Points of the Sun, which, by reaſon of its immenſe Diſtance, may be look'd upon as parallel, are collected in one Point at that Diſtance.

Plate XV. *Fig.* 2.] Now if with theſe Rays you make the Experiment above-mention'd, the ſeveral Images made by the homogeneal Rays, ſuppoſing the Board at a juſt Diſtance, are exactly terminated; and therefore the oblong Image R V, which is made of all theſe Images, is likewiſe regularly terminated.

This Experiment will ſucceed in the ſame Manner, if the Rays paſs thro' a Priſm made of any Body which is denſer than Air.

Experiment 3. *Plate* XV. *Fig.* 2.] Let a triangular Priſm be made of Wood and two glaſs Planes, and fill'd with Water; ſuch as is repreſented at B B (*Plate* XVII. *Fig.* 3.) If you make uſe of this Machine inſtead of the Priſm B B in this *Fig.* the Experiment will ſucceed in the ſame Manner; and, in paſſing thro' Water, heterogeneous Rays in the ſame Manner are ſeparated by Refractions.

Experiment 4.] If any Perſon, ſtanding 15 or 20 Foot off, looks at the Hole thro' which the Light is let in, it will appear round; but if before his Eyes he hold a triangular glaſs Priſm, or the watery one mention'd in the laſt Experiment, ſo that the Rays coming from the Hole (after ſuch Refractions as the Light ſuffers in the foregoing Experiment) reach the Eyes, the Hole will appear oblong. The Situation of the Priſm will be found, if holding it horizontally with one Edge (or the refracting Angle) upwards, it be a little mov'd about its Axis, ſo as to make the Image of the Hole to aſcend and deſcend; and the Priſm be held faſt in that Poſition in which the Hole appears moſt depreſs'd.

This Experiment, as well as the foregoing ones, proves the different Refrangibility of the Rays; for by the homogeneal Rays of each Refraction, the Hole appears in the imaginary Foci of the Rays coming from the ſeveral Points of

of the Hole*, which Image is round; the Rays, * 737
which undergo a different Refraction, enter the Eyes in different Directions; and you have several Images, all which form the oblong Image, which is really seen.

But that *this different Refrangibility does not de-* 855
pend upon the refracting Medium, but the different Constitution of the Rays themselves, is prov'd, because those Rays, which in one Case undergo the greatest Refraction, are in any Refraction turn'd out of the Way more than any.

Experiment 5. Plate XV. *Fig.* 4.] All Things being dispos'd, as in the first Experiment, at any Distance from the Prism B B; let the oblong Image of the Sun fall upon the Vertical Prism C C, which is also moveable about its Axis; as the Rays go thro' it, let it be turn'd about its Axis, and left fix'd where the Rays are least of all turn'd out of the Way by Refraction thro' the Prism: In that Case the Rays are refracted in the same Manner thro' this Prism as thro' the first, but they are not dispos'd the same Way, for that wou'd form a square Image. But here the Image, keeping the same Breadth, is inclin'd at R V, the Rays at V being mostly turn'd out of the Way, as in the Refraction thro' the first Prism B B.

The Demonstration, before given *, *of the con-* 856
stant and settled Ratio between the Sines of the An- * 639
gles of Incidence and Refraction, may be referr'd to any homogeneous Rays; but considering the different Refrangibility of the Rays, this Proportion varies, as it follows from the Experiments of this Chapter.

But *the Refrangibility in all the different Sorts* 857
of Rays is every Way unchangeable, as will appear by the Experiments to be mention'd hereafter.

CHAP. XIX.

Concerning the Colours of the Rays, and their Unchangeableneſs.

858 *THE different Refrangibility of the Rays goes along with the different Colours; and every Sort of Rays, as they are more or leſs inflected by Refraction, have a particular Colour of their own, and which is wholly unchangeable.*

In Reſpect of the Colours, the ſame Thing is to be obſerv'd, as has been taken Notice of in regard to other Senſations *; the Colours are Ideas which have nothing common with the Rays, by which they are excited: Therefore we muſt define what we mean by colour'd Rays and colour'd Objects.

* 502 580, 6

DEFINITION I.

859 *An Object is ſaid to be of ſuch a Colour, whoſe Idea is excited in the Mind by the Rays reflected from the Object.*

DEFINITION II.

860 *Homogeneous Rays, which, ſtriking upon the Retina, excite in our Mind an Idea of any Colour, are call'd Rays of that Colour.*

We have ſaid that the Rays excite an Idea, by which we underſtand that the Rays put the Fibres into a trembling Motion, and that Motion occaſions an Idea in the Mind.

Plate XVI. *Fig.* 1.] It is very evident from the Experiments of the foregoing Chapter, that Rays of different Refrangibility have a different Colour; for thoſe Experiments ſhew that the Image of the Sun, which is oblong, is tinged

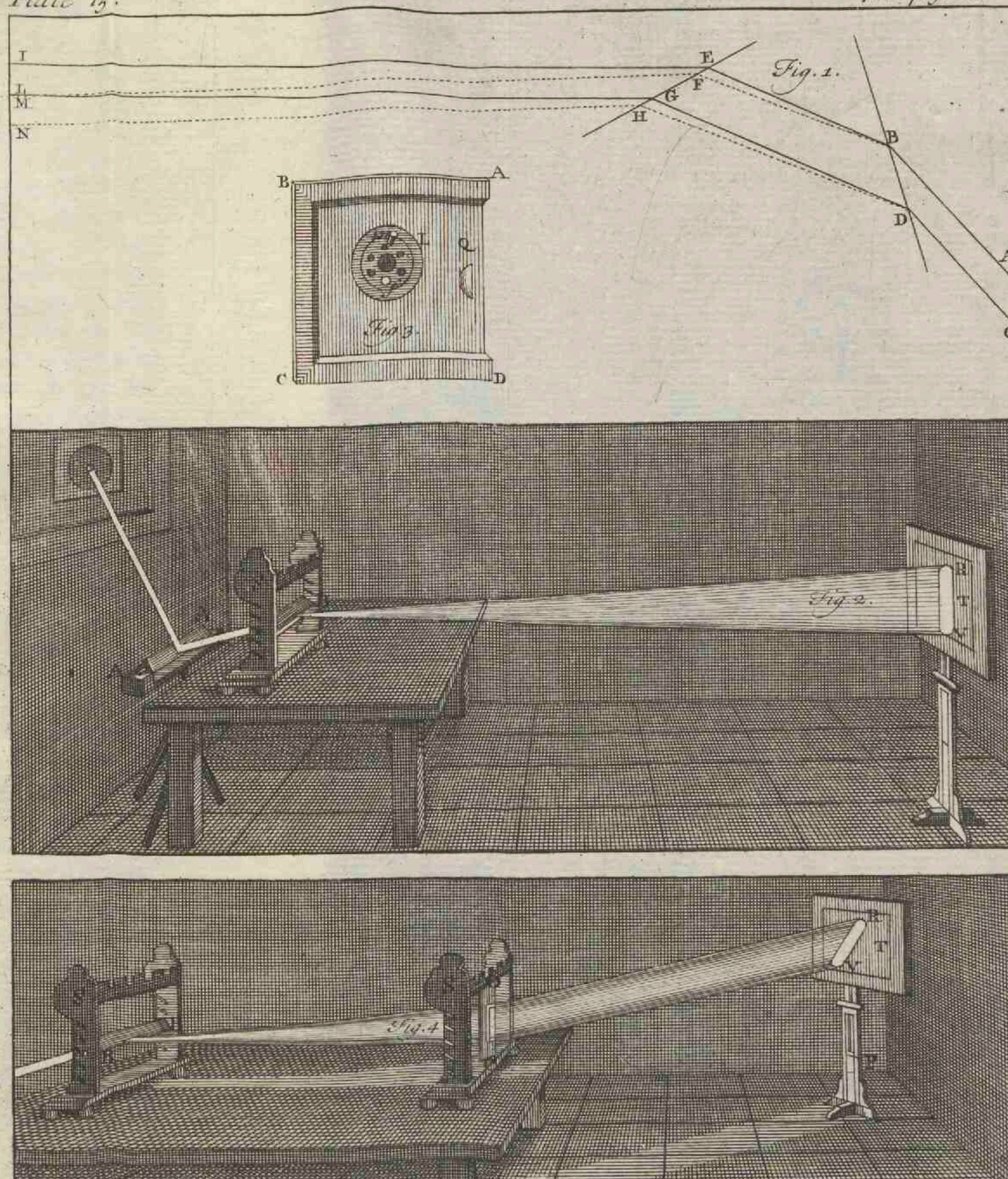
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Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.

tinged with different Colours. *The Rays, which* 861
are least turn'd out of the Way by Refraction, are red; the rest of the Colours are in the following Order, namely Orange, Yellow, Green, Blue, Purple, and Violet, of which last Colours are the Rays that are most refracted *. The oblong Image of the Sun above-mention'd, as has been said *, is * 853
made up of an innumerable Quantity of round Images; if their Diameters be diminish'd (which is done by intercepting the Sun's Rays, so that only those that come from the Center of the Sun shall pass thro' the Prism) the Centers of the particular Images which make up the oblong Image will not be chang'd; and therefore the Length of the Image *a h*, between parallel Lines, is not chang'd: And this alone wou'd remain the same, if the Breadth of the Image, shou'd be infinitely diminish'd: And therefore this Length alone is to be consider'd in determining the Limits of the Colours in the Image itself; these Colours are represented in this Figure by the Letters *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, and the Number which is set down against each Colour denotes the Space taken up by it in the Image, the whole Lenth of the Image being divided into 360 Parts.

If the Breadth of the oblong Image of the Sun be 862
diminish'd, the heterogeneous Colours are more separated in the Image; because there are fewer particular Images confounded in the several Points, where Rays of different Refrangibilities differ little from each other.

The Colour of any Ray, as also its Refrangibility, 863
cannot be changed by any Refractions, or Reflexions, or mingling of the Rays together.

In this Chapter I shall speak of Reflexion and Refraction, and of the Mixture of Rays in the following one.

864 That the Refrangibility is not chang'd, by Refraction, is prov'd by the *5th* Experiment of the foregoing Chapter; which may alſo be referr'd to Colour; but is more clearly evinc'd by the following Experiment. Concerning which it is to be obſerv'd (as may be alſo ſaid of what follows) that the Experiments are to be made with Priſms of clear Glaſs, free from Veins; for they occaſion the Light to move irregularly; and the Rays are not duly ſeparated by the Refractions.

Experiment 1. *Plate* XVI. *Fig.* 2.] Every Thing being as in the firſt Experiment of the foregoing Chapter, you muſt make the Experiment with a Sun-Beam, going thro' an Hole of half an Inch Diameter: The Frame or Stand S, in which the Priſm is, muſt be ſuch, that the little flat Board *t*, to be us'd in this Experiment, may move between its Sides; this Board has an Hole F of ⅛ of an Inch Bore, thro' which the Light refracted by the Priſm is tranſmitted, whereby the Rays in the oblong Image are better ſeparated from one another, the Rays being moſtly intercepted; this oblong Image R V, at the Diſtance of 10 or 12 Feet from the Priſm, falls upon the Board *t* of a Stand like the former; in which Board alſo there is a ſmall Hole F like that in the firſt; thro' this the Rays paſs upon a ſecond Priſm laid upon this Stand, and are refracted in the ſame Manner as in the firſt. By moving the firſt Priſm a little about its Axis, the Image R V aſcends or deſcends, whereby the different Rays are ſucceſſively tranſmitted thro' the Hole; in every Caſe, the Rays refracted thro' the ſecond Priſm, and ſtriking upon the flat Board T which is cover'd with white Paper, are not diſpers'd at H; but the Image is round, if the Rays fall perpendicularly upon the Paper, and alſo of the ſame

Colour

Colour as the Rays falling upon the ſecond Priſm. Yet the Image H is ſo much the more lifted up, as the Rays, by Refraction thro' the firſt Priſm, are more turn'd out of the Way; that is, thoſe, that are moſt refrangible in the one Caſe, do alſo ſuffer the greateſt Refraction in the other.

It will appear alſo by the following Experi- 865
ments, that the Refrangibility and Colour are not chang'd by Reflexion.

Experiment 2.] The Rays which, for Example, make the red Part of the oblong colour'd Image, whatever Body they are reflected from, are always red; that is, all Bodies appear red in that Light: In the violet Light they are violet; green in the green; and ſo on in the other Colours.

This will appear by trying it with Vermillion, Orpiment, blue Bice, or Cloth of any Colour, *&c.*

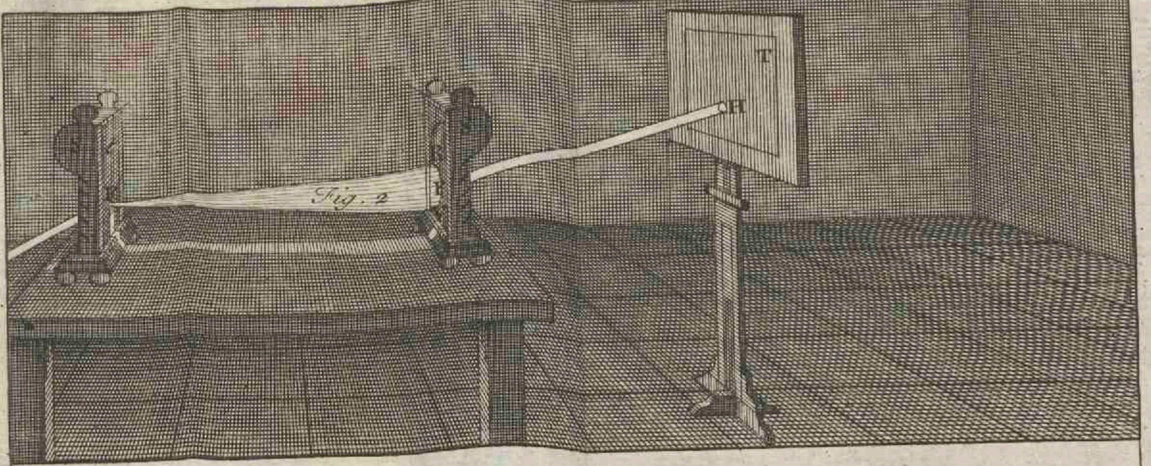
Experiment 3. *Plate* XVI. *Fig.* 3.] Let the Light enter the dark Room thro' two Holes of a Quarter of an Inch Diameter each, in the round Plate moveable in the Window; let theſe Beams be about two Inches aſunder, and reflected by the plane Mirror S.

The Plate and Mirror muſt be ſo diſpos'd that the two Beams may fall upon two Priſms A A, which are laid horizontally upon the ſame Frame; ſo that the oblong Image, produc'd by the Refraction of thoſe Priſms, may touch one another at their Sides. Let one Priſm be turn'd a little about its Axis, that the Red of one Image may be juſt on the Side of the Violet of the other: Let theſe Colours, and none of the reſt, be intercepted by a wooden Ruler that has a white Paper paſted upon it, ſo that the

Red be at R, and the Violet at V, the reſt of each Image falling upon the Wall, which muſt be cover'd with a black Cloth. If any Perſon ſtand at O, and thro' the Priſm B B looks at thoſe Colours, R and V, (in the Manner deſcrib'd concerning the Hole, in *Experiment* 4. of the foregoing Chapter) he will ſee the Colours ſeparated from one another, the Red at *r*, and the Violet at *v*; which therefore, being reflected in going thro' the Priſm B B, undergoes a greater Refraction.

In the firſt Experiment of this Chapter we gave a Method, whereby to ſeparate the heterogeneous Rays better than in other Experi-
866 ments; in the following Experiments, Lights of divers Colours become much more homogeneous, which is requir'd in the ſixth Experiment of this Chapter.

Experiment 4. *Plate* XVII. *Fig.* 1.] Let the Sun's Light enter the dark Room thro' an Hole of $\frac{1}{8}$ of an Inch; the Sun Beam muſt be reflected by the Priſm A A to the convex Lens V, which ſtands upon a Foot, and is about 3 or 4 Inches wide; the Length of the incident and reflected Rays, taken together, is about ſeven Feet; the Convexity of the Lens is ſuch, that the Foci of the Rays coming from the ſeveral Parts of the Hole, at the Diſtance of 10 or 12 Feet from the Lens, will form the Repreſenta-
*711 tion of the Hole, if a Paper be held there *. Juſt beyond the Lens place the Priſm B B, whereby the Rays (as in the firſt Experiment of the foregoing Chapter) are diſpers'd; now placing the flat Board T, at the Diſtance at which the Rays, coming from the ſeveral Points, are collected, there will fall upon it a well terminated oblong colour'd Image R V, whoſe Length


T
H
Fig. 2

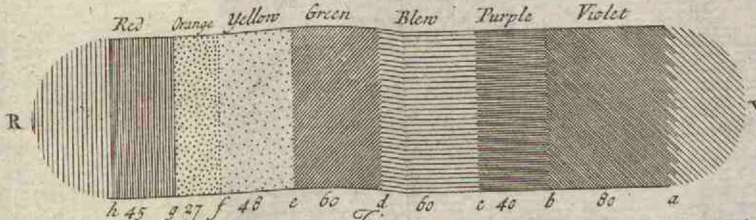
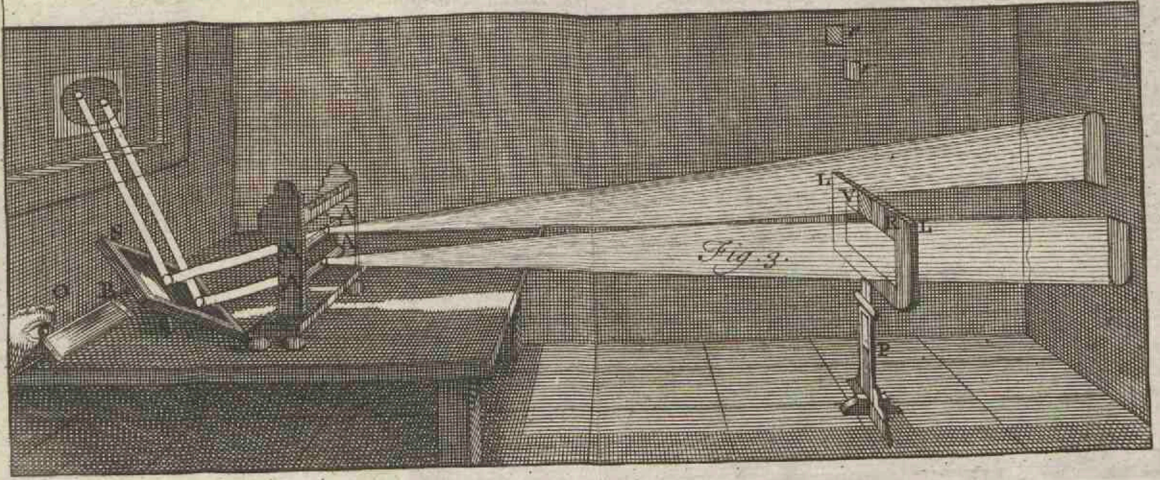

Red Orange Yellow Green Blew Purple Violet
R
V
h 45 g 27 f 48 e 60 d 60 c 40 b 80 a

Fig. 1.


L
V
R
L
Fig. 3.
S
O
R
P

Length will have a greater Proportion to its Breadth than in other Experiments; and which therefore is made up of Rays more homogeneous*; and so much the less mix'd, as the Hole * 862
in the Window is the less. By moving forward or backward the Board T, one may find the Distance at which the Image is most distinct and terminated without the Penumbra.

Now that the Rays, separated in this Experiment, are homogeneous enough, is prov'd from this, that they can be no more dispers'd by a new Refraction: And that this is the Property of homogeneous Rays, follows from their equal Refrangibility; which has been already confirm'd by an Experiment *, and is more fully * 864
demonstrated by the following one.

Experiment 6.] Take two Circles of Paper of an Inch Diameter each, and let Light fall upon them in such a Manner, that the one may have the homogeneous Rays of any Colour fall upon it, and the other may be enlighten'd by the Rays of the Sun; if both these Papers be look'd at thro' the Prism at the Distance of some Feet, as in the third Experiment of this Chapter, the Circle, enlighten'd by the heterogeneous Light, appears oblong, and ting'd with different Colours, as in the fourth Experiment of the foregoing Chapter; but neither the Colour nor Figure of the other Circle is chang'd.

Experiment 6.] Upon a white Paper draw black Lines parallel to one another, and about the sixteenth Part of an Inch wide; let these be enlighten'd by throwing upon the Paper the oblong Image, which is describ'd in the fourth Experiment, so that the Lines may lie long-wise in the Image. Besides this you must have a convex

vex Lens, about five or ſix Inches wide, ſuſtain'd upon a Foot, ſuch as are repreſented at V (*Plate* XIX. *Fig.* 2.) which collects the red Rays that come from a radiant Point, ſix Foot diſtant from the Glaſs, at an equal Diſtance on the other Side. If this Lens be plac'd at the Diſtance of ſix Feet from the Image above-mention'd, the Parts of the black Lines that are enlighten'd by the Red falling upon the Paper, by means of the Rays which are collected by the Lens, will be exactly repreſented in the red Image at the Diſtance of ſix Feet; but you muſt bring the Paper forward about three Inches and a Half, to make thoſe Parts in the Lines which are enlighten'd by the Purple, to appear diſtinct in that Part of the Image which is of the ſame Colour: The intermediate Colours give Images at intermediate Diſtances; the Violet is ſo weak, that the Threads cannot be repreſented in it.

This Experiment does alſo confirm, that the Colour of reflected Rays is not chang'd by a new Refraction thro' the Lens; as alſo that the moſt refrangible Rays are more inflected than the others in paſſing thro' the Lens.

867 This laſt Experiment does alſo prove, *that the different Refrangibility of the Rays is the Cauſe that hinders the Perfection of Teleſcopes.* For the Foci of the Points, that are equally diſtant, fall at different Diſtances from the Lens, according to their different Colours; whence all the Repreſentations of the Points are unequally diſtant from the Eye-Glaſs; and therefore they cannot be all perfectly ſeen thro' it.

868 Concerning the Reflexion of the Rays it is to be obſerv'd, that *thoſe Rays are more eaſily reflected totally, which have the greateſt Refrangibility*; for the greater is the Refraction of the Rays, the

the leſs Obliquity is requir'd to make them be totally reflected *. * 793

Experiment 7. Take a Priſm, plac'd as before *, in the Experiment where it was obſerv'd, * 790
that by moving the Priſm about its Axis, the Rays that firſt went thro', when their Inclination is increas'd, become wholly reflected; but if the Priſm be gently mov'd in this Caſe, we ſhall perceive that the violet Rays are the firſt which will be wholly reflected, then the purple Rays, and all the reſt in the ſame Order, as they are in the oblong Image of the Sun, ſo often mention'd; which appears, if the reflected Rays be ſeparated by the Refraction of the Priſm.

CHAP. XX.

Of the Mixture of Colours, where we ſhall ſpeak of Whiteneſs.

THAT the Refrangibility and Colour of 869
the Rays are not chang'd, by the Mixture of Rays of different Refrangibility, has already been ſaid *, and now we muſt prove it by Expe- * 863
riments.

Experiment 1. *Plate* XVI. *Fig.* 3.] This Experiment muſt be made in the ſame Manner as the third of the foregoing Chapter; here you muſt make the Red R, and the Violet V be confounded and mix'd together, by throwing them upon the ſame Part of the Ruler L L, which thereby will appear of a purple Colour in that Place. But if a Perſon looks at them thro' a Priſm, the Colours will appear ſeparated; and therefore neither the Colour nor Refrangibility are chang'd by this Confuſion of Colours.

Expe-

Experiment 2. *Plate* XVII. *Fig.* 2.] If the oblong colour'd Image of the Sun (of which Memtion was made in the firſt Experiment of the 18*th* Chap.) falls at R V upon the convex Lens L, mention'd in *Experiment* 4, of the foregoing *Chap.* which muſt be placed at ſix or ſeven Foot from the Priſm B B, the divergent Rays will converge by the Refraction of the Lens, and interſect one another at the Diſtance of 9 or 10 Feet at A; if the Board T be placed at a greater Diſtance, the Rays, which diverge again after the Interſection, will fall upon it diſpers'd; and you will again have an oblong colour'd Image; but the Colours by reaſon of the Interſection at A, will appear in a contrary Order, and will not be chang'd by having been mix'd together at A.

Experiment 3. *Plate* XVII. *Fig.* 2.] Every Thing ſtill remaining as in the former Experiment, if with a black Paper you intercept ſome of the Rays of the Image R V, which changes the Mixture (which this Way may be varied in any Manner) the Colours of the other Rays, that are again ſeparated, are no Way chang'd.

870 *If the Rays of the Sun*, as they come to us, *are wholly reflected by any Body*, *that Body appears White*; but theſe Rays are an Heap, or Parcel
* 847 of Rays of various Colours *; whence we de-
858 duce, that *a Mixture of different Colours makes a*
871 *Whiteneſs*; for if the Colours which are obſerv'd in the oblong Image of the Sun, ſo often mention'd, be mix'd and confounded together, in the ſame Proportion as they are in that Image, a Whiteneſs will be produced; which alſo proves, that in that Reſpect the Rays are unchangeable. The Rays that come from the Sun appear white;

white; but, if they are ſeparated, their Colours are diſcover'd; and, if they be mix'd again, the Whiteneſs will be reſtor'd.

Experiment 4. *Plate* XVII. *Fig.* 2.] Things being diſpos'd as in the two foregoing Experiments; let the Board T be plac'd at A, in the very Place where all the Rays of the Image R V are confounded together; there will be a Whiteneſs at A; if with a black Paper you intercept the Red of the Image R V, the White will vaniſh, and the Colour at A be bluiſh; but if you intercept the violet and blue Rays, the White becomes reddiſh.

Experiment 5. *Plate* XVII. *Fig.* 3.] Take three triangular Priſms, made of Wood and Plates of Glaſs which contain Water, as B B, D D, D D; the Plates of Glaſs in each of them make an Angle of about 70 Degrees: The Length of the Plate is of ſix or ſeven Inches, and their Breadth of three Inches; theſe Plates are fix'd in another Manner in the Priſms D D, D D, than in the Priſm B B, ſo as to make their Baſes bigger, that is, theſe Priſms are ſhorter and deeper than the other. Let the Sun's Rays be refracted thro' the Priſm B B, as in the 3d *Experiment* of the 18*th Chap.* And let the oblong Image of the Sun at the Diſtance of three or four Foot fall upon the Surface of the Priſm D D, plac'd parallel to the Surface of the Priſm B B, out of which the Rays go. In the ſecond Priſm the Rays undergo a contrary Refraction than in the firſt; becauſe of the Paralleliſm above-mention'd: And becauſe the Edge of the Angle, form'd by the Glaſs Plates in the Priſm B B, is turn'd upwards, and that of D D downwards; therefore the firſt Refraction is deſtroy'd by the ſecond, and the Rays go out of the Priſm D D parallel to one another,

another, and fall upon R V; for if the Prisms be brought together, so that the parallel Surfaces may touch one another, the Light will pass thro' a Medium terminated with parallel Planes, (which is form'd by the two Prisms join'd together) thro' which Light, of any Degree of Refrangibility, will pass without Change of Di-
* 628 rection*. Now the Prisms are separated, that the heterogeneous Rays may be separated, before they again become parallel; if these colour'd Rays fall upon the third Prism D D, and in passing thro' it undergo a Refraction like that which they have undergone in passing thro' the first or second Prism; the Rays that go out at *r v* converge, on account of unequal Refractions in Rays of different Colours, and concur at A, in which Place also Whiteness will be produc'd, as in the foregoing Experiment.

Experiment 6.] If an oblong colour'd Image of the Sun be made, after the Manner describ'd in *Experiment* 1. of the 18*th Chap.* and a Person standing at the Distance of the Prism, that refracts the Light, looks at the Image thro' the said Prism, as was done in respect of the Hole in the fourth Experiment of the same Chap. he will see a round and white Image; the second Refraction destroying the first; for thereby the Rays, being again mix'd, enter the Eye, and in this Case make the Object appear white.

872 *The Mixture of all the Colours, which are observ'd in the oblong Image of the Sun, is not necessary for producing White*: The Whiteness of the Sun's Rays is a little inclin'd to yellow; and therefore if Part of the yellow Rays be taken out of the Mixture, the White will be the more perfect. From the Mixture of four or five Colours, in a just Proportion, White will be produc'd.

Pri-

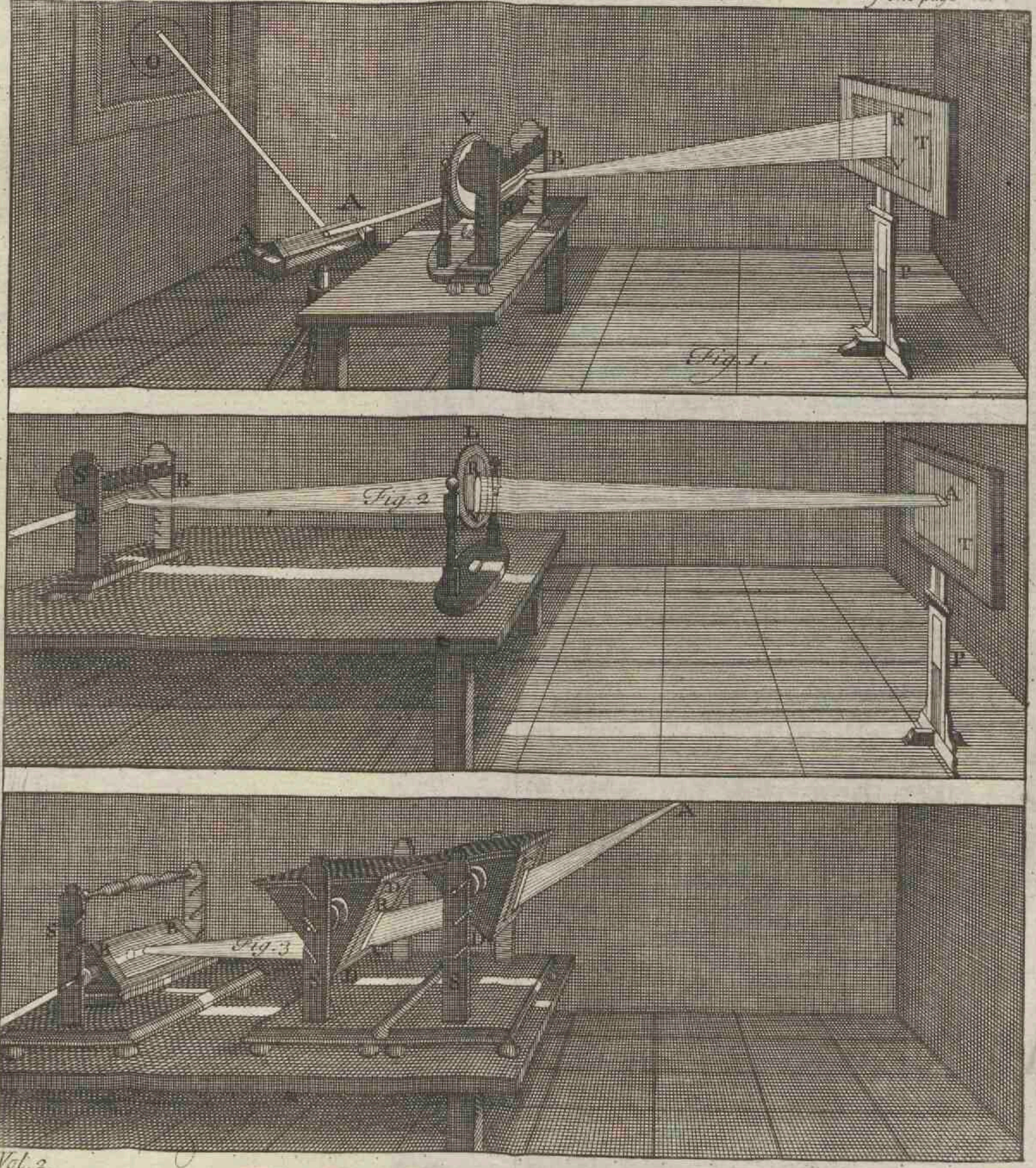


Fig. 1.
Fig. 2
Fig. 3

Primary, that is, homogeneous, *Colours, being* 873
mix'd, produce innumerable Colours, different from the primary or homogeneous ones. From a Mixture of other Colours one may produce a Colour like that which is homogeneous; but *when there can be no Difference obſerv'd by the naked Eye between an homogeneous and a mix'd Colour, one may perceive a ſenſible Difference thro' a Priſm.*

Experiment 7.] Thro' a Priſm look at any 874
ſmall Objects, ſuch as Letters upon Paper, Flies, and other ſuch things; if they be expos'd to the common open Light, they will appear confus'd; but if they be enlighten'd by the homogeneous Light of the fourth Experiment of this Chapter, they will appear diſtinct when ſeen thro' the Priſm.

CHAP. XXI.

Of the Rainbow.

HAVING made an End of conſidering what relates to the Rays, whereby Bodies are enlighten'd; before we leave this Subject, we muſt explain a Phænomenon, which is too remarkable and common to be paſt by in Silence.

The *Iris* or *Rainbow* is what every Body has often ſeen; we muſt explain what is the Cauſe of it, having firſt laid down ſome Things for that Purpoſe.

Plate XVIII. *Fig.* 1.] *Let there be a denſe Me-* 875
dium encompaſs'd with a rarer, terminated by the Circle BDFH. *Let homogeneous Rays that are parallel to one another fall upon it*, and let AB be one of theſe Rays; let the Semidiameter CB be drawn and continued to N; it will be perpendicular

cular to the Surface ſeparating the Mediums: A B N therefore is the Angle of Incidence; This Angle is equal to the oppoſite vertical Angle CBL, whoſe Sine is CL, perpendicular to BL and going thro' the Center; the Ray is refracted
* 624 towards the Perpendicular*, and C B M is the Angle of Refraction, whoſe Sine is C M drawn from C perpendicular to B D: There is the ſame
* 639 Proportion between ſuch Lines as CL and CM*, for every Ray, as there is for A B. The Ray B D does in Part penetrate into the rarer Medium in the Direction D E, and is in Part reflected along D F; and makes the Angle of Reflexion
* 805 C D F equal to the Angle of Incidence* B D C; whence B D and D F are equal. The Ray D F does alſo in Part go out of the denſer Medium along F G, and is in Part reflected along F H; which in the ſame Manner does in Part go thro' H I, and is in Part reflected: But this Reflexion, and other farther Reflexions and Refractions we ſhall not conſider; they are too weak, on account of the ſeveral Diviſions that the Light has undergone.

Plate XVIII. *Fig.* 1.] The Ray F G, which after one Reflexion goes out of a denſer Medium, makes the Angle G P A with the incident Ray A B, which varies in different incident Rays; therefore, tho theſe Rays ſhou'd be parallel, *they will be ſcatter'd when they go out, after one Reflexion,* as may be ſeen by the ſecond Figure.

The Ray E E, which, being continued, goes thro' the Center C, is not turn'd out of its Way
* 806 either by Reflexion or Refraction *.
629 As you recede from this Ray, the returning Ray is continually leſs and leſs inclin'd to the incident one. So the Ray D D, which goes out of a denſer Medium along *d d*, and returns along the Line, makes a greater Angle with *d d*,

than the intermediate Rays between D D and E E do make with their returning Rays, which go out of the denser Medium.

Let B B be a Ray, in respect of which this Inclination is the least of all, that is, which makes the Angle G P A (*Fig.* 1.) the biggest of all. Beyond B B the returning Rays are more inclin'd to the incident ones; thus A A returns along *a a*. 876

From this Dispersion *of the returning Rays* receding from the denser Medium, they become continually weaker and weaker, and their *Colour cannot be perceived throughout the whole Space which they fill*, tho the Colour of the incident Rays be vivid. *The Colour* in the returning Rays *is only sensible*, *where the neighbouring Rays are parallel*, and those next to them diverge out very little; so that at a great Distance they are dense enough to be perceiv'd. *These only are said to be efficacious*, and will be such, when the incident Rays which are near one another, being refracted, concur in the very Point of Reflexion. 877

Plate XVIII. *Fig.* 3.] Let A B, *a b*, be neighbouring Rays parallel to one another, falling upon a circular Surface that terminates a denser Medium; if these being refracted along B D, *b d*, do concur in D the Point of Reflexion, the reflected ones D F, D *f*, will make the same Angles with one another as the incident ones D B, D *b*; therefore the refracted Rays F G, *f g*, will be parallel * and efficacious *. In this Case the following Method will serve to determine the Angle made by the incident Ray with the returning one; that is, the Angle A P G, which here is the greatest of all. * 627 * 877

Let us call the *Ratio* of I to R, that which is found between the Sines of the Angle of Incidence and Refraction, when the Light goes 878

 out

out of a rarer Medium, by which a denſer is encompaſs'd, into a denſer contain'd in the Circle itſelf. Therefore, having drawn C m perpendicular to bD, and the Arc mn with the Center C and Semidiameter Cm,

I, R :: CL, CM :: Cl, Cm :: CL—Cl=Ll, CM—Cm=Mn.

Draw B o perpendicular to B L, and alſo Bp perpendicular to B D; and draw bp, ſo that it may make a right Angle with Bp; laſtly, join together by Lines the Points B, C, and M, m, the Triangles Bbo, BCL are ſimilar; for they are rectangular, and the Angles o Bb and CBL (the Difference of each of which from a right Angle is the Angle o BC,) are equal.

It may be prov'd in the ſame Manner, that the Triangle BMC and Bbp are ſimilar; the Triangle Mmn, which is rectangular at n, is alſo ſimilar to this, for the Sides Mn Bp, which are perpendicular to the Line B D, are parallel; as alſo Mm and Bb, becauſe the Lines BD, bD, are biſected at M and m into equal Parts. Therefore alſo B b is the Double of Mm, and Bp the Double of mn.

Hence we deduce

BC, BL :: Bb, Bo.

BC, BM :: Bb, Bp.

Therefore

BL, BM : : Bo = Ll, Bp = 2 Mn : : I, 2 R : : CL, 2 CM, by comparing theſe Proportions with the aforeſaid Proportion.

Now ſince the Squares of proportional Quantities are themſelves proportional, you will have

BL^q, CL^q : : BM^q, $4CM^q$.

Whence we deduce

$BL^q + CL^q$ :: BC^q, BL^q :: $BM^q + 4CM^q = BC^q + 3CM^q$, $BM^q = BC^q - CM^q = BL \times LC^q - CM^q$. By

By subtracting the first and second Term from the third and fourth, (which does not change the Proportion) you will have

$BC^{q}, BL^{q}, :: 3\,CM^{q}, LC^{q}-CM^{q}, :: 3\,R^{q}, I^{q}-R^{q}$; for there is the same Ratio between CM and LC as between R and I.

If therefore you know the Ratio between R and I, you have the Ratio between the Semidiameter BC, and the Line BL, which is the Sine of the Angle BCL, which Angle therefore is given; and by Consequence you have the Arc BN, and also FG, for they are equal.

Having the Sine BL, you have also the Sine of the Angle BCM; because (as we have shewn before)

$$BL, BM :: I, 2R.$$

Therefore the Arc BD is determin'd, to which DF is equal.

Hence we may easily find the Arcs NH and 879
BF; if the former be taken out of the latter, and the Remainder be divided into two equal Parts, we shall have, as is well known, the Measure of the Angle APG.

When the Ratio between I and R varies, the Angle APG is changed, which therefore becomes different, according to the different Refrangibility of the Rays.

If the abovesaid Surface be enlightened by hetero- 880
geneous Rays, as they flow from the Sun, *the efficacious Rays of different Colours do not make equal Angles with the incident ones, and* so *by the Help of this Refraction the Colours are separated.*

Plate XVIII. *Fig.* 4. *Experiment* 1.] Let the Sun's Light enter the dark Chamber, thro' a Slit in the moveable round Plate O, and being horizontally reflected from the Looking-glass S, let it pass thro' a Slit in the little Board or Stand T;

* 630 as has been before explain'd.* Take a Phiol exactly cylindric, made of clear Glaſs, and full of Water. Let the Beam or Ray at *f g* fall upon the Surface of the Phiol, it will be refracted in the Water towards *h i*, and there reflected, and will go out of the Phiol at *l m*. The Phiol may be eaſily ſo placed, as to make theſe Rays efficacious; and, becauſe of the Breadth of the incident Ray or Beam, efficacious Rays of all Colours will go out of the Phiol in the ſame Time; for they are very little diſtant from one another in their Incidence. If theſe efficacious Rays fall upon a white Paper, at the Diſtance of 4 or 5 Feet from the Phiol, they will produce vertical *Faſciæ* or Pillars, of various homogeneous Colours, ariſing from the efficacious Rays of each Colour; if alſo, the Eye be placed any where at the Diſtance of ſome Feet from the Phiol, as at N, in theſe efficacious Rays, it will ſee in the Phiol that Colour whoſe Rays enter the Eye, and by a ſucceſſive Motion of the Eye, it will perceive all
* 861 the afore-mention'd Colours.*

881 *Plate* XVIII. *Fig.* 5.] But as to thoſe Rays, which after a double Refraction in a denſer Medium emerge, they will be efficacious, if they are parallel after the firſt Reflexion; for then F H, *f h*, are in the ſame Manner inclin'd to H *h* as B D, *b d*, to B *b*; and therefore ſuppoſing the incident Rays A B, *a b*, to be parallel, the emer-
* 927 ging Rays H I, *h i*, will alſo be parallel*.

In this Caſe *d* D is Half of the Difference between the Arcs D E and *d f*, or D B and *d b*, but their Difference is B *b* — D *d*; if therefore this laſt be ſubtracted from the other, there will remain the Double of the Arc D *d*, whoſe Triple therefore is B *b*. If by Lines the Points D, *d*, and B, *b*, be join'd, the Triangles B E *b* and D E *d* will be ſimilar, as is known; which therefore obtains, tho' the Arcs B*b*, D*d*, be so very small, that they may be taken for right Lines.

There is therefore that Ratio between E D and E *b*, which obtains between these Arcs, that is, E D is the third Part of E*b*, or E B; because we suppose the Arc B *b* to be extremely small. M D therefore is divided into two equal Parts at E; and M E is a third Part of E B.

Now if (as in *Fig.* 3.) the Triangles B *o b*, B *p b*, and M *m n*, be form'd, M *m* will be the third Part of B *b*, and B*p* the Triple of M *n*; now if, *mutatis mutandis*, we apply to this Figure what was demonstrated with respect to *Fig.* 3.* * 878 because in this B *p* is equal to 3 M *n*, whose Square is 9 M *n*q, we shall have

BCq, BLq : : 8 Rq, Iq—Rq.

From which Proportion, as was said of *Fig.* 3. the Arc B N may be discover'd to which H G is equal; and because in this Case

BL, BM : : I, 3 R,

You have also the Arc B D, to which (because the Angles of Reflexion are equal to the Angles of Incidence) * D F and F H are equal. * 805

882 From which Things being found, we may easily deduce the Arcs G F D N, and B H, whose half Difference is the Measure of the Angle H P B, which is form'd by the emerging Ray with the incident one; which Angle in this Case is the least of all that are like it, and is different according to the different Refrangibility of the Rays. Whence also in this Case the *effi-* 883 *cacious Rays of various Colours, supposing the incident ones parallel, are separated after a double Reflexion.*

Plate XVIII. *Fig.* 4. *Experiment* 2.] This Experiment is perform'd after the same Manner as the former, only the Situation of the Phiol must be a little chang'd, that after two Reflexions in the Phiol, the Rays may come to the Eye or Paper towards N.

884 What has been hitherto explain'd, may be applied *to the Rainbow*; for which Phænomenon *it is requir'd, that Drops of Water ſhould be ſuſpended in the Air; that the Spectator ſhould be placed with his Back towards the Sun, between it and the Drops; and that there ſhould be a dark Cloud behind the Drops*, that the Colours may be more ſenſible, which are ſcarcely perceiv'd, if vivid Light enters the Eye at the ſame Time.

If theſe Things being ſuppos'd, we conceive each Drop to be cut by Planes paſſing thro' the Sun and the Eye of the Spectator; what has been demonſtrated of a Medium, terminated
* 878, with a circular Surface,* may be applied to each
879, of theſe Sections.
880, Now here we ſpeak of Rays that penetrate
881, 882, out of Air into Water. In red Rays, that is,
883. thoſe which are leaſt of all refrangible, the *Ratio* between the Sine of the Angle of Incidence and the Sine of the Angle of Refraction, that is, between I and R, is that of 108 to 81; or which is the ſame, of 4 to 3; with which Numbers, if the Computation be made, the Angle
* 879 APG (*Fig.* 3.) will be 42 Deg. 2 Min.*, and the Angle API (*Fig.* 4.) will be 50 Deg. 57
* 882 Min.* If we ſpeak of the violet Rays, I and R are to one another as 109 to 81; which Numbers give the Angles APG (*Fig.* 3.) of 40 Deg.
* 879 * 882 17 Min*, and API (*Fig.* 4.) of 54 Deg. 7 Min.*

Plate XIX. *Fig.* 1.] Let the Drops be ſuppos'd to be diffus'd in the Air, and enlighten'd by the Sun's Rays, which are parallel to one another, and to the Line OF, that paſſes thro' the Eye of the Spectator. Let the Lines *e* O, E O, *b* O, B O, be conceiv'd to be drawn; and

let the Quantity of the following Angles be thus, (*viz.*) *e*OF of 40 Deg. 17 Min. EOF 42 Deg. 2 Min. *b* O F 50 Deg. 57 Min. BOF 54 Deg. 7 Min. These same Lines with the incident Rays *d e*, DE, *ab*, A B, form Angles that are respectively equal to the aforemention'd; therefore, if the Drops be conceiv'd at *e*, E, *b*, B, the violet efficacious Rays, after one Reflexion in the Drop *e*, enter the Eye; and the red efficacious Rays come to the Eye from the Drop E; in like manner after one Reflexion, the other intermediate Colours are observ'd between *e* and E, in the above-mention'd Order*. After two * 861
Reflexions in the Drop, the efficacious red Rays come to the Eye from the Drop *b*; and the efficacious violet ones from the Drop B; the intermediate Colours appear between these Drops after the same Manner as between E, *e*; but they are dispos'd in a contrary Order, and by reason of their double Reflexion are also weaker.

Let us conceive a Line at O *e*, to be revolv'd about a fix'd Line O F, preserving the Angle *e* OF, and to form a Cone or Part of a conic Surface: In every Situation the Line *e*O will, with the Rays of the Sun that are parallel to one another, and to the Line OF, form an Angle of 40 Deg. 17 Min. *If* therefore *the Drops* 885
be diffus'd near Part of the Surface of this Cone at the same or different Distances, *the Eye will see a* violet Arc or Bow: The same may be said of the other Colours; and therefore Drops being suspended in the Air, it sees an Arc or *Bow* of the Breadth *e*E, *ting'd with the homogeneous Colours* before-mention'd*, that are dispos'd in the * 861
same Order as in the Experiments with Prisms; because the heterogeneous Rays are separated as much in the Drops as in the Prism*. * 852
880

886 By the ſame Way of reaſoning it is plain *there will be a broader* Arc or *Bow ſurrounding the firſt, in which the ſame Colours will appear in a contrary Order, and weaker.*

Experiment 3.] Hang up a black Cloth in the Light of the Sun; and let a Spectator look at it ſtanding between the Sun and the Cloth; then if Water be made to fall in ſmall Drops between the Spectator and the Cloth, the Spectator will ſee a Rainbow, at leaſt the inner one.

CHAP. XXII.
Of the Colours of thin Plates.

WE paſs on to the Colours of natural Bodies; and before we go any farther, we think it proper to examine thin Plates. Whoever attentively has obſerv'd very thin Glaſs, or Bubbles made of Water thicken'd with Soap, muſt have perceiv'd ſeveral Colours in them. Rays of Light, by Help of a thin tranſparent Plate, are ſeparated from one another, and *ac-*
887 *cording to the different Thickneſs of the Plate, the Rays of ſome Colours are tranſmitted, and thoſe of others are reflected; and the ſame very thin Plate is of another Colour, when ſeen by the tranſmitted Rays, than when ſeen by the reflected ones.*

Experiment 1. *Plate* XVIII. *Fig.* 6.] Take two Object-Glaſſes belonging to long Teleſcopes, AB and CD; and let one of them be laid upon the other; then let them be preſs'd together hard, and in the Middle, where the Glaſſes touch one another, you will ſee a tranſparent Spot, which is incompaſs'd with colour'd Circles. If the Light, reflected by the Air that is between

between the Glaſſes, comes to the Eye at O, there will appear a black Spot; and the Colours, which, as you recede from the Center, are ſo diſpoſed, that by reaſon of the ſame Colours coming over again, they may be referr'd to ſeveral Orders, will be as follows; BLACK, Blue, White, Yellow, Red: VIOLET, Blue, Green, Yellow, Red: PURPLE, Blue, Green, Yellow, Red: GREEN, Red; which Colours are alſo incompaſs'd with other Colours; but, as you recede from the Center, grow continually weaker and weaker.

If the Light paſſes thro' the Glaſs to the Eye at O, the tranſparent Spot which tranſmits all the Rays is White; and by that Series, as you recede from the Center, there will appear Colours, which are alſo referr'd to ſeveral Orders contrary to thoſe above-mention'd: WHITE, yellowiſh Red, Black Violet, Blue: WHITE, Yellow, Red, Violet, Blue: GREEN, Yellow, Red, bluiſh Green: RED, bluiſh Green, which are alſo incompaſs'd with weaker Colours.

Experiment 2.] Blow up ſoap'd Water into a Bubble, to form a thin Plate of Water. Let this be cover'd with a very clear Glaſs, leſt, by the Agitation of the Air, the Colours, to be obſerv'd in that Bubble, ſhou'd be confounded by the Motion of the Water. Such a Bubble, becauſe the Water continually runs down every Way, is very thin at Top, and the Thickneſs in going down is continually increas'd; and for the ſame Reaſon the Thickneſs of the Whole is continually diminiſh'd. Before the Bubble breaks, the Top of it becomes ſo thin, as to tranſmit the whole Light and appear Black. If in that Caſe the Bubble be obſerv'd by reflected Light, when

when it is enlighten'd by the Reflexion of a whitiſh Sky, and the extraneous Light is intercepted by placing any black Body behind the Bubble; the black Spot above-mention'd will appear, and be encompaſs'd with the ſame colour'd Circles, diſpos'd in the ſame Order as about the black Spot in the former Experiment. As the Water deſcends, the Rings are continually dilated till the Bubble burſts.

When the extreme Circumference of the Bubble appears red by the reflected Rays, if it be look'd at ſo as to be ſeen by the tranſmitted Rays, it will appear blue; and generally the Colours produc'd by tranſmitted and reflected Rays, in the ſame Manner as in the foregoing Experiment, are oppoſite to one another.

888 By comparing theſe Experiments, it follows, that *if we increaſe the Thickneſs of a very thin Plate, its Colour will be chang'd*, and *there will be the ſame Changes ſucceſſively, and in the ſame Order, whether the Plate be form'd out of a rarer or a denſer Medium.* For in the Plate of Air, between the Glaſſes, and the watery one in the Bubble, whoſe Thickneſs increaſes as it goes farther from the
889 Middle, the Colours will be in the ſame Order. Yet *in a denſer Plate a leſs Thickneſs is requir'd than in a rarer, to have it ting'd with the ſame Colour.*

Experiment 3.] Every thing being diſpos'd as in Experiment 1. if you wet the Edges of the Glaſſes a little on one Side, the Water will by degrees inſinuate itſelf between the Glaſſes; and there will be obſerv'd the ſame colour'd Circles as in the Air, neither will their Order be changed, but the Circles will be leſs; when the Water is got as far as the Center, all the Portions of the Circles in the Water will be ſeparated from the Portions of the Circles in the Air, and be all reduc'd into a leſs Space. *The*

The Colour of a Plate depends upon its Thickness * 890
and Density, and not upon the encompassing Medium. * 887
* 889

Experiment 4.] If you take a Piece of Isinglass or Talk, so thin as to have it colour'd, the Colours will not be chang'd by wetting it; that is, if instead of Air the Plate is incompass'd with Water.

The Colour of the same Plate is so much the more 891
vivid, as its Density differs more from the Density of the circumambient Medium. This is prov'd by the foregoing Experiment, in which the Colours of the Plate, when wet, are more languid than those of the same Plate incompass'd with Air. In the third Experiment also the Colours are less vivid than in the second; in both there is a Plate of Water; but in the second Experiment it is inclos'd with Air, and in the other with Glass; but Water and Glass differ less in Density than Air and Water.

If Mediums equally differ in Density, the Colours 892
will be more vivid, if the denser be incompass'd with the rarer: For a very thin Glass Plate, which is colour'd on account of its Thinness, being incompass'd with Air, the Colours will be more vivid than in *Experiment* 1. in which a Plate of Air is incompass'd with Glass.

A Plate of the same Density, incompass'd with the 893
same Medium, will reflect so much the more Light
as it is thinner. Yet if the Thickness be too much di- 894
minish'd, it does not reflect the Light. All this is plain from the foregoing Experiments; in the three first, the colour'd Circles which are the least, and which are also the thinnest, reflect Light best of any; but in the Center, where the Spot is the thinnest of all, there is no sensible Reflexion; as this clearly appears in the second: In the first there is also a very thin Plate

of

of Air, which does not reflect Light; for the transparent Spot in the Center is much bigger than those Parts of the Surfaces of the Glasses, which immediately touch by the yielding Inwards of the compress'd Parts.

895 *If there are Plates of the same Medium, whose Thicknesses are in an Arithmetical Progression of* the Natural Numbers 1, 2, 3, 4, 5, 6, 7, *&c. If the thinnest of them all reflects any homogeneous Rays, the second will transmit the same*, the third again will reflect them, *and the Rays will be alternately reflected and transmitted*; that is, the Plates whose Thicknesses in the above-mention'd Progression answer to the odd Numbers 1, 3, 5, 7, *&c.* reflect the Rays which the others transmit, whose Thicknesses answer to the even Numbers 2, 4, 6, 8, *&c.*

This Property of the Plates obtains in respect of any Sort of homogeneous Rays, with this Difference, that different Thicknesses are requir'd for different Colours, as has been said be-
887 fore; the thinnest of all for reflecting Violet, and they must be thickest for reflecting Red; if the Thicknesses are intermediate, the Rays of an intermediate Refrangibility are reflected, that
896 is, *as the Refrangibility of the Ray increases, the Thickness of the Plate, that reflects it, is diminish'd.*

Experiment 5.] Let the Experiment be made in a dark Room to produce the oblong Image of the Sun upon a Paper, such as is mention'd in *Experiment* 1. *Chap.* 18. Take two Object-Glasses of long Telescopes (such as were mention'd in the first Experiment of this Chapter) let them be press'd together, and so dispos'd, that every single Colour of the Image above-mention'd may be successively seen in them as in a Looking-glass; that is, that the Glasses may

be

be ſucceſſively enlighten'd by ſeveral homogeneous Rays; which may be done, by gently moving about its Axis the Priſm that ſeparates the Rays to make the oblong Image. The Rings, mention'd in the firſt Experiment, appear, but more in Number, and only of one Colour; by Reaſon of the Unchangeableneſs in homogeneous Rays: * In the Interſtices of thoſe Rings the * 863
Rays are tranſmitted, as plainly appears by holding a Paper behind, upon which the tranſmitted Rays will come; the Rings are leaſt of any, when they are violet; then are ſucceſſively dilated, conſidering the following Colours, quite to the Red. The Rings being of any Colour, if you meaſure exactly the Diameters of the Circles that may be conceiv'd to be in the Middle of the Breadth of the Rings, the Squares of their Diameters will be to one another as the odd Numbers 1, 3, 5, &c. and meaſuring in the ſame Manner the Diameters of the Circles in the Middle of every one of the Interſtices between the Rings, the Squares of their Diameters will be as the even Numbers 2, 4, 6, &c. Now in uſing ſpherical Glaſſes, the Thickneſſes of the Plate of Air, in the Circle above-mention'd, are as the even and odd Numbers.

Definition.

An homogeneous Colour, in a Plate of any Medium, is ſaid to be of the firſt Order, *if the Plate be the thinneſt of all thoſe that reflect that Colour; in a Plate whoſe Thickneſs is triple, it is ſaid to be* of the ſecond Order, *&c.* 897

A Colour of the firſt Order is the moſt vivid of any; and ſucceſſively in the following Orders, in the ſecond, third, &c. *it is leſs and leſs vivid.* * 898 * 893

When a Plate of Air is inlighten'd with heterogeneous Rays, as that between the Glaſſes of

of the Telescopes, or any *Plate* like it of any other Subſtance, as in *Experiment* 1. and 2. ſeveral of the Rings ſeen in the laſt Experiment are confounded together, and that Colour is ſeen
899 which is made of their Mixture; for *the ſame Thickneſs of a Plate is often requir'd, for reflecting different Colours of various Orders:* So a Plate, which reflects the Violet of the third Order, does alſo reflect the Red of the ſecond Order, as may be deduc'd from the laſt Experiment, if you attentively conſider it: Therefore in the firſt and ſecond Experiment, the third violet Ring is confounded with the outward Edge of the ſecond red Ring, and purple Colour is produc'd; yet all the Red of the ſecond Order is not abſorb'd, becauſe the red Ring is wider than the violet one.

900 *The more the Thickneſs of a Plate is increas'd the more Colours it reflects, and different ones*, of different Orders. The violet Plate of the tenth Order falls in with the blue one of the ninth Order, and the yellow one of the eighth Order, and laſtly with the red one of the ſeventh Order; and the Colour of the Plate is made up of a Mixture of thoſe Colours.

901 *If* in the firſt and ſecond Experiments *a Spectator look obliquely upon the Plates*, ſuch as that made of Air, and that which is made of Water, the Rings will be dilated as they are ſeen more obliquely, that is, in that Motion of the Eye *the Colour of the Plate* in a determinate Place *is chang'd*; yet the Dilatation is greater in the firſt
902 Experiment; which proves, that *the Colour is more chang'd by the Obliquity of the Rays, if the Plane be incompaſs'd with a denſer Medium, than if it be inclos'd by a rarer Medium.*

Plate XVIII. *Fig.* 7.] The Demonſtration of which Propoſition is eaſily deduc'd from the Laws

Laws of Refraction. Let L and *l* be thin Plates; the last incompass'd with a denser, and the first with a rarer Medium; let them both be of the same Thickness: If the Rays A B, *ab*, equally inclin'd to the Plates, fall upon them, there will be at L a Refraction towards the Perpendicular; * on the contrary, at *l* the Rays are refracted * 624
from the Perpendicular; * and tho B D and *b d* * 625
are equal, *b c* is longer than B C; and therefore there is a greater Change in the Motion of the Light in the Plate *l* than in the Plate L. *The* 903
Density of the Plate L *being increas'd, the Medium with which it is incompass'd remaining the same, there will be a less* Difference between B C and B D, and therefore a less *Change of Colour*; and *if the* 904
refracting Power of the Plate be so *increas'd*, that the refracted Rays (whatever be the Obliquity of the incident ones) shall not sensibly differ, *there will be no sensible Difference in the Colour of the Plate, whatever Situation the Eye is plac'd in.*

Hence we may easily deduce, that *the Colour* 905
of some Plates will vary by changing the Position of the Eye, and that the Colour of others is permanent.

CHAP. XVIII.

Concerning the Colours of Natural Bodies.

WHAT relates to the Colours of all Sorts of Bodies may be easily deduc'd, from what has hitherto been explain'd.

We have shewn that the Rays of Light have Colours peculiar to themselves and unchangeable, so as not to be chang'd by Reflexion. * * 863

Therefore *the Rays reflected from Bodies, ac-* 906
cording as a greater or less Refrangibility is proper to the Colour of the Body itself, have a greater or less Refrangibility.

Experi-

Experiment 1.] In the Middle of a black Paper fix two ſquare Pieces of Ribbon, the one red and the other violet, which muſt be join'd ſo as to touch one another at their Sides in the ſame Manner as the red and violet Colours in the third Experiment of *Chap.* 19. The black Paper muſt be ſo plac'd, that the Ribbons may be well inlighten'd by the Light that comes into the Room thro' the Window: If a Spectator looks at theſe Ribbons thro' a Priſm, as in the Experiment above-mention'd, the Colours will appear ſeparated in the ſame Manner as in that Experiment.

Experiment 2. *Plate* XIX. *Fig.* 2.] Place the two Ribbons mention'd in the former Experiment at R and V; let the laſt be violet, the firſt red; let them be inlighten'd by the Flame of a Candle; at ſix Feet Diſtance place the convex Lens V; (of which Mention has been made in *Exper.* 6. *Cap.* 19.) at the Diſtance of about ſix Feet, you will have the Repreſentation of the Ribbon R upon a white Paper at *r*; at a leſs Diſtance you will have an exact Repreſentation of the other at *v*. You may determine when the Repreſentations are exact, by binding black Threads upon the Surface of the Ribbons; for theſe Threads appear diſtinctly, where the Repreſentation is exact.

907 That *Bodies have various Colours, becauſe different Rays are reflected from Bodies differently colour'd*; and that *a Body appears of that Colour, which ariſes from the Mixture of the reflected Rays*, may not only be deduc'd from the foregoing Experiments, but may be alſo demonſtrated directly by others.

Experi-

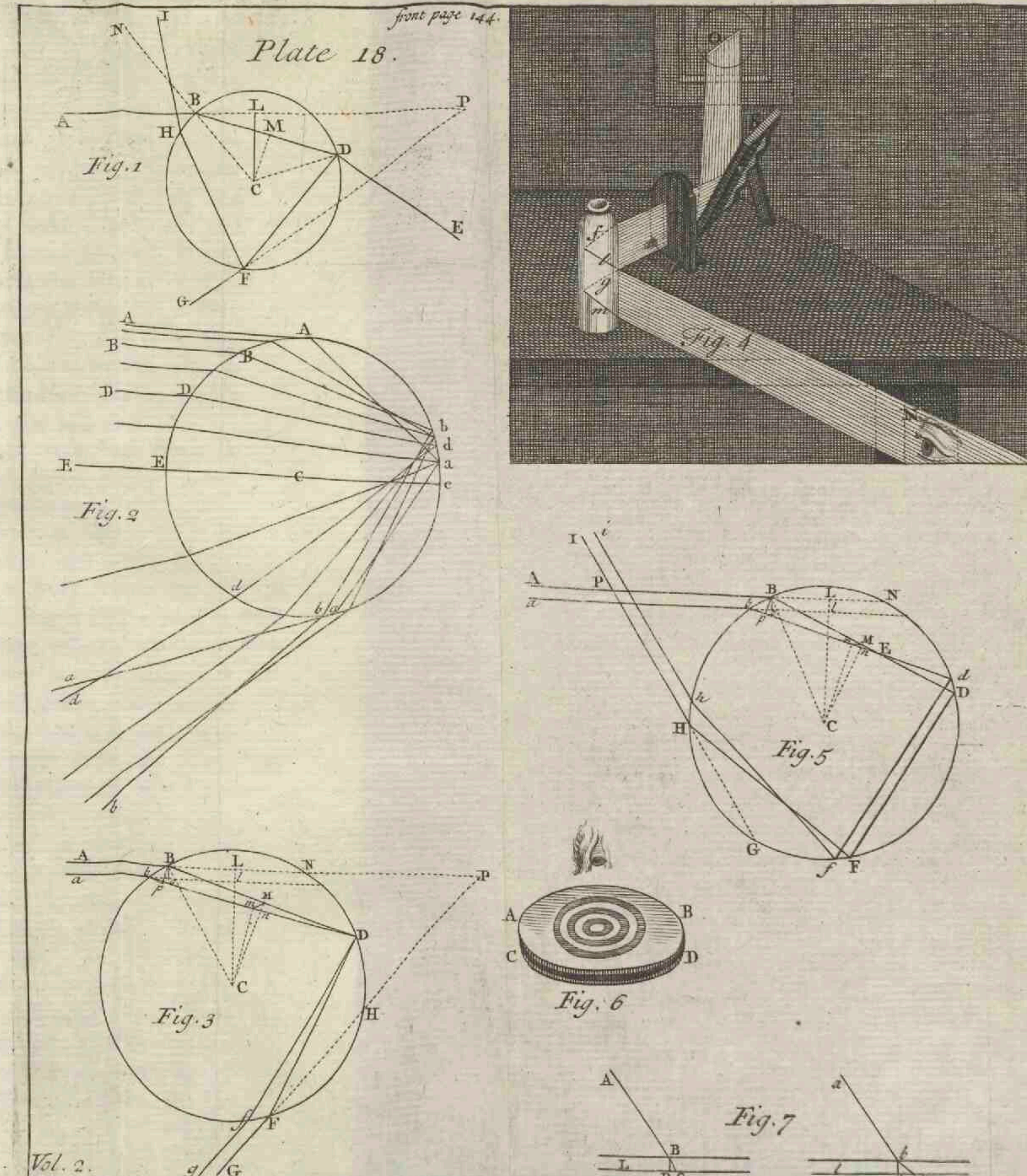

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Plate 18.
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Vol. 2.

Experiment 3.] Take two Bodies of any Kind, the one red, the other blue; let them be enlightened successively, in a dark Place, by the Colours of the coloured Image, which is made by the Refraction of the Prism; every one of the Colours will be reflected by both; but the red Rays are copiously reflected from the red Body, whilst the blue Body reflects but few of them, which plainly appears by comparing both Bodies, when they are enlightened by the red; the contrary may be observed in blue Colours, which are copiously reflected from the blue Body, whilst only a few are reflected from the red one.

The Rays, which are not reflected from a Body, penetrate into it, and there suffer innumerable Reflexions and Refractions, as we have explained between N° 842, and 843; till at length they unite themselves to the Particles of the Body itself.* Therefore *a Body grows hot so* *546
much the sooner, as it reflects Light less copiously. 908
For which Reason *a white Body*, which reflects al- 909
most all the Rays with which it is enlightened, * *870
heats the slowest, whilst a black Body, into which almost all the Rays penetrate, because only few are reflected,* *acquires Heat sooner than any other.* *845

To determine that Constitution of the Surfaces of Bodies, upon which their Colour depends, we must take Notice of the smallest Particles, of which these Surfaces are made up: These Particles are transparent *, and are sepa- *841
rated by a Medium of different Density from the Particles themselves; they are also thin, *843
otherwise the Surface would as it were be covered by a transparent Body, * and the Colour *843
would depend upon the Particles under these. Therefore in the Surface of every coloured Body there are innumerable small thin Plates; but by

leſſening the Plate, keeping the ſame Thickneſs, its Properties, as to the Reflexion of Light, are not changed ; for the leaſt Plate, in reſpect of the Rays of Light, is very large : Wherefore, what has been demonſtrated in the preceding *Chap.* may be applied to theſe Plates in the Surfaces of Bodies. From whence we deduce the following Concluſions.

910 *The Colour of a Body depends upon the Thickneſs*
*890, *and Denſity of the Parts of the Body, which are in*
911 *the Surface, between the Pores of the Body.**
* 898, *The Colour is ſo much the more vivid and homo-*
899,
900 *geneous, as the Parts are thinner.**
912 Cæteris paribus, *the aforeſaid Parts are of the*
*896, *greateſt Thickneſs when the Body is red; and of the*
861 *leaſt, when violet.**
913 *The Parts of Bodies are much denſer than the*
*902,
903, *Medium contained in their Interſtices.**
904. *This Denſity is leſs in* the Tails of Peacocks, and
914 in ſome Silks, and in general in all *Bodies, whoſe*
*901 *Colour varies according to the different Situation of*
903 *the Eye.**
915 *The Colour of a Body is more obſcure and darker,*
*891 *when a denſer Medium enters its Pores;** for then the Parts, upon which its Colour depends, are ſurrounded by a denſer Medium than before.

We experience this in all Bodies, which are thoroughly penetrated by Water and Oil : When the Bodies are dry, they recover their former Colour, unleſs in ſome Caſes, in which ſome Parts are carried away by the Action of the Water, or Oil, or when ſome Parts of the Water, or Oil, are ſo united with the Parts of the Body, as to change the Thickneſs of the Plates.

From ſuch a Cauſe are deduced the Changes in the Colours of ſome Liquors, by their being
916 mixed with others. *Often the ſaline Particles, ſwimming in one Liquid, unite themſelves to the ſaline Parti-*

Plate 19.

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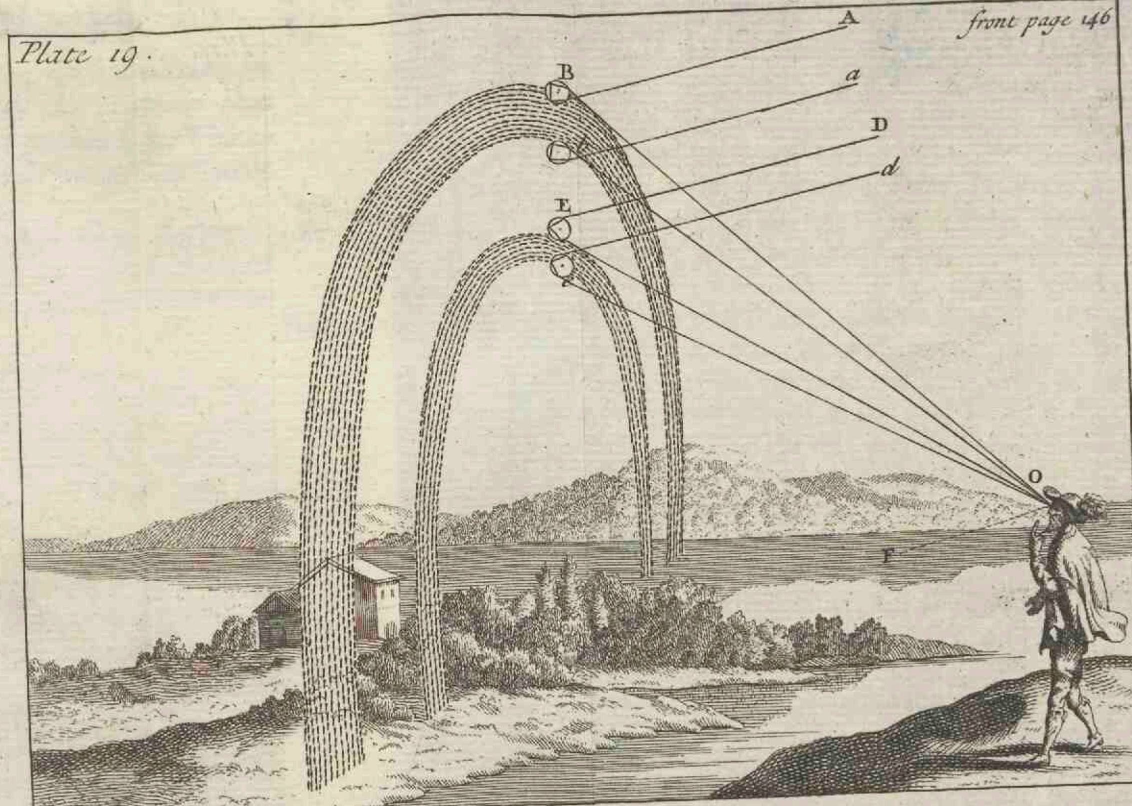

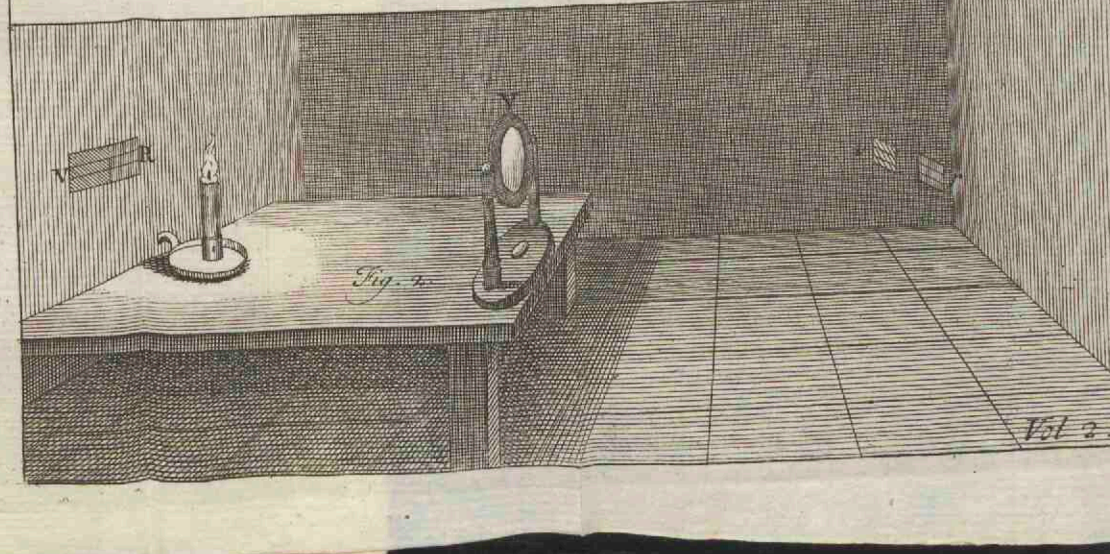

Particles swimming in another; or *the united Particles are separated by the Actions of others that are superadded*; *on all which Accounts* the Thickness of the Particles *is changed*, and together with it *the Colour of the Liquids.** *888

Sometimes the Colour of a Liquid is different, when seen by reflected Rays, from what it is, when seen by transmitted ones: We have shewn before whence this arises.* 917 *887

Experiment 4.] An Infusion of *Lignum Nephriticum*, that is not too much tinged, appears blue by reflected Rays, but yellow, if the Phial, which contains the Infusion, be placed between the Light and the Eye.

Experiment 5.] If you pour Spirit of Vinegar into the Infusion of *Lignum Nephriticum*, it will appear yellow in any Position whatever.

In this Case the Thickness of the Particles is changed, and the Rays, that were transmitted through every one of them, are now intercepted; but though the Liquor is placed between the Eye and the Light, it is seen by reflected Rays; for we may easily conceive that such Rays come to the Eye by the various Reflexions which the Light undergoes in the Liquid. But this Colour only is sensible, because the Rays cannot penetrate directly through the Liquid.

From this we may deduce the Reason, why *a* 918
coloured Liquid in a Glass, of the Figure of an inverted Cone, if it be placed between the Eye and the Light, appears of a different Colour, in different Parts of the Vessel; in the lower Part all the Rays which are transmitted thro' the Particles, are not intercepted; then they are more and more intercepted, according as there is a greater Quantity of the Liquid between the Eye and the Light; till at

length they come to be all intercepted; and only thoſe Rays which are reflected by the Particles penetrate the Liquid; in which Caſe the Colour coincides with the Colour of the Liquid ſeen by the reflected Rays.

919 *Clouds* often *appear very beautifully coloured*; they conſiſt of aqueous Particles, between which Air is interſperſed; therefore, *according to the va-*
920 *rious Thickneſs of thoſe aqueous Particles*, the Cloud
388 will be of a different Colour.

The End of the Third Book.

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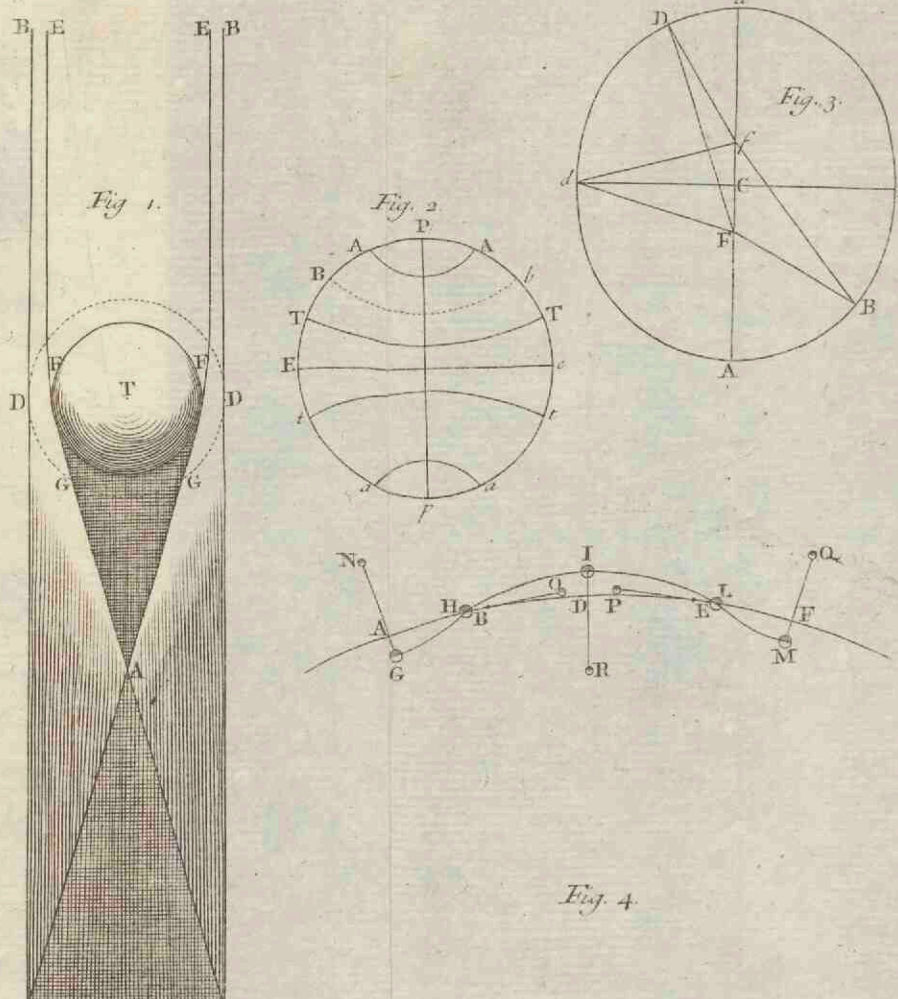
Plate 24.



Mathematical ELEMENTS

OF

Natural Philosophy,

Confirmed by

EXPERIMENTS.

BOOK IV.

PART I. *Of the System of the World.*

CHAP. I.

A general Idea of the Planetary System.

*HE who attentively considers that *15
Space can be terminated by no Bounds, will scarce be able to deny, that the Supreme Almighty Intelligence has every where manifested the same Wisdom which He has shewn to the Inhabitants of the Earth in a small

Compafs. What I here call a fmall Compafs, immenfly exceeds our Comprehenfion; yet it is but fmall, compared with infinite Space.

921 *Our Earth, with fixteen other Bodies* (for we have no Knowledge of any more (*moves in a determinate Space*; neither do thefe Bodies recede from, or come nearer to one another, beyond their fet Bounds; and their Motions are performed according to unchangeable Laws.

Definition I.

922 *This Collection of feventeen Bodies is called the* Planetary Syftem.

The whole Art of *Aftronomy* is almoft employed concerning thefe alone; and thefe will be chiefly my Subject in this Work: The other Bodies that conftitute the Univerfe, are too far diftant from us, for their Motions (if they are moved) to fall under our Obfervations: Of thefe only the lucid Bodies can be perceived by us; and of thofe only the more remarkable ones, and which are lefs diftant from us than the reft; even moft of fuch as are feen by the Telefcope are invifible to the naked Eye.

Definition II.

923 All thefe Bodies are called *fixed Stars.*

They are called fixed, becaufe, as far as can be perceived, they keep the fame Pofition, with refpect to one another: We muft take Notice of fomething peculiar concerning thefe hereafter.

924 But as to the Planetary Syftem: *In this* we have faid *there are* feventeen *Bodies, which are all fpherical: One only fhines by its own Light, the reft are opaque, and are vifible only by the Light which they borrow from that.*

925 *The Sun is that lucid Body, and far the greateft of all in the Planetary Syftem; it is quiefcent in the middle*

dle of it, at leaſt is agitated by a very ſmall Motion.

Definition III.

The other ſixteen are called *Planets*.

Theſe are divided into two Claſſes; ſix are called the Primary Planets; *ten are called the* Secondary Planets. When we ſpeak of the Planets, without any Diſtinction, we always underſtand the Primary ones. 926

The Primary Planets move round the Sun, and are carried at different Diſtances from it, in Curves that return into themſelves. 927

A Secondary Planet revolves round a Primary one, and accompanies it in its Motion round the Sun. 928

The Planets in their Motions deſcribe Elliptic Lines, not much different from Circles. *And all thoſe* Lines *are fixed*; at leaſt, there is but a ſmall Change to be obſerved in a long Time, in their Situation. 929

Plate XXIV. *Fig.* 3.] An Elliptic Line is formed, if a Thread, whoſe Extremities are fixed in the two Points F and *f*; is moved, remaining ſtretched; as is to be ſeen in this Figure, in which the Thread is repreſented at F *d f*, F E *f*, F B *f*. The Points F, *f*, are called the Foci; the Line A *a*, which paſſes through them, and is terminated on each Side by the Circumference of the Ellipſe, is called the *greater Axis*; and it is the greateſt Line that can be drawn in the Ellipſis. The middle Point C of the Axis is the Center of the Ellipſe; and the *leſſer Axis* D *d* falls perpendicularly through this Point upon the *greater Axis*. 930

The Orbits of all the Primary Planets are in ſuch a Poſition, that one of their Foci falls in with the Center of the Sun; let the Ellipſe A D *a d* 931

 repreſent

represent the Orbit of a Planet, F will be the Center of the Sun.

DEFINITION IV.

932 *The Distance between the Center of the Sun and the Center of the Orbit, is called* the Eccentricity of the Planet; as F C.

933 *In every Revolution the Planet approaches once to the Sun, and once recedes from it*; and at its greatest Distance is at *a*, the Extremity of the greater Axis of the Orbit, and at its least Distance, in the opposite Extremity A.

DEFINITION V.

934 *That Distance of the Planet from the Sun, is called the* mean Distance, *which is equally different from the greatest and the least.* At this Distance the Planet is in the Extremities D, *d*, of the smaller Axis.

DEFINITION VI.

935 *The Point of the Orbit, in which the Planet is at its greatest Distance from the Sun, is called* the Aphelium; as *a*.

DEFINITION VII.

936 *The Point of the Orbit, in which the Planet is at its least Distance from the Sun, is called* the Perihelium.

DEFINITION VIII.

937 These Points are commonly called the *Auges* or *Apsides*.

DEFINITION IX.

938 *The Line which joins the Apsides*, that is, the greater Axis of the Orbit, *is called*, the Line of the Apsides.

Every

Every Orbit is in a Plane which passes through the Center of the Sun. 939

DEFINITION X.

The Plane of the Orbit of the Earth is called the Plane of the Ecliptic. 940

This Plane is to be continued every Way; and *Astronomers* consider the Position of the Planes of the other Orbits, with respect to this.

DEFINITION XI.

The Points, in which the other Orbits cut the Plane of the Ecliptic, are called the Nodes. 941

DEFINITION XII.

The Line which joins the Nodes of any Orbit, that is, the common Section of the Plane of the Orbit with the Plane of the Ecliptic, *is called* the Line of Nodes. 942

A Planet is not carried with an equal Celerity in 943
all the Points of its Orbit; the less it is distant from 944
the Sun, the swifter is its Motion; and the Times, in which the several Arcs of its Orbit are run thro', are to one another, as the Area's formed by Lines drawn from the Planet to the Center of the Sun: The Arcs A B and *a* E are run through in Times, which are to one another, as the Area's of the mixed Triangles A F B, *a* F E.

All the Planets are carried the same Way, and their Motion in their Orbits is contrary to that Motion which we observe daily in all the Cœlestial Bodies, by which in one Day they seem to be carried round the Earth; of which hereafter. 945

DEFINITION XIII.

A Motion, such as is that of the Planets in their Orbits, is said to be in Consequentia, and direct. 946

DEFI-

Definition XIV.

947 *The contrary Motion is called a Motion* in Antecedentia; *and sometimes* Retrograde.

948 *The more distant the Planets are from the Sun, the slower they move in their Orbits*; so that the periodical Times of the most distant ones are greater, both because they have a greater Orbit to run through, and a slower Motion.

Definition XV.

949 *The Line which passes through the Center of the Planet, and about which it moves, is called* the Axis of the Planet.

950 *The Planets*, at least most of them, *and the Sun itself move round their Axis:* There are Two, of which, in this respect, Astronomers have been able to make no Observations, but which, in all Probability, have this Motion.

951 *This Motion* agrees or conspires with the Motions of the Planets in their Orbits, that is, it *is* in Consequentia.

952 *The Axes* themselves *are moved by a parallel Motion*, so that all the Points of the Axis of a Planet describe equal and similar Lines.

Definition XVI.

953 *The Extremities of the Axis are called* the Poles of the Planet.

954 *Plate* XX. *Fig.* 1.] Astronomers compare together accurately enough the Distances of the Planets from the Sun, to give us an Idea of the whole System. The Dimensions of the Orbits are represented in this Scheme, in which the Points N N shew the Nodes of each Orbit.

955 Neverthelefs *we cannot compare the Dimensions of this System with any that we know upon the Surface of the Earth*; for no Astronomers will assert,

that the Obſervations made concerning ſuch a Compariſon, are free from Error.

But, that the ſeveral Parts of the Syſtem may be compared together, we ſuppoſe the mean Diſtance of the Earth from the Sun divided into 1000 equal Parts, which we make uſe of in meaſuring the other Diſtances. 956

The Sun ☉, as was ſaid before, is agitated by a ſmall Motion in the middle of the Syſtem; it moves round its Axis in the Space of 25 Days: And its Axis is inclined to the Plane of the Ecliptic, making an Angle of 87 Degr. 30 Min. 957

Mercury ☿ is the leaſt diſtant from the Sun of any of the Planets; its mean Diſtance from the Sun is 387, its Eccentricity 80, the Inclination of its Orbit, that is, the Angle, formed by the Plane of its Orbit with the Plane of the Ecliptic, is 6 Degr. 52 Min. it performs its Revolution round the Sun in 87 Days, 23 Hours. 958

The next is *Venus* ♀, whoſe Diſtance from the Sun is 723, its Eccentricity 5, the Inclination of its Orbit 3 Deg. 23 Min. It performs its Periodical Motion in 224 Days, 17 Hours; and its Motion round its Axis is performed in 23 Hours. 959

The third Planet in order from the Sun is our Earth ⊖; its mean Diſtance from the Sun is 1000, its Eccentricity 169: It is moved in the Plane of the Ecliptic; its Periodical Time is 365 Days, 5 Hours, 51 Min. and the Motion about its Axis is performed in 23 Hours, 56 Min. 4 Sec. Its Axis makes an Angle with the Plane of the Ecliptic of 66 Degr. 31 Min. 960

The mean Diſtance of *Mars* ♂ from the Sun is 1524, its Eccentricity 141, the Inclination of its Orbit 1 Degr. 52 Min. Its Periodical Time 686 Days, 23 Hours. Its Revolution about 961 about its Axis is performed in 24 Hours, 40 Min.

962 *Jupiter* ♃, the biggeſt of all the Planets, is diſtant from the Sun, at a mean Diſtance 5201, its Eccentricity 250. The Inclination of its Orbit 1 Degr. 20 Min. The Periodical Time 4332 Days, 12 Hours; and its Revolution about its Axis in 9 Hours and 56 Min.

963 The mean Diſtance of *Saturn* ♄, the moſt diſtant Planet from the Sun, is 9538; its Eccentricity 547; the Inclination of its Orbit 2 Degrees 30 Min. The Periodical Time 10759 Days, 7 Hours. It is encompaſſed with a Ring which does not touch the Planet, but never leaves it. This Ring is not viſible without a Teleſcope.

The mean Diſtance being given, if you add the Eccentricity, you will have the greateſt Diſtance; but if you ſubſtract the Eccentricity from the mean Diſtance, you will have the leaſt
836 Diſtance.

964 The three Planets, *Mars*, *Jupiter*, and *Saturn*, which are more diſtant from the Sun than the Earth, are called the *Superior Planets*; *Venus* and *Mercury* are called the *Inferior ones*.

965 *Of the Primary Planets, three are accompanied by Secondary ones.*

Five Planets called Satellites, move about *Saturn*; four about *Jupiter*; one about the Earth (*viz.*) the Moon.

The ſecondary Planets, except the Moon, are not viſible to the naked Eye.

966 *The Satellites, by Lines drawn to the Center of the Primary Planets, deſcribe Area's about them proportional to the Times*; as has been ſaid of the Primary Planets, with reſpect to the Center of the
944 Sun.

The

The Moon moves about the Earth in an Ellipse, 967
one of whose Foci is in the Center of the Earth, 968,
from which the mean Distance of the Moon is 60 969
Semidiameters of the Earth and a Half: *Its Eccentricity is liable to Change*; the mean one is of 3 Semidiameters and a Third. The Plane *of its Orbit* forms an Angle with the Plane of the E-
cliptic of 5 Degr. *but this Inclination is not con-* 970
stant, or always the same. In the Motion of the Moon round the Earth, neither the Line of the Nodes, nor the Line of the Apsides, is carried in a parallel Motion; but the *Line of the Nodes* Westward, or in *Antecedentia*; *the Lines of the Apsides* Eastward, or in *Consequentia*; the first performs its Revolution in about 9 Years, the second in 19. The Periodical Time of the Moon's Motion about the Earth is 27 Days and about 7 Hours; and it is turned about its own Axis exactly in the same Time.

Plate XX. *Fig.* 2.] The first or inmost of the 971
Satellites of *Jupiter* is distant from *Jupiter*'s Center $2\frac{1}{6}$ Diameters of *Jupiter*: It is moved round *Jupiter* in one Day, 18 Hours, 28 Min.

The Distance of the Second is 4 and an Half Diameters of *Jupiter*: Its Periodical Time is 13 Hours, 18 Min.

The Distance of the Third is $7\frac{1}{6}$ Diameters; its Periodical Time 7 Days, 4 Hours.

The Fourth is distant $12\frac{2}{3}$ Diameters: It performs its Motion in 16 Days, 18 Hours, 5 Min.

Plate XX. *Fig.* 3.] The first or inmost Satel- 972
lite of *Saturn* is distant from *Saturn*'s Center $\frac{39}{40}$ of a Diameter of the Ring: Its Periodical Time is 1 Day, 21 Hours, 18 Min.

The Distance of the Second is $1\frac{1}{4}$ Diameter of the Ring: Its Periodical Time is 2 Days, 17 Hours, 41 Min.

The Diſtance of the Third is $1\frac{1}{4}$ Diameter of the Ring; its Periodical Motion is 4 Days, 13 Hours, 47 Min.

The Diſtance of the Fourth is 4 Diameters of the Ring; its Periodical Time 15 Days, 22 Hours, 41 Min.

The Diſtance of the Fifth is 12 Diameters of the Ring; its Periodical Time is 79 Days, 7 Hours, 53 Min.

973 Concerning the Motion of theſe, as alſo of the Satellites of *Jupiter* about their Axes, we can hitherto determine nothing certain from Aſtronomical Obſervations.

If we take Notice of the Diſtances and Periodical Times of the Planets, we ſhall find that the following Rule holds good in our Syſtem, whereever ſeveral Bodies are moved round the ſame Point, that is *about the* Sun, Saturn, *and* Jupiter;
974 (*viz.*) *The Squares of the Periodical Times are to one another, as the Cubes of the mean Diſtances from the Center.*

975 *Plate* XX. *Fig.* 4.] To give a Notion of the Dimenſions of the Bodies themſelves in our Syſtem, we have contrived the fourth Figure, in which all the Primary Planets, and *Saturn*'s Ring, are deſcribed, according to their Dimenſions; the Sun, whoſe Magnitude exceeds all the reſt, is repreſented by the greateſt Circle (*Fig.* 1.) that is, the Circle which terminates the Figure.

These Dimenſions repreſent the Proportions of the Bodies one to another exactly enough, if you except the Earth, which, for the Reaſon already
955 mentioned, cannot be ſo compared with the other Bodies, as to leave no Room to doubt what Proportion it bears to them.

976 Yet *the Earth's Diameter may be meaſured*, and contains 3.400669 Perches, each of which is equal to 12 *Rhynland* Feet; but altho' the Diameters of the other

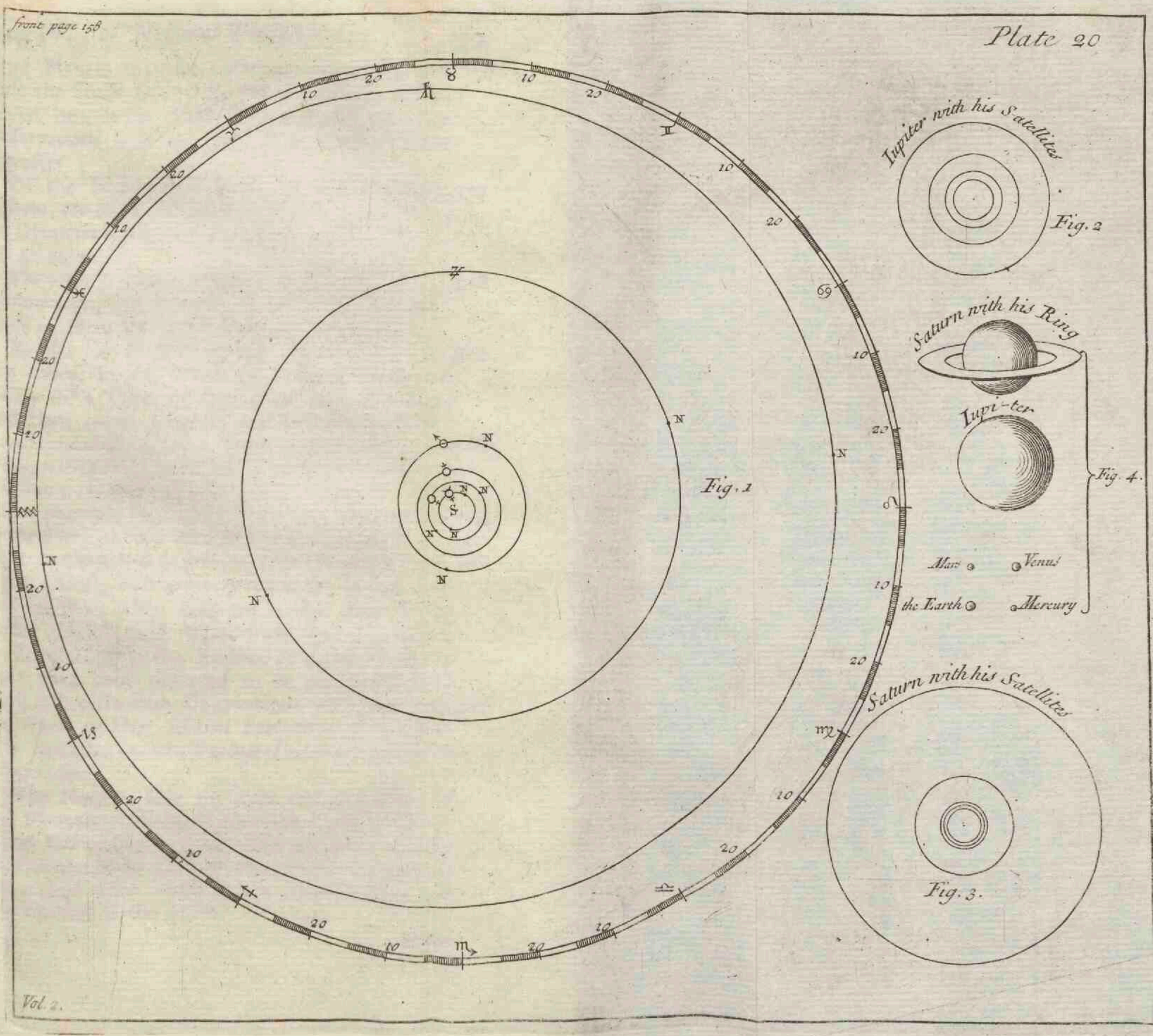

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Plate 20
Fig. 1
Iupiter with his Satellites
Fig. 2
Saturn with his Ring
Iupi-ter
Fig. 4.
Mars
Venus
the Earth
Mercury
Saturn with his Satellites
Fig. 3.
Vol. 2.

other Planets may be compared together, and with the Sun's Diameter, yet it can't be determined how many Feet they contain, till after Obſervations ſhall be made at a proper Time hereafter.

Of the Bodies that make up the Planetary 977
Syſtem, *the Moon only can be compared to the Earth*; its Diameter being to the Diameter of the Moon, as 40 to 11.

The other ſecondary Planets are not meaſured by 978
Aſtronomers, but it can't be doubted, but that ſome of them are bigger than the Earth.

Beſides the Bodies already mentioned, there 979
are others in the Planetary Syſtem, which are viſible for a Time, as they come near the Sun, and then recede from it, and become inviſible; they are called *Comets*. They *appear moſt com-* 980
monly with Tails, and the Tail is always turned from the Sun; *in their Motion they deſcribe Area's, by Lines drawn to the Center of the Sun, proportional* *944
to the Times, as has been ſaid of the Planets.* 966

As to Comets, it is probable that they move in el- 981
liptic Orbits, that are very eccentric; ſo that they are inviſible, when they are in that Part of the Orbit which is moſt diſtant from the Sun; which is deduced from the Periods of ſome of them, that have been obſerved to be pretty regular: And it is plain from Obſervations, that *ſome have* 982
deſcribed in their Motion Portions of very eccentric Eclipſes, in one of whoſe Foci was the Center of the Sun.

The Notion, that we have hitherto given of the Planetary Syſtem, is founded upon Aſtronomical Obſervations; and what we have already ſaid admits of no Diſpute among Aſtronomers, if we except what relates to the Elliptic Line and the Motion of the Earth.

Some

Some affirm, that the Orbits of the Planets are not Elliptic, but that in their Motion they describe another Oval: *Kepler* has deduced from *Tycho Brahé's* Observations, that these Lines are Elliptic; and we shall shew in the following Part, that no other Curves can be described by the Planets.

Those that say the Earth is at rest, have no Astronomical or Physical Argument for a Foundation of their Opinion; that is, don't reason from *Phænomena*: Neglecting the Simplicity of the System, and the Analogy of the Motions, they assert, that their Opinion is not contrary to Observations; in which they err, as we shall shew in the following Part.

CHAP. II.

Concerning the Apparent Motion.

WHOEVER, after having read the former Chapter, looks upon the Heavens, will scarcely believe, that he beholds the System which is explained there; and a more exact Consideration of the heavenly Motions will en-
983 crease his Doubt. No Wonder, *since we can observe very little in the Heavens but false Appearances.*

The common Observer of the Heavens is a Spectator, who, thinking himself to be at rest, is carried about by various Motions, and beholds Bodies, concerning whose Distance and Magnitude he makes false Judgments. The true System of the World was unknown for many Ages, even to the most exact Observers of the Heavens.

But

But we must explain how all Things, which 984
are observed in the heavenly Bodies, have Place in the System that has been explained, in respect of a Spectator upon the Earth; that is, we shall deduce the Appearances from the true Motions. Which cannot be done, unless we first lay down some general Things concerning the apparent Motion in general.

It is certain, that we have no Art, by which we can discover the true Motion, only the relative Motion can be perceived by the Senses; and it is that only concerning which we treated in the former Chapter. Who can reasonably affirm or deny, that all the Bodies, which are known to us, are not carried in a common Motion through the immense Spaces?

The relative Motion to be distinguished from the 985
apparent one; for the apparent Motion is the Change which appears to be in the Situation of the Bodies, and depends upon the Change of the Picture in the Bottom of the Eye; for Objects have the same apparent Relation to one another, as their Representations have in the Eye; for they are seen as they are painted in the Eye; * *716
and the Change in that Picture, from the Motion of the Bodies, most commonly differs from the Change of the Relation between the Bodies themselves; as follows from the Formation of that Picture.

The Heavens are nothing but an immense Space, 986
which cannot be seen, and would appear black, * *845
if innumerable Rays of Light, flowing from the heavenly Bodies, did not continually penetrate our Atmosphere. Most of them come to us from the Bodies in right Lines, yet a great many suffer various Reflexions in the Atmosphere, and enlighten the whole Atmosphere; which is the Reason that, in the Day, Bodies are enlight-

ened, even without the Reflexion of the Clouds, to which the Rays of the Sun cannot come directly.

Theſe Rays are heterogeneous and white; for there are Bodies enlightened by theſe Rays which appear white: And theſe Bodies ſeen through Priſms, at the Extremities, are tinged with Colours, which does not happen in an homogeneous
*874 Colour; * alſo a Circle of white Paper of Half an Inch Diameter, being put upon black Cloth, if it is enlightened by theſe Rays, it will appear ob-
*861 long through the Priſm; * and the ſame Colours, which are obſerved in the Rays of the Sun, are ſeen here in the ſame Manner: All which Things would not happen, if the Air, as many think, was a blue Liquid; that is, through which only the Sun's blue Rays, at leaſt moſtly ſuch, paſs.

987 *When we look at the black Sky, the white Rays,* beforementioned, *enter our Eyes, whence the blue Colour of the Sky ariſes.* Becauſe we are accuſtomed to ſee a Colour where there is a coloured Object, we alſo refer the Colour of the Heavens to an Object; but ſince this is ſeen equally towards all
988 Parts, *we conceive a concave ſpherical Surface, in whoſe Center we are placed; we imagine this Surface to be opaque, and therefore diſtant from us beyond all viſible Bodies.*

When a Body is between a Plane and the Eye, of whoſe Diſtance we cannot judge, the Body appears to us to be applied to the Plane, whatſoever the Diſtance is between that and the Plane; for there is no Reaſon why the Parts of the Plane, which are painted at the Sides of the Image of the Body in the Eye, ſhould not appear at the ſame Diſtance with the Body.

989 Thence alſo *all the celeſtial Bodies* (of which the leaſt diſtant from us, (*viz.*) the Moon) is yet ſo removed that we can give no Judgment of

of its Diſtance *, *are referred to that imaginary Sphere above-mentioned; and they all appear equally diſtant, and ſeem to move in the Surface of a concave Sphere.* So the Moon appears to be amongſt the fixed Stars, although its Diſtance bears ſcarcely any ſenſible Proportion to the Diſtance of *Saturn*; and the Diſtance even of *Saturn* itſelf is nothing, compared with the immenſe Diſtance of the fixed Stars. It is no Wonder therefore, that the common People know nothing of the Magnitude of the celeſtial Bodies, and the Immenſity of the Heavens. *732

We ſee from what has been ſaid, how the Motion of any Body being given, and the Motion of the Earth being known, the apparent Motion may be determined.

We have ſaid that a Sphere is imagined beyond the fixed Stars, in whoſe Center is the Spectator: * The Orbit of the Earth is ſo ſmall, *988
in reſpect of the Diameter of this Sphere, that the Center of the Sphere is not ſenſibly changed by the Alteration of the Place of the Spectator, whilſt he is carried along with the Earth. Wherefore *in all the Points of the Earth's Surface, and at* 990
any Time, the Inhabitants of the Earth imagine the ſame Sphere, to which they refer the heavenly Bodies; and which hereafter we ſhall call *the Sphere of the fixed Stars.*

Theſe Things being laid down, *if we conceive* 991
a Line to be drawn through the Earth, and a Body, which, being continued beyond the Body, cuts the aforeſaid Sphere; we have a Point, to which the above-mentioned Body is referred, and *which is the apparent Place of that Body.*

Whilſt the Body, or the Earth, or both are moved, this Line is moved alſo, and *the apparent* 992
Motion is the Line, which is deſcribed amongſt the fixed Stars by the Extremity of the Line above-

 mentioned,

mentioned, *which goes through the Earth and the Body, whose apparent Motion is observed.*

993 Therefore *the same Appearances will follow from the Earth's being moved out of its Place, as if the Body had been moved, and the same also may be deduced from the Motion of both.*

994 But *if the Body and the Earth be so moved, that the Line which passes through these Bodies be carried in a parallel Motion, the Body will seem to be at rest amongst the fixed Stars*; because in this Case, the Space, gone through by the End of the Line amongst the fixed Stars, cannot exceed the Space gone through by the Earth; but the Line that is equal to the whole Space which the Earth can go through, at so great a Distance as the fixed Stars, is not sensible to us.

995 *From the Motion of the Earth round its Axis* there *is* also *produced an apparent Motion*, which will be easily deduced in its proper Place from the Foundation laid down in this Chapter.

That the apparent Motion differs from the relative, and is varied by the Motion of the Spectator, is what Sailors every Day observe.

CHAP. III.

Of the Phænomena or Appearances of the Sun from the Motion of the Earth in its Orbit.

Plate XXI. *Fig.* 1.] LET the Sun be at S, and the Earth in its Orbit at T; and let *r s* be the Sphere of the fixed Stars; the
*991 apparent Place of the Sun will be at *s.* * *When*
996 *the Earth is carried in its Orbit from* T to *t*, *the Sun seems to move in* Consequentia, and to run
*992 thro' the Arc *s r*,* which measures the Angle *r* S *s* equal to the Angle T S *t*, so that the Celerity of the

the apparent Motion of the Sun depends upon the Celerity of the angular Motion of the Earth, with respect to the Center of the Sun; which Motion encreases upon a double Account; on account of the Distance from the Sun being lessened, and the Celerity of the Earth being encreased: Both which Causes always concur; * *944
wherefore the Inequality of the apparent Motion of 997
the Sun is sensible. In a whole Revolution of the 998,
Earth, the Sun also seems to run thro' a whole Circle.

DEFINITION I.

999 *This apparent Way of the Sun is called* the Ecliptic Line. It is the Section of the Sphere of the fixed Stars with the Plane of the Ecliptic, supposed to be continued to this Sphere.

This Way is divided into 12 equal Parts, each of which contains 30 Degr. These Parts are called the Signs, and are distinguished by these Names; *Aries* ♈, *Taurus* ♉, *Gemini* ♊, *Cancer* ♋, *Leo* ♌, *Virgo* ♍, *Libra* ♎, *Scorpius* ♏, *Sagittarius* ♐, *Capricorn* ♑, *Aquarius* ♒, *Pisces* ♓. Whence these Parts have their Names, we shall explain when we treat of the fixed Stars.

1000 *The Sun is longer a going thro' the six first Signs than the six last, and the Difference is nine Days.*

1001 Although a Circle has neither Beginning nor End, yet when several Points must be determined in it, some Point must be taken as *the Beginning*; this, *in the Ecliptic Line, is the first Point of* Aries; we shall shew how it may be determined hereafter. It is not fixed to one Place amongst the fixed Stars; therefore *the Orbits of the* 1002
Planets, which alter so little, that they may be looked upon as unchangeable, * *don't preserve the* *929
same Situation, in respect of this Point.

DEFINITION II.

1003 *The Distance of the Sun from the first Point of* Aries, *measured in* consequentia, *is called* the Sun's Longitude.

1004 *The Longitudes of the other heavenly Bodies are measured after the same Manner in the Ecliptic;*
1005 *they are referred to this Line, by conceiving a great Circle to pass through the Body, and cut the Ecliptic perpendicularly*; for the Point, in which the Ecliptic is cut by this Circle, determines the Longitude of the Body.

DEFINITION III.

1006 *The Distance of a heavenly Body from the Ecliptic is called its* Latitude. It is measured by an Arc of a great Circle, perpendicular to the Ecliptic, intercepted between the Body and the Ecliptic.

DEFINITION IV.

1007 *If we imagine a Line to go thro' the Center of the Sphere of the fixed Stars, and perpendicular to the Ecliptic, the Points, in which this cuts the above-mentioned Sphere, are called the* Poles of the Ecliptic.

DEFINITION V.

1008 *The* Zodiac *is a Zone which is imagined in the Heavens, which the Ecliptic Line cuts into two equal Parts, and which, on either Side, is terminated by a Circle parallel to the Ecliptic Line, and eight Degrees distant from it.* On Account of the small Inclinations of the Orbits of the Planets, and the Moon to the Plane of the Ecliptic, no Bodies of
1009 the Planetary System appear without the *Zodiac*.

DE-

DEFINITION VI.

Those of them that have the same Longitude are 1010
said to be in Conjunction.

DEFINITION VII.

Those whose Longitudes differ 180 Degr. are said 1011
to be in Opposition.

CHAP. IV.

Of the Phænomena of the Inferior Planets, arising from the Earth's and their own Motions in their Orbits.

Plate XXI. *Fig.* 2.] LET S be the Sun, A V B *v* the Orbit of an inferior Planet; let T be the Earth in its Orbit, and *a* v *b* Part of the Sphere of the fixed Stars; the apparent Place of the Sun is v.* *991

If from the Earth there be drawn to the Orbit of the Planet the Tangents T A *a*, T B *b*, it is evident that the Planet, in its apparent Motion, is never removed farther from the Sun, than the Distance v *a*, v *b*; and that the Planet accompanies it in its apparent Motion round the Earth.

DEFINITION I.

The apparent Distance of the Planet from the 1012
Sun is called its Elongation; v *a* or v *b* is *the*
greatest Elongation: This varies upon two Ac- 1013
counts; (*viz.*) because the Earth and the Planet
revolve in elliptic Lines.* *929

The Planet performs its Motion sooner than the 1014
Earth;* therefore, *in its Motion*, it *passes be-* *948
tween the Earth and the Sun, and then moves be-

yond the Sun, in respect of the Earth: So that it is in Conjunction with the Sun in two Manners, but *never in Opposition*.

That we may have an Idea of the apparent Motion of the Planet, we must conceive the Lines T B *b*, T S v, T A *a*, to move along with the Earth; so that the Points A, V, B, and *v*, whilst the Earth performs its Revolution, may run thro' the Orbit of the Planet; but the Planet, which moves swifter, passes successively through these Points over and over.

1015 *When* it is carried in its Orbit from V to D, it seems to move amongst the fixed Stars from v to *d*: In this Case, *the apparent Motion is in* An-
1016 tecedentia, and *the Planet is retrograde*. In D it is said to be *stationary*; because *it appears, for some Time, in the same Place amongst the fixed Stars*: This obtains, when the Orbit of the Planet, in the Place in which the Planet is, is so inclined to the Orbit of the Earth, in the Place in which the Earth is, that, if the Line *t d* be drawn parallel to the Line T D, and at a small Distance from it, D *d* be to T *t* as the Celerity of the Planet in its Orbit, to the Celerity of the Earth; these
*53 Lines are run through in the same Time; * and the Line, which is drawn through the Earth and the Planet, is carried in a parallel Motion; for which Reason the apparent Place of the Planet is
991 not changed.

Between *d* and B, the Orbit of the Planet is more inclined to the Orbit of the Earth; wherefore the Extremity of the Line passing through the Earth and the Planet (although the Planet
1017 moves swifter than the Earth) is carried *in Consequentia*; *towards which* Part also *the apparent Mo-*
*992 *tion of the Planet is directed.** Yet since the apparent Motion of the Sun exceeds the apparent Motion of the Planet, the Elongation is increased, which becomes

becomes greateſt, when the Planet is at B. Whilſt the Planet goes through the Arc B *v*, its apparent Motion is alſo *in Conſequentia*, and exceeds the apparent Motion of the Sun to which it is coming, and then goes beyond it, receding from it, till it comes to A. Between A and E the Motion *in Conſequentia* is continued; but the Sun, whoſe apparent Motion in this Caſe is ſwifter, as has been explained concerning the Arc *d* B, comes towards the Planet, and the Elongation is diminiſhed. At E, in the ſame Manner 1018
as at D, *the Planet is* ſtationary, between E and V it is again retrograde.

The Orbit of the Planet is inclined to the Plane of *the* Ecliptic; * therefore it *does not* *958,
ſeem to move in the Ecliptic Line, *but* ſometimes 959
leſs, ſometimes more diſtant from it, and *appears to be carried in an irregular Curve, which ſometimes cuts the Ecliptic.*

Plate XXI. *Fig.* 3.] Let N V N be the Orbit of the Planet, whoſe Nodes are N N; let S be the Sun; T *t* the Orbit of the Earth in the Plane of the Ecliptic; the Earth T; the Planet V. If V A be imagined to paſs through the Planet, and to be perpendicular to the Plane of the Ecliptick, the Angle V T A, or rather the Arc which meaſures it, is the Latitude of the Planet: * This is called *the Geocentric Latitude*, to *1006
diſtinguiſh it from the Latitude of the Planet ſeen from the Sun, which is called the *Heliocentric Latitude*, and is in that Caſe the Angle V S A. Here we ſpeak of the *Geocentric Latitude*, becauſe we examine the Phænomena as they appear from the Earth.

When a Planet appears in the Node, it appears 1019
in the Ecliptic Line; and the Curve, which is deſcribed by the Planet, by its apparent Motion in the Zodiac, cuts the Ecliptic Line; *as the Planet* 1120
recedes

recedes from the Node, its Latitude is encreafed, which is alfo different, according to the Situation of the Earth; fo the Planet remaining at V, the Latitude is greater if the Earth be at T, than if it was at *t*. Now, if the Earth remaining in its Place, we imagine the Planet to be carried from V to *v*, the Angle *v* T B will be lefs than the Angle V T A upon a double Account, from the Planet coming nearer the Node, and the Spectator being moved farther off.

Now, if we confider that both the Earth and the Planet are continually moved, we fhall eafily conceive that the Latitude is changed every Moment from each Caufe, which fometimes act contrariwife, and fometimes confpire in encreafing and diminifhing the Latitude; whence it neceffarily follows, that the Apparent Motion is performed in an irregular Curve, which, as was faid before, cuts the Ecliptic as often as the Planet paffes the Node, that is, twice in each of its Revolutions: This Curve alfo does not recede from the Ecliptic, on either Side, beyond certain Limits in the Zodiac.

We difcover alfo fome remarkable Phænomena of the Inferior Planets by means of the Telefcope, which are owing to their Opacity.

Plate XXI. *Fig.* 4.] Let S be the Sun, T the Earth, A, B, C, v, D, E, F, V, an inferior Planet, *ex. gr. Venus* in its Orbit. This Planet fhines with Light borrowed from the Sun, and that Hemifphere only which is turned to the Sun is enlightned, the other Hemifphere is invifible: Therefore that Part only of the enlightened Hemifphere, which is turned to the Earth, can be feen from it; in V the Planet cannot be feen; in v it would appear round, if the Sun's Rays did not hinder it from being feen.

Going

Going from v *the Planet continually decreases*; 1021
at D it has the Figure *d*; at *e* and *f* it is drawn as it appears at E and F, and continues to decrease, *till it vanishes at* V, *and then again encreases successively, changing its Figure,* 'till the whole enlightened Hemisphere be turned towards Earth.

When the Node is at V, or near it, *the Planet* 1022
appears in the very Disk of the Sun, and as it were applied to *it*, and *is observed as a black Spot which moves on the Sun's Surface* : In this Case, properly speaking, we don't see the Planet, but we perceive where it intercepts the Sun's Rays.

The less distant the Planet is from the Earth, the 1023
greater it appears, * and the more lucid; but as it *733
comes nearer the Earth, the lucid Part that is visible is less; so that on one Account the Light encreases, and on another it is diminished; *and there is a Distance at which the reflected Light is greatest.*

CHAP. V.

Concerning the Phænomena of the Superior Planets, arising from their Motions and the Motion of the Earth in their respective Orbits.

THE Apparent Motions of the Superior Planets do in many Things agree with what has been explained in respect of the Inferior Planets, and in many Things disagree. *They do not* 1024
always accompany the Sun, but are often observed in Opposition; but in their Opposition (as has been said of the Inferior Planets) *they do not always seem to be carried in* Consequentia, *but often* 1025
appear stationary, and often retrograde.

Plate

1026 *Plate* XXII. *Fig.* 1.] Let M be *a Superior Planet*, for Example, *Mars* in its Orbit, ATHB the Orbit of the Earth. The Periodical Time of the Earth is ſhorter than the Periodical Time
*948 of *Mars* *; therefore the Earth in its Motion goes between it and the Sun; in which Caſe the Planet *appears* at F, amongſt the fixed Stars *oppoſite to the Sun.* Through M draw the Lines B M, A M, that touch the Earth's Orbit, which, being continued, go to G and D in the Sphere of the fixed Stars. Let us imagine, that whilſt the Planet is carried about in its Orbit, thoſe Lines are alſo moved; ſo that the Points A and B, in which the Lines that go through the Planet touch the Orbit of the Earth, perform a Revolution in the Periodical Time of the Planet. Now ſince the Earth revolves faſter, it paſſes through the Points A and B in its Motion. In this Motion the apparent Place of the Planet, ſeen from the Earth, is not removed from the Place of the Planet ſeen from the Sun beyond F D and F G. Let T be ſuch a Point in the Orbit of the Earth, that the Line *t m*, being drawn, may be parallel to T M; let T *t* be to M *m*, as the Celerity of the Earth to the Celerity of the Planet; in which Caſe theſe ſmall Lines are gone through
*53 in the ſame Time; * in the mean time the Planet
*994 ſeems to be at reſt, * and is ſaid to be ſtationary. In the ſame Manner it is ſtationary when the Earth is at H. In the Motion of the Earth between T and H, the Planet appears to move in *Antecedentia* from E through F, and is ſaid to be retrograde; whilſt the Earth goes through the reſt of its Orbit, the Planet is direct.

1027 The Phænomena, which relate to the Latitude, are like thoſe which have been explained, in re-
1008 ſpect to the inferior Planets.

Jupiter

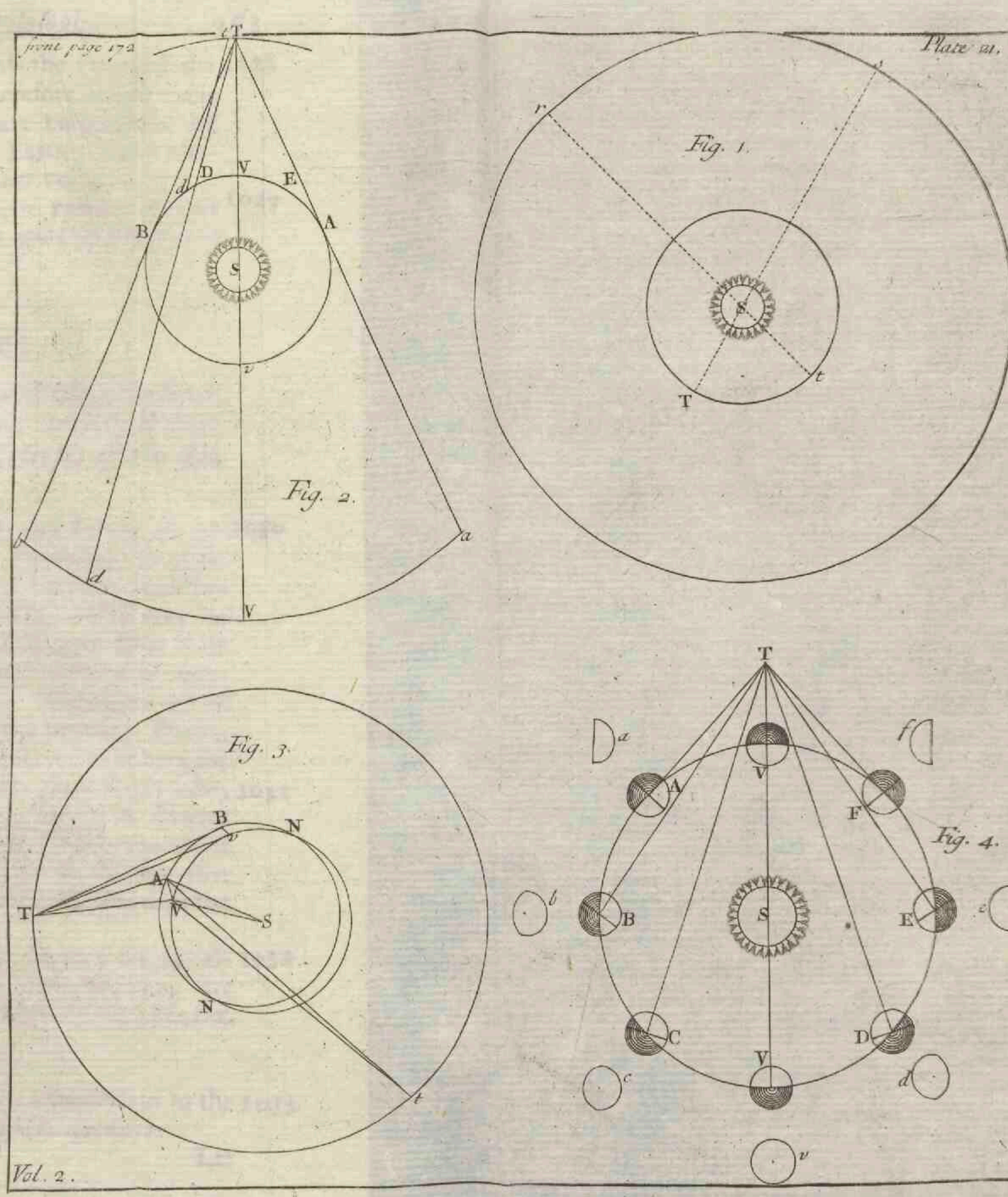
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Plate 21.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
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Jupiter and *Saturn* encompaſs the Orbit of the Earth at a great Diſtance; wherefore almoſt their whole Hemiſpheres, which are enlightened by the Sun, are viſible from the Earth; and therefore theſe Planets *always appear round.* 1028

Becauſe *Mars* is leſs diſtant, it *appears a little gibbous, between the Conjunction and Oppoſition with the Sun.* 1029

CHAP. VI.

Concerning the Phænomena of the Satellites, from their Motion in their Orbits. Where we ſhall ſpeak of the Eclipſes of the Sun and Moon.

THE *Satellites of* Jupiter *and* Saturn *do always accompany their Primaries in their Motion, and never appear to recede from them beyond certain Limits on either Side,* which may be eaſily determined from their Diſtances from their Primaries; *and they are alternately carried* in *Antecedentia* and in *Conſequentia.* Sometimes all of them are on the ſame Side of the primary Planet, and ſometimes the Primary is obſerved to be between them; *they are* all *always in the ſame Right Line,* 1031 *or very little diſtant from it.* All which Things may be deduced from this, That the Motion about the primary Planets is performed in Planets that make ſmall Angles with one another, and with the Plane of the Ecliptic. 1030

All *the Satellites of* Saturn *or* Jupiter are not always viſible at the ſame Time; *ſometimes* they *are hid by their Primary,* and *often immers'd in its Shadow.* 1032

DEFINITION I.

Plate XXII. *Fig.* 2.] Such an Immerſion in the Shadow is called an *Eclipſe of the Satellite.* 1033

Let

Let S be the Sun, T *t* the Orbit of the Earth, I *Jupiter*, M*m* the Orbit of a Secondary of *Jupiter*. Whilst the Secondary moves from M to *m*, it undergoes an Eclipse; and, not being enlightened by the Sun, becomes invisible. If the Earth be at T, the Emersion into the Shadow is easily observed; on the contrary, the Emersion is more sensible, if the Earth be placed at *t*.

1034 Amongst the Bodies that accompany *Saturn*,
*963 we have said that there is *a Ring*; * concerning which it is to be observed, *that an Observer upon the Earth never sees it wider than it is represented in the 4th* Fig. *of Plate* XX. *and that sometimes it is invisible*; namely, when the Plane of the Ring being continued, goes through the Earth; for the Thickness of the Ring is not sensible. The Ring is also invisible, when its Plane continued passes between the Earth and the Sun; for then the enlightened Surface of the Ring is turned from the Earth: In each Case *Saturn* appears round, yet in the last Case, by reason of the Rays that are intercepted by the Ring, there appears a black Belt upon the Surface of the Planet, like that which is occasioned by the Shadow of the Ring.

The Phænomena of the Earth's Satellite, namely of the Moon, are very remarkable in respect to us, and therefore particularly to be explained.

1035 It is very often in Conjunction with the Sun, and as often in Opposition to it, but not at every Revolution of the Moon in its Orbit; for whilst the Moon, after one entire Revolution of 27 Days and 7 Hours, returns again to the Place
1036 amongst the fixed Stars, in which it was in Con-
*960 junction with the Sun, the Sun is gone from that
996 998 Place, and is about 27 Degr. distant from it: * there-

therefore *the neighbouring Conjunctions are twenty-nine Days and a Half distant from one another.*

Definition II.

The Lunar Periodical Month *is the Time of one* 1037
Revolution of the Moon in its Orbit.

Definition III.

The Moon's Synodical Month, or a Lunation, 1038
is the Time that the Moon spends between the two next Conjunctions with the Sun.

The Moon is invisible in its Conjunction with the 1039
Sun, because the enlightened Hemisphere is turned from the Earth. Let T (*Plate* XXII. *Fig.* 3.) be the Earth, N the Moon between the Sun and the Earth, the enlightened Hemisphere will be *m l i*, which cannot be seen from the Earth.

Whilst the Moon is carried, in its Orbit, *from the* 1040
Conjunction to the Opposition, the enlightened Part, which is directed towards the Sun, *does continually become more and more visible to the Inhabitants of the Earth*; and in the Points A, B, C, the Moon does successively acquire the Figures *a*, *b*, *c*.

At P, *in* its *Opposition with the Sun, it appears* 1041
round; then going through D, E, F, *it decreases*, as it is represented at *d*, *e*, *f*.

Definition IV.

The Conjunction of the Moon with the Sun is 1042
called the New-Moon.

After the Conjunction, the Moon is as it were renewed.

Definition V.

The Opposition of the Moon with the Sun is called 1043
the Full-Moon, *because the whole Moon appears enlightened.*

De-

Definition VI.

1044 *The Conjunction and Opposition of a Satellite with the Sun, are called by the common Name* Syzygies.

1045 At A and F, the dark Part of the Moon is a little enlightened by the Rays that are reflected from the Earth; and therefore it is seen by a Spectator to whom the Sun is not visible, that is, in the first Case, after the Setting of the Sun, and in the second, before its Rise.

Definition VII.

1046 *When the Light of the Sun is intercepted by the Moon, so that, in respect of any Observer upon the Earth, the Sun is partly or wholly covered, the Sun is said to undergo an* Eclipse.

Properly speaking, this is an Eclipse of the Earth, on whose Surface the Shadow or *Penumbra* of the Moon falls.

Definition VIII.

1047 An Eclipse of the Moon *is the Obscuration of the Moon by the Shadow of the Earth.*

1048 *The Eclipse of the Sun is never observed, except at the Time of the New-Moon.*

1049 *The Moon is never eclipsed but at the Time of the Full-Moon.*

1050 Yet the Luminaries are not eclipsed at every one of the Syzygies, because the Moon does not move
*969 in the Plane of the Ecliptic, * in which the Sun and Earth always are; wherefore, upon Account of the Moon's Latitude, its Shadow, at the New-Moon, often does not touch the Earth; and itself, at the Full-Moon, passes beside the Shadow of the Earth.

1051 But *when the Moon* has no Latitude, or but very little, that is, when it *is in the Node, or near it, at its Syzygies, an Eclipse is observed*; in that

Plate

Caſe the Moon appears to be in the Ecliptic, or very near it; and this it is that has given the Name to that Line.

Plate XXIII. *Fig.* 1.] That what relates to the Eclipſe of the Moon may appear the more plainly, let O O be the Way of the Moon, R R the Plane of the Ecliptic; the Center of the *904,
Earth's Shadow is always in it; * N is the Node 939
of the Moon's Orbit.

If the Center of the Earth's Shadow be at A, the Moon that goes by at F will not be darkened.

If the Moon be leſs diſtant from the Node at 1052
the Full-Moon, as at G, the Shadow of the Earth is at B, and *the Moon is darkened in part; this is called a partial Eclipſe.*

If, ſuppoſing the Shadow at D, the Moon be 1053
Full, *the Moon* will *be wholly darkned* at I, it runs into the Shadow at L, and goes out of it at H; and *the Eclipſe is ſaid to be Total.*

The Eclipſe is ſaid to be Central, when the Cen- 1054
ter of the Moon goes through the Center of the Shadow, which only happens in the very Node N.

We have hitherto ſpoken of the Shadow of the Earth; becauſe, when we mention the Earth, we underſtand its Atmoſphere which is joined to it, of which we have ſpoken elſewhere: * *The Shadow* *418
of the Atmoſphere is properly *conſidered in Lunar* 1055
Eclipſes; for the Shadow of the Earth itſelf does not reach the Moon.

Plate XXIV. *Fig.* 1.] Let T be the Earth, the Atmoſphere about it F D G G D F. The Sun's Rays B D, B D, touching the Atmoſphere; theſe go ſtreight on, and terminate the Shadow of the Atmoſphere, out of which if the Moon be, it is immediately enlightened by the Sun's Rays, but it is not enlightened in the ſame Manner all the while it is between B D and B D.

1056 *The Rays which enter the Atmosphere obliquely* are
*617 refracted; * and, as they come towards the Earth, they continually penetrate into a Medium which
*424 429 is denser and denser, * and therefore are every Moment inflected and *move into Curves.* So the
*617 Rays E F, E F, penetrate the Atmosphere in the Curves F G, F G, that touch the Earth. All the Light between E F, E F, is intercepted by the Earth, and the Rays G A, G A, terminate the Earth's Shadow.

The Light between E F and B D, being refracted by the Atmosphere, is scattered between G A and B D continued, and beyond A, the Point of the Earth's Shadow, the Lights that
1057 come from all Parts are confounded, but are continually weaker and weaker the farther from the Earth: So that *the Shadow of the Atmosphere is* not a perfect Shadow, but *a weak Light*, whereby the Moon is visible in an Eclipse.

1058 *The Shadow of the Atmosphere* is Conical, because the Sun's Diameter is greater than the Diameter of the Atmosphere, which is scarce bigger than that of the Earth; and this Cone *does not reach quite to Mars*, as appears from immediate Observations; but the Shadow of the Diameter, in the Place where it is cut by the Moon's Orbit, is scarce one Fourth less than the Diameter of the Earth.

With the same Reasoning that we have proved, that the Moon comes into the Shadow of the Atmosphere, when the Moon in its full is in the Node or near it; it is also proved, that the Moon's Shadow falls upon the Earth *at the New-Moon, when the Moon is in the Node or near the Node*;
1059 therefore in that Case *the Sun undergoes an Eclipse*; concerning which, several Things are to be observed.

Plate XXII. *Fig.* 4.] Let S be the Sun, T the Moon; let the Shadow of it fall upon any Plane G H. This Shadow is encompassed with a Penumbra, for beyond L and E that Plane is enlightened by one entire Hemisphere of the Sun; as you go from L to H, and from E to G, the Light is continually diminished, and near G and H the Rays come to the Plane only from a small Part of the Sun's Surface.

Definition IX.

This diminished Light, which encompasses the 1060
Shadow G H *every Way, is called* the Penumbra.

In the Eclipse of the Moon, the Shadow of the 1061
Earth is encompassed with *the like Penumbra*, but this is only sensible near the Shadow, and therefore *has but a small Breadth*; *but* if *an Observer* be placed upon a Plane upon which the Shadow falls, he *may observe the whole Penumbra*; as is 1062
the Case *in the Eclipse of the Sun.* An Observer I or F can only see the Semidiameter of the Sun, the rest of the Diameter is hid by the Moon; and going from L towards H, the Sun is continually more and more hid by the Moon, till it becomes wholly invisible in the Shadow itself.

Hence it follows, that *there is a Solar Eclipse,* 1063
though the Shadow of the Moon does not touch the Earth, provided the Penumbra comes to its Surface. And also, *that the Eclipse is not observed in all the* 1064
Places in which the Sun is visible; *and that it is* 1065
different, according as the Shadow or a different Part of the Penumbra goes through the Place, *in the Places in which it is observed.*

But the Eclipse of the Moon is every where the 1066
same, where the Moon is visible, during the Eclipse.

But when the Shadow itself of the Moon falls upon 1067
the Earth, the Sun's Eclipse is said to be Total; if only the Penumbra reaches the Earth, it is said to be

Partial; and this is what happens when we consider an Eclipse in general.

1068 But, as to particular Places, *it is said to be Total in those Places where the Shadow passes*; *Central, in those* where the Center of the Shadow passes, that is, *where the Center of the Moon covers the Sun's Center*; and lastly, *Partial, where the Penumbra only goes by*; and this is drawn in *Fig.* 6.

1069 *Plate* XXII. *Fig.* 4.] *The wider the Shadow* GH *is, the more Places is the Eclipse of the Sun Total in, and the longer is the Sun wholly obscured.* But the Breadth of the Shadow is different according to the differenr Distances of the Moon from the Earth, and of the Earth from the Sun.

1070 *If there be an Eclipse of the Moon, supposing the Earth in the Perihelion,* and *the Moon in the Apogæum*, that is, at the greatest Distance from the Earth, the Shadow of the Moon does not reach the Earth, and *the Moon does not cover the whole Sun*; *such an one is* called *an Annular Eclipse*, and is represented in *Fig.* 5.

CHAP. VII.

Of the Phænomena arising from the Motion of the Sun, the Planets, and the Moon, about their Axes.

1071 THE *Sun's Motion about its Axis is sensible, by observing the Spots*, which are observed very often upon the Sun's Surface. These Spots seem to change their Figure and Situation every Day, and sometimes to move swifter, sometimes slower; all which Things may be easily deduced from the Motion of a Spherical Surface; and the Sun, which, if it was not moved by such a Motion, would only once in a Year successively turn

turn its whole Surface to the Earth, now shews it to the Inhabitants of the Earth in less than the Space of one Month.

Such like Phænomena arise from *the Rotation of* 1072 *Jupiter, Mars, and Venus, about their Axis,* which Motions *become sensible, by observing the Spots in the Surface of the Planets.*

Whilst the Earth is moved round its Axis, the Observer, who is carried round, imagines himself to be at rest, and all the heavenly Bodies to be in Motion.

Definition I.

The Points, in which the Axis of the Earth, be- 1073 *ing continued both Ways, touches the Sphere of the fixed Stars, are called the* Poles of the World.

Definition II.

The apparent Motion, arising from the Motion of 1074 *the Earth about its Axis, is called* The Diurnal Motion.

Definition III.

A Plane is conceived to pass through the Center 1075 *of the Earth, perpendicular to its Axis, and continued every Way, and the Circle, in which it cuts the Sphere of the fixed Stars, is called* The Cœlestial Æquator.

In the Motion of the Earth round the Sun, the 1076 Æquator is moved; but since the Plane of this Circle is carried by a parallel Motion, *the Cœlestial Æquator is not moved.** *994

Definition IV.

Circles, whose Planes go through the Axis of the 1077 *Earth, are called* Meridians.

They all pass through the Poles of the World, and 1078 *are perpendicular to the Æquator.*

Definition V.

1079 *The Arc of any Meridian, which is intercepted between the Æquator and a Star, is called* the Declination of that Star.

Plate XXIII. *Fig.* 2.] Let an Obſerver be upon the Earth T, who directs his Sight along T A; after a little Time, when the Line T A ſhall be be carried by the Motion of the Earth to T *a*, if the Spectator directs his Sight through the ſame Line, the Body A will appear to have been carried through the Arc *a* A; but when the Line has returned to its former Situation T A, the Body will ſeem to have performed one whole Revolution. But if he directs his Sight along the Axis of the Earth produced, becauſe that is at reſt, the Body, which is ſeen in the Axis, will appear not to
1080 have moved; therefore *in the Poles of the World the*
*1075 *diurnal Motion is not obſerved.* * But that Bodies, which are near the Poles, are moved round them is plain; and that the Body by its diurnal Motion deſcribes ſo much a greater Circle round the immoveable Pole, as it is farther diſtant from it.
1081 Therefore *the whole Sphere of the fixed Stars ſeems to revolve about the Axis of the Earth continued,* in Antecedentia, *in that Time in which the Earth really turns about its Axis.* Therefore the diurnal Motion is common to all the cœleſtial Bodies, except ſo far as it is diſturbed by the Motions above-mentioned.

The Æquator is equally diſtant from both Poles, and divides the Heavens into two Hemiſpheres, whoſe middle Points are the Poles, which therefore are equally diſtant from the ſeveral
1082 Points of the Æquator; therefore *the heavenly Bodies which are in the Æquator by their diurnal Motion ſeem to deſcribe the Æquator itſelf*, the greateſt Circle of all that can be deſcribed by

by the diurnal Motion; *the other Bodies describe* 1083
Circles parallel to the Æquator.

The Axis of the Earth is inclined to the Plane of the Ecliptic in an Angle of 66 Degr. 31 Min. * *960
The Poles of the World therefore *are distant from* 1084
the Poles of the Ecliptic 23 Degr. 29 Min. *and the Plane of the Æquator makes an Angle with the Plane of the Ecliptic of* 23 Degr. 29 Min. Both Planes pass through the Center of the Earth; but since this may be looked upon as the Center of the fixed Stars, * it follows, that *the Æquator and* 1085
the Ecliptic Line are great Circles, which are inclined *988
to each other, and *cut one another in two opposite* 990
Points, in the Beginning of Aries, *and the Beginning of* Libra; which Points, in the Way of the Sun, are determined by these Intersections. * *1001

When the Sun is in those Points, it seems to de- 1086
scribe the Æquator by its diurnal Motion; * *when it* 1087
is carried about *in the Ecliptic* by its apparent Mo- *1082
tion, it continually recedes more and more from the Æquator, and its Declination is increased, *and it describes less Circles every Day;* * *till it comes to* *1083
its greatest Distance from the Equator, which is 23 1088
Degr. 29 Min. * *then it comes back to the Æquator* *1084
again, and goes beyond it also 23 Degr. 29 Min. *advancing towards the opposite Pole.*

DEFINITION VI.

Those Circles, described by the Sun in its diurnal 1089
Motion, which are most distant from the Æquator, that is, 23 Degr. 19 Min. *are called* the Tropics.

One touches the Ecliptic Line in the first Degree of *Cancer*, and is called the Tropic of *Cancer*; the other is called the Tropic of *Capricorn*, and passes through the first Point of the Sign *Capricorn*, and there touches the Ecliptic Line.

DEFINITION VII.

1090 *The Pole of the World, which is next to the Tropic of* Cancer, *is called the* Arctic Pole, *and also the* North Pole; *the Opposite is called* the Antarctic, *and also* the South Pole.

DEFINITION VIII.

1091 *The Circles* that are described in the diurnal Motion by the Poles of the Ecliptic, that is, by the Points *which are distant from the Poles of the World* 23 Degr. 29 Min. *are called* the Polar Circles.

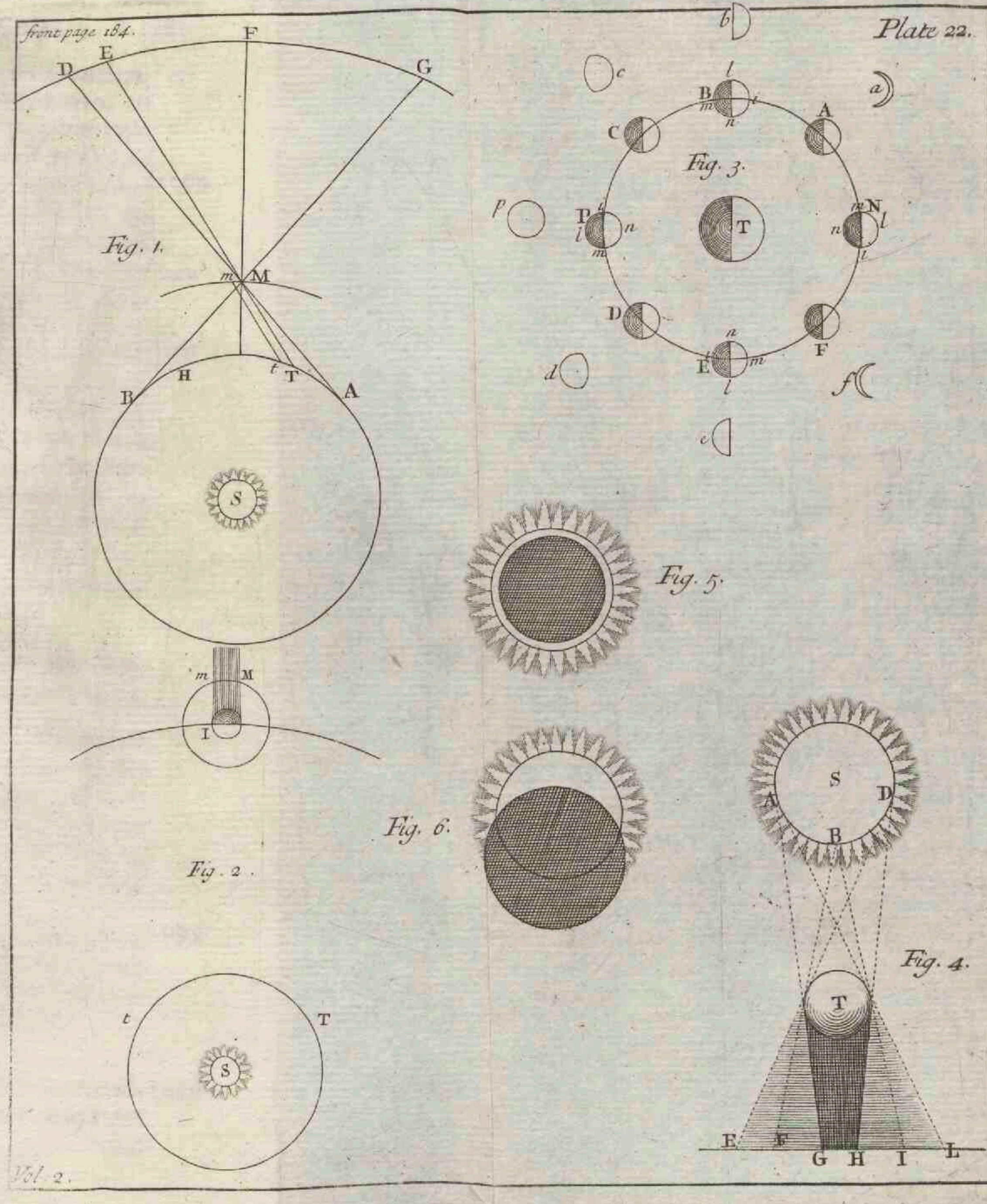
The Arctic Polar Circle is that which surrounds the Arctic Pole; the other opposite one borrows its Name from the Antarctic Pole.

1092 There remains to be explained *the Moon's Motion about its Axis, whose Effect is, that the same Face of the Moon is always turned towards the Earth.*

Plate XXII. *Fig.* 3.] Let the Moon be at N, the Face which is turned to the Earth is *m n i*; if the Moon did not turn about its Axis, and all its Points were carried through parallel Lines, the Line *m i* would coincide with the Line *l n* in the Situation of the Moon at B, and the aforesaid Hemisphere *m n i*, would be at *l m n*; but because, whilst the Moon describes a fourth Part of its Orbit, it performs likewise $\frac{1}{4}$ of its Revolution round its Axis, the Face, which would be at *l m n*, is now at *m n i*, that is, again turned to the Earth. After the same Manner it is proved, that this same Face *m n i*, when the Moon is at P, is seen by an Observer on the Earth, and that it is turned towards the Earth at E; as also in all other Points of the Moon's Orbit.

1093 *The Axis of the Moon* is not perpendicular *to the Plane of its Orbit*, but *a little inclined* to it: The Axis keeps its Parallelism in its Motion round the Earth, as has been said of the Primary *front page 184.*

Plate 22.



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[illegible] of Elements [illegible] Book [illegible]

Definition [illegible]

[illegible] called the Arctic [illegible] the Opposite [illegible] the South Pole.

Definition VIII.

The Circles [illegible] described [illegible] the Pole of the Ecliptic, [illegible] called the Polar Circles.

[illegible] Polar Circle is that which [illegible] the Antarctic Pole.

[illegible] all its Points were carried [illegible] the Moon at B, and the [illegible] would [illegible] Part of its [illegible] the Moon is [illegible] on the Earth, and [illegible] Moon's Orbit.

[illegible]

mary Planets; * therefore it changes its Situation, *952
in respect of an Observer upon the Earth, to whom sometimes one, sometimes the other Pole of the Moon is visible, whence *it seems to be agitated by a* Sort *of libratory Motion.* There is an- 1094
other libratory Motion observed in the Moon; the Motion about the Axis is equable, and it is carried in its Orbit with an unequal Celerity; * therefore *966
when the Moon is at its *Perigæum*, that is, at its least Distance from the Earth where it is moved the swiftest in its Orbit,* that Part of its Surface, *966
which, on Account of its Motion in the Orbit, would be turned towards the Earth, is not wholly turned from it on Account of its Motion round its Axis: Therefore some of that Part of the Surface of the Moon, which before was not visible, is seen at the Side; which, when the Moon is at its *Apogæum*, is again visible.

CHAP. V.

Of the Phænomena which relate to the Surface of the Earth, and its particular Parts.

WE have explained the Cœlestial Phænomena hitherto examined, by considering the Spectator as carried about by those Motions wherewith the Earth is really moved. Now we shall consider him as placed upon the Surface of the Earth, and carried from one Place to another upon it.

The first Phænomena to be here observed is, 1095
that, *by reason of the Interposition of the Earth, one Half of the Heavens is invisible to the Observer who is placed upon the Surface of the Earth.*

DEFINITION I.

That Circle in the Heavens, which separates the vi- 1096
sible from the invisible Part, when the Rays are

not

not intercepted by the Inequalities of the Earth's Surface, *is called the* Horizon.

When the Height, to which the Spectator can be raised above the Surface of the Earth, is very small, compared with the Semidiameter of the Earth; the Eye of the Spectator may be looked upon as placed in the Surface itself.

Plate XXIII. *Fig.* 4.] Let the Earth be at T, and the Observer at S, and P E *p e* the Sphere of the fixed Stars; if you conceive a Plane at H H to touch the Earth and go through S, it will be the Plane of the Horizon, whose Section with the Sphere of the fixed Stars is the Horizon. A Plane, as *h b*, is conceived to go through the Center of the Earth, parallel to H H; the Distance *h* H is insensible, by reason of the immense Distance of the fixed Stars; therefore the Section of that Plane, with the Sphere above-mentioned, may be taken
994 for the Horizon.

DEFINITION XII.

1097 *The Ascent of the* Stars, *above the Horizon, is called their* Rise.

DEFINITION III.

1098 *The Descent, below the Horizon, is called the* Setting *of the Stars.*

DEFINITION IV.

1099 *If we conceive a Line drawn through the Observer and the Center of the Earth*, which must necessarily be perpendicular to the Horizon, *it will reach the Point* Z *among the fixed Stars, which is called the* Zenith.

DEFINITION V.

1100 *The Point* N, *opposite to it, is called the* Nadir.

DEFINITION VI.

1101 *The Section which a Plane of the Meridian, that goes through the Observer, makes with the Horizon, is called the* Meridian Line; and is directed from North to South.

DEFI-

Definition VII.

The Eastern Part of the Heavens *is that, from which we see the Bodies rise above the Horizon; and the* East Point *is that, in which a Line directed Eastwards, perpendicular to the Meridian Line, and going thro' the Observer, cuts the Sphere of the fixed Stars.* 1102

Definition VIII.

The Point, opposite to this, is called the West Point; *and the* Western Point of the Heavens *is opposite to the Eastern Part.* 1103

Definition IX.

The Amplitude *is an Arc of the Horizon, which is contained between the East or West Point, and the Point in which the Star rises or sets.* The first is called the Rising, and the other the setting Amplitude: And each is either Northern or Southern Amplitude. 1104

Definition X.

The Height or Altitude of a Star, above the Horizon, *is the Arc of a Circle perpendicular to the Horizon, in whose Center the Spectator is, terminated by the Horizon and the Star.* 1105

Definition XI.

The Difference of the Height of a Star, according to the different Position of the Observer, as he is supposed in the Center, or on the Surface of the Earth, is called the Parallax of the Star. 1106

There is only the Parallax of the Moon, which can be determined by Observations: The Distance of the rest of the Bodies in the Planetary System is too great to be compared with the Semidiameter of the Earth; and the Parallax depends upon the Ratio which the Semidiameter of the Earth has to 1107

to the Diſtance of a Planet; therefore even *the*
1108 *Parallax of* Mars, *in Oppoſition with the Sun, is too ſmall for the niceſt Obſervations.*

1109 Where there is a *Parallax*, it *diminiſhes as a Body aſcends above the Horizon, and vaniſhes in the Zenith.*

The apparent Height of the Stars is alſo changed upon another Account, which equally affects all the
1110 heavenly Bodies. The Rays are inflected *by the*
1111 *Refraction of the Atmoſphere,** and *the Stars ap-*
*1056 *pear higher than they are;** *yet the higher they*
*624 *are, the leſs is that Inflexion;** becauſe the Rays
*639 fall leſs obliquely on the Surface of the Atmoſphere.
1112 *In the* Zenith *there is no Refraction**; *even at the*
*629 *Diſtance of twenty or thirty Degrees from the* Zenith, *it is not ſenſible.*

1113 Since *the Stars* are raiſed *by this Refraction*, they *are viſible before they come to the Horizon.*

Plate XXIV. *Fig.* 2.] All theſe Things relate to the Surface of the Earth in general, now we muſt examine the ſeveral Parts of it; theſe are determined, by referring to the Earth the ſeveral Circles which we have before conſidered in the
1114 Heavens; ſo *on the Earth we conſider the Æquator, the Meridians, the Tropics, and Polar Circles*; and theſe Circles divide the Surface of the Earth in the ſame Manner as the Sphere of the fixed Stars is divided by the Circles in the Heavens: And therefore the Circles in the Heavens, and thoſe upon the Earth, do ſo mutually correſpond with each other, that a Line being drawn from the Center of the Earth to a Circle in the Heavens, it will go through the ſame Circle in the Earth. If the Poles are P, *p*, the Æquator will be E *e*, the Tropics T T, *t t*, and the Polar Circles A A, *a a*.

Definition XII.

1115 *The Meridian, which goes through a Place, is called the* Meridian of the Place.

The

The Plane of it is perpendicular to the Horizon; because it goes through the Center of the Earth, and the Observer. 1116

*A Meridian Line, drawn in any Place, is Part of the Meridian of the Place.** 1117 *1101

Definition XIII.

The Latitude of a Place *is its Distance from the Æquator*; that is, the Arc intercepted between that Place and the Æquator. 1118

Definition XIV.

Circles, parallel to the Æquator, are called Circles of Latitude. 1119

By determining the Latitude of the Place, we determine the Circle of Latitude, which goes through the Place; now, to determine the Situation of several Places, in respect of each other, we must determine Places upon the several Circles; which is done, by supposing a Meridian to pass through any remarkable Place, which, by its Section, determines a Point upon each Circle of Latitude, from which the Distances of Places are measured.

Definition XV.

The Meridian above-mentioned, taken at Pleasure, is called the First Meridian. 1120

Definition VI.

The Distance of a Place from the first Meridian, measured on a Circle of Latitude that goes through a Place, is called the Longitude of the Place. 1121

Astronomers refer every thing to the Meridian of the Place in which they make their Observations. 1122

In explaining the Phænomena which relate to the several Parts of the Surface of the Earth, we shall consider the Observer going from the Pole to to the Æquator; and firſt only take Notice of the diurnal Motion.

1123 *Plate* XXIII. *Fig.* 3.] When the Spectator is at S, in the very Pole of the Earth T, the cœleſtial Æquator E *e* coincides with the Horizon, and the Pole of the World P is in the *Zenith*; in that Caſe, becauſe the Circles which are parallel to the Horizon, are alſo parallel to the Æquator; all the heavenly Bodies appear to be carried by

*1083 a Motion parallel to the Horizon, * in Circles which are repreſented by the Lines A *a*, B *b*. *The heavenly Bodies in the Hemiſphere* E P *e never ſet, and the others are never viſible. The Ho-*

1124 *rizon in this Situation is ſaid to be parallel, or this Situation is called a parallel Sphere.*

1125 *Plate* XXIII. *Fig.* 4.] *If an Obſerver* upon the Earth T *recedes from the Pole,* and is at S, *the Horizon is ſaid to be oblique, or the Sphere is oblique*; then the Axis P *p* is inclined to the Horizon *h h*, ſo much the more as the Obſerver is farther from the Pole.

DEFINITION XVII.

1126 *The Angle, which the Axis of the Earth makes*

*1105 *with the Horizon, is called* the Height of the Pole.*

1127 This *Height of the Pole is equal to the Latitude.* The Height of the Pole is the Angle P T *h*, whoſe Meaſure is the Arc P *h*; the Latitude is meaſured by an Arc, which upon the Earth cor-

*1118 reſponds to the Arc Z E in the Heavens: * But it is equal to the Arc P *h*; for the Complement of each of them, to a Quarter of a Circle, is the Arc Z P.

1128 *In this Poſition of the Obſerver,* becauſe the Æquator is inclined to the Horizon, *all the heavenly Bodies are carried by the diurnal Motion in Circles inclined to the Horizon,* repreſented by the Lines A *a*, B *b*.

Some

Some of the heavenly Bodies rise and set at every Revolution of the Earth; namely, those which are between the Parallels to the Æquator B *b* and *b i*; because all the Parallels between those Two are cut by the Horizon. 1129

The Planes of the Æquator and the Horizon go through the Center of the Earth; therefore these Circles cut one another mutually into two equal Parts, and Half of the Æquator is above the Horizon; therefore *the heavenly Bodies, which are in the Æquator, are above the Horizon during half a Revolution of the Earth about its Axis*;* and, on Account of the Equability of the Motion about the Axis, *are invisible during an equal Time.* 1130 *1082

These also rise due East, and set due West (that is, in the very Points of the East and West;) for the Section of the Planes of the Æquator and the Horizon, is perpendicular to a Plane perpendicular to both these Planes; and this last Plane is the Plane of the Meridan of the Place.* Wherefore the above-mentioned Section is perpendicular to the Meridian Line,* and consequently goes through the East and West Points.* 11 *1078 1116 *1117 *1102

Bodies between the Equator and a Parallel B *b, which touches the Horizon*, as in the Circle A *a*, *continue longer above than below the Horizon*; *and this Difference is so much the greater, the more the Circle* A *a approaches that Pole, which is above the Horizon.* On the contrary, *as the Body goes towards the opposite Pole, its Time of Continuance above the Horizon is the longer.* 1103 1132 1133

This Inequality of the Time that a Body is above and below the Horizon encreases as the Height of the Pole does, because of the Diminution of the Angle made with the Horizon by the Æquator and its Parallels. 1134

Bodies, whose Distance from the Pole is equal to the Height of it, never set; for such is the Distance 1135

of

of the Circle B *b*, which touches the Horizon, but has no Part of it below the Horizon.

Bodies, leſs diſtant from the Pole, do not ſo much as come down to the Horizon.

1136 It appears by the ſame Reaſoning, that *Bodies, whoſe Diſtance from the oppoſite Pole does not exceed the Height of the Pole*, never riſe above the Horizon, and *are always inviſible.*

1137 Bodies, whoſe Diſtance E Z from the Æquator is equal to the Height of the Pole, go through the Zenith Z; for E Z is equal to the Latitude of the Place to which the Height of the Pole is
*1126 equal. *

1138 *Plate* XXIII. *Fig.* 5.] *When a Spectator* S has receded as far as he can from the Pole, he *comes to the Æquator*, whoſe Points are equally diſtant
1075 from each Pole; then the Axis P *p* is in the Ho-
1114 rizon, with which the Æquator makes a right
1075 Angle, for which Reaſon the *Horizon is ſaid to*
1114 *be Right*; or this is called a *Right Sphere.*

The Horizon cuts into two equal Parts all the Circles, that are parallel to the Æquator, which are repreſented by the Lines A *a*, B *b*; therefore
1139 *all the heavenly Bodies, at every Revolution of the Earth, riſe, and ſet, and are viſible and inviſible during equal Times.*

1140 *The Æquator itſelf goes through the Zenith, and therefore all the Bodies that are in it paſs through it alſo.*

If what we have explained concerning the Diurnal Motion be applied to the Bodies of whoſe other apparent Motions we have ſpoken before, the Phænomena will be eaſily determined from the Motions joined together: Thoſe that relate to the Sun are more remarkable than the reſt, and therefore more particularly to be explained.

DE-

DEFINITION XVIII.

We call a Natural Day the Time elapsed between 1141
the Recess of the Sun from the Meridian of a Place, and its next Return to the same Meridian.

This Day differs from the Time of the Revolution 1142
of the Earth about its Axis, which Times would be equal, if the Sun appeared immoveable amongst the fixed Stars; but whilst by the Diurnal Motion, in the Time of one Revolution of the Earth about its Axis, the Sun is carried round from East to West, that is, *in Antecedentia*,* it is car- *1080
ried by a contrary Motion in the Ecliptic,* where- *996
by it comes later to the Meridian.

But as the Sun does not every Day go through an equal Space in the Ecliptic,* all the *Natural* *997
Days do not equally exceed the Revolution of the 1143
Earth about its Axis; therefore these Days are *unequal to one another*.

Natural Days are unequal also upon another Account, namely, by reason of the Inclination of the Ecliptic in respect to the Æquator; whence it follows, that the Annual Course of the Sun is unequally inclined to the Æquator in different Points; and, though the Sun should equally go forward every Day in the Ecliptic, the natural Days would not equally exceed the Time of the Revolution about the Axis; for if the Motion of the Sun be resolved into two Motions,* of which *192
the one is parallel to the Æquator, and the other perpendicular to it, the first is only to be considered in determining the Excess above-mentioned, and that it is unequal, is plain from the different Inclination above-mentioned.

These two Causes of Inequality often concur, and often act contrarywise.

Every Natural Day is divided into twenty-four 1144
equal Parts which are called Hours. Each Hour is

divided into sixty Minutes; and each Minute into sixty second Minutes, or Seconds; and so on. That *these Parts of Time vary in different Days,* appears
*1143 plainly from what has been * said; they are by Astronomers reduced to Equality, by considering the Number of Hours in the whole Revolution of the Sun in the Ecliptic, and dividing the whole Time into as many equal Parts as there are Hours, twenty-four of which are taken for one Day.

1145 *The Time, whose Parts are* by this Method *reduced to Equality, is called Mean Time, and that Reduction is called the Æquation of Time.*

1146 *We always make use of the Days and Hours of the Mean Time in determining the Periods of the heavenly Motions.*

Definition XIX.

1147 The Artificial Day *is the Time that the Sun stays above the Horizon.*

We always speak of it, when we mention Day
1148 in Opposition to Night. *In determining the Length of Artificial Days, we shall not attend to the Æquation of Time.*

1149 *The* Crepusculum *always comes before the Sun's*
1150 *Rise, and follows its Setting; this is that dim Light which we commonly call Morning and Evening* Twilight.

1151 *The Twilight is produced by the Atmosphere, which is enlightened by the Sun's Rays, and whose Particles reflect the Light* every Way; from whence some Rays come *to us, though the Sun be depressed eighteen Degrees below the Horizon.*

1152 *In the parallel Sphere,* that is, to all those that
*1138 dwell under the Æquator, * *the Days and Nights*
*1139 *are equal to one another all the Year round,* * and
1144 are of twelve Hours.

1153 *In the oblique Sphere the Days are longer or shorter, according to the different Distance of the Sun from the*

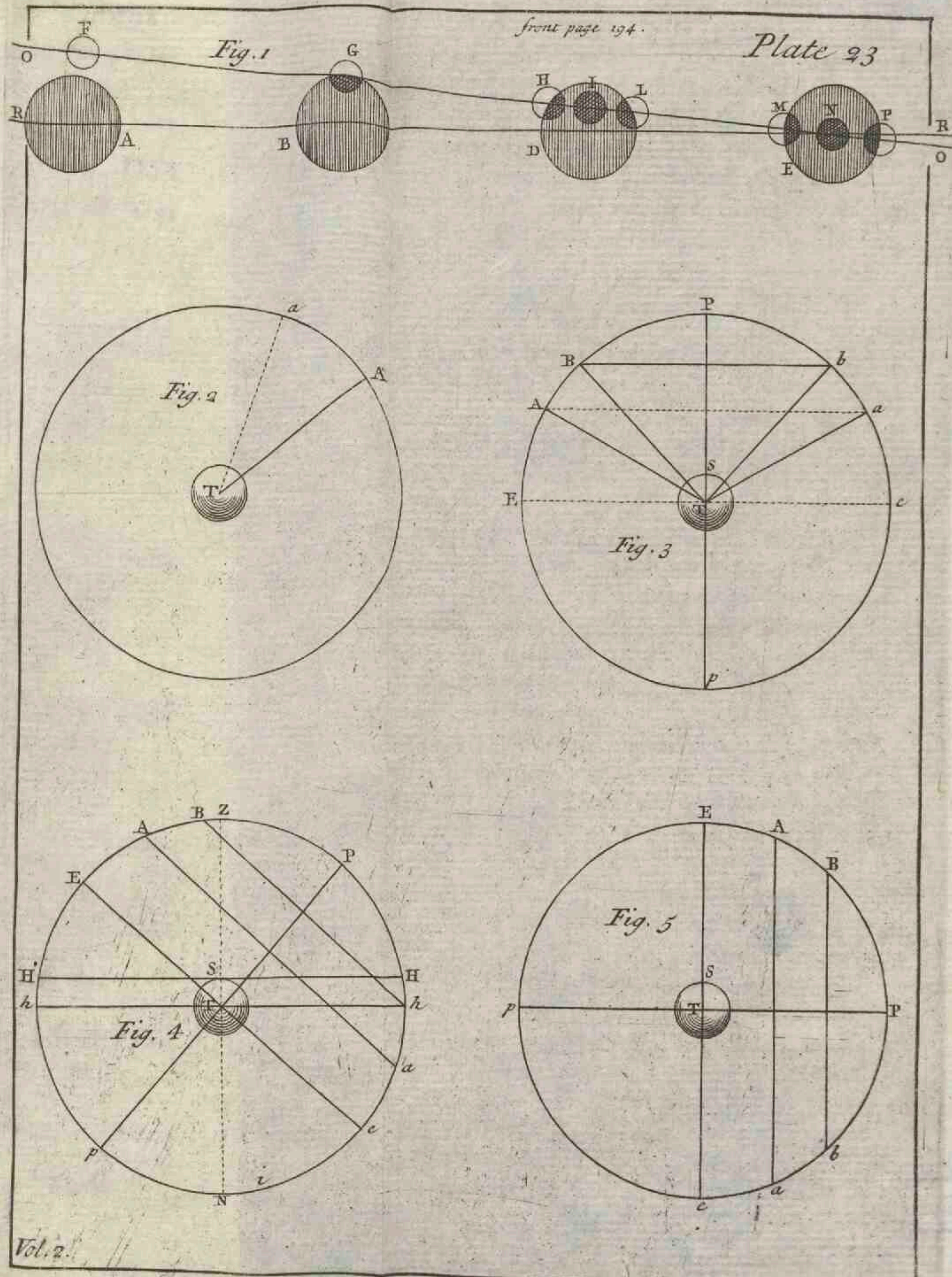
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Plate 23
Fig. 1
Fig. 2
Fig. 3
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the Æquator, towards either Pole;* for the Sun *1131
recedes from the Æquator towards the Poles 23 *1132 *1087
Degr. 29 Min.* 1088

The Sun is in the Æquator about the 11*th of* March, *and the* 12*th of* September, *and then the* 1154
Day is equal to the Night,* *which happens all* *1194
over the Earth, except just at the Poles.

Definition XX.

Those Points of the Ecliptic, in which it is cut 1155
by the Æquator,* *are called the* Æquinoctial *1085
Points; because the Sun is in those Points, when the above-mentioned Equality of Day and Night happens.

Definition XXI.

These Points of the Ecliptic, in which the Tropics touch that Circle,* *are called the* Solsticial *1089
Points; because for a few Days, when the Sun comes to those Points, and goes beyond them, it does not sensibly change its Declination, and the Length of the Days not sensibly vary.

Under the Poles, if there be any Inhabitants 1156
there, they can only once in a Year see the rising and the setting Sun, and *only one Day with one Night make up their whole Year.* The Sun continues above the Horizon all the while it goes
through one Half of the Ecliptic;* the rest of the *1085
Time it is hid under the Horizon. But yet *their* 1123 1157
Day is lengthened upon account of the Refraction;* *1113
and the Twilights last very long, for they last as long as the Declination of the Sun towards the
hidden Pole does not exceed 18 Degr.* *1151

At the Arctic Pole, in the first six Signs, from 1158
Aries to *Libra*, the Sun is above the Horizon; therefore at that Pole *the Day exceeds the Night*
nine Natural Days,* *besides the Diminution of the* *1000
*Night on Account of the Refraction.** *1157

These general Things which relate to the different Positions of the Horizon being explained, some more particular Things are to be examined.

1159 *The whole Surface of the Earth is divided into five Zones.* The first *is contained between the two Tro-*
1160 *pics* T T, *t t*, (Plate XXIV. Fig. 2.) *and called the* Torrid Zone; *there are* two Temperate Zones, *and* two Frigid Zones. The Northern Temperate Zone *is terminated by the* Tropic of *Cancer* T T, and the Arctic Polar Circle A A. The
1161 Southern Temperate Zone *is contained* between *t t*, the Tropic of *Capricorn*, and the Polar Circle
1162 *a a. The Frigid Zones are circumscribed by the Polar Circles, and the Poles are in the Centers of them.*

1163 *In the Torrid Zone, twice a Year, the Sun goes*
*1137 *through the Zenith at Noon.** For the Elevation
1160 of the Pole is less than 23 Degr. 29 Min. and the
1127 Distance of the Sun from the Æquator towards the Pole, which is above the Horizon, is twice in
1087 a Year equal to the Height of the Pole. For
1088 which Reason also in the Limits of that Zone,
1164 namely *under the Tropics, the Sun comes to the*
*1087 *Zenith only once in a whole Year.**

1089 *In the Temperate and Frigid Zones,* the least
1165 Height of the Pole exceeds the greatest Distance
1087 of the Sun from the Æquator; and therefore to
1162 their Inhabitants *the Sun never goes through the*
1162 *Zenith.** Yet *the same Day the Sun rises to a greater*
1166 *Height, the less the Height of the Pole is*; because
*1137 thereby the Inclination of the Circles of the Diurnal Motion with the Horizon is less.

1167 *In the Torrid Zone, and in the Temperate Zones,*
*1129 *every Natural Day the Sun rises and sets*; for the
1137 Distance of the Sun from the Pole always exceeds
1168 the Height of the Pole.* Yet *every where but under*
*1087 *the Æquator** *the Artificial Days are unequal to*
1160 *one another*;* which Inequality is so much the
1161 1152 *1132 greater,

greater, the less the Place is distant from a Frigid Zone. *1174

1169 But *in the Polar Circles*, just where the Temperate Zones are separated from the Frigid ones, the Height of the Pole is equal to the Distance of the Sun from the Pole, when it is in the neighbouring Tropic; * and therefore in that Case, *1089 that is, *once a Year, the Sun in its diurnal Motion* 1091 *performs one entire Revolution without going down under the Horizon.*

1170 But *every where in a Frozen Zone* the Height of the Pole is greater than the least Distance of the Sun from the Pole;* therefore, *during some Revolutions of the Earth, the Sun* is at a Distance from *1089 1162 the Pole which is less than the Pole's Height, and during all that Time, it *does not set*, nor so much as touch the Horizon.* But where the Distance *1135 from the Pole, as the Sun recedes from it, does exceed the Height of the Pole or Latitude of the Place, * the Sun rises or sets every Natural *1127 Day;* then in its Motion towards the opposite *1129 Pole, *it stays in the same Manner below the Horizon*, 1171 as was said of the Motion *above the Horizon.** *1136

These Times, in which the Sun makes entire Revolutions above the Horizon, and below it, in its diurnal Motion, are so much the greater, that is, *the longest Day and Night last the longest, the less the Place in the Frigid Zone is distant* 1172 *from the Pole*, till at last, at the Pole itself, they take up the Time of the whole Year.

Form the same Causes, namely, the Obliquity of the Ecliptic in respect of the Æquator, by which are occasioned all the Things which relate to the Inequality of Days, which is different in different Places; we also deduce the Difference of Seasons, which succeed one another every Year; I shall speak of them first in respect to the Frigid and Temperate Zones, and then in respect to the Torrid Zone.

The Rays of the Sun communicate Heat to the Air, not only when they come directly from the Sun, but when they are reflected irregularly
582 from Bodies or the Surface of the Earth.

This Effect is so much greater as the Rays strike the less obliquely against the Surface of the Earth; and that upon a double Account. 1. If you resolve the Motion of the Light into two
*192 Motions, * one of which is parallel, and the other perpendicular to the Surface of the Earth, the Light acts upon Bodies only by this last Motion, which diminishes as the Obliquity encreases. 2. There are more Rays acting at one Time upon the same Part of the Surface of the Earth, the more directly they come upon it.

1173 Hence we deduce, that *the Causes of Heat encrease when the Days encrease*, by the Sun coming towards the Pole, which is above the Horizon; because the Sun does daily ascend to a greater Height; so that to the diminished Obliquity is added the longer Continuance of the Sun above the Horizon, both which concur to the encreasing of the Heat; the Nights also are diminished as the Days encrease, and the Height that is produced by Day has less Time to decrease in.

In the Northern Zones, as follows from this, the Cause of the Heat is the greatest of all when
*1090 the Sun comes to the Tropic of *Cancer*.* *Yet the*
1174 *Heat is not always the greatest where the Cause of Heat is the greatest*; for the Heat encreases as long as that which is acquired by Day is not wholly destroyed by Night; for though the daily Agumentations be diminished, as long as there is an Augmentation the Heat encreases.
1175 The most intense Cold is not upon the shortest Day,

Day, in which the Obliquity of the Sun's Rays is the greateſt, and the Abſence of the Sun the longeſt; but the Cold encreaſes, as long as the Diminution of Heat does laſt; concerning which one may reaſon in the ſame manner as concerning the Encreaſe of Heat.

The Year is divided into four Seaſons; the hotteſt 1176
is called the Summer; the coldeſt the Winter; the temperate Seaſon that follows the Winter, Spring; and the Autumn comes in between Summer and Winter.

In the Northern Regions, in the Beginning of 1177
Spring, the Sun appears to be in the Beginning of Aries. *In the Beginning of Summer the Sun comes to the Tropic of* Cancer. *When the Sun enters* Libra, *the Autumn begins. In the Beginning of Winter the Sun performs its diurnal Motion in the Tropic of* Capricorn; all which may be eaſily deduced from 1174
what has been explained.* *1175

In the Southern Regions, the Summer happens 1178
in the Time of the Winter above-mentioned, and they have their Spring whilſt the former have their Autumn; and ſo of the other Seaſons.

The general Cauſes, upon which the Diviſion above-mentioned depends, are often diſturbed by Cauſes relating to particular Places; eſpecially *in* 1179
the Torrid Zone, of which we ſaid we muſt treat of ſeparately. In moſt Places of this Zone *there are only two Seaſons obſerved*, (viz.) *Summer and Winter, which are* chiefly *diſtinguiſhed by dry and wet Weather.*

When the Sun comes to the Zenith of any Place, 1180
there are almoſt continual Rains; upon which Account *the* Heat is diminiſhed, which *Time is referred to, or called Winter.* As the Sun recedes, the Rains diminiſh, *the Heat is encreaſed, and that* 1181
Time is referred to Summer.

1182 *In the Middle of the Torrid Zone there are two Summers, and as many Winters; because the Sun*
*1163 *comes up twice to the Zenith.* *

Towards the Sides of the Zone, tho' the Sun comes twice to the Zenith, yet ſince there is but a ſmall Time between its coming to it the firſt and ſecond Time, both the Winters are confounded into one; wherefore only two Seaſons in a Year are obſerved there.

CHAP. IX.

Concerning the Phænomena ariſing from the Motion of the Axis of the Earth.

*952 WE have ſaid that the Axis of the Earth is carried by a parallel Motion *; we have not conſidered a ſmall Motion, whereby it is really moved, of which we ſhall now ſpeak.

The Axis of the Earth, keeping the Inclination
1183 *of* 66 Degr. 31 Min. *to the Plane of the Ecliptic, revolves in* Antecedentia, that is, is ſucceſſively
1184 carried towards all Parts; and its Extremities, (*viz.*) *the Poles of the World deſcribe Circles round the Poles of the Ecliptic*, from Eaſt to Weſt. *And this Revolution is performed in the Time of about* 25000 *Years; which Period is called the Great Year.*

Becauſe the Earth is looked upon as immoveable by its Inhabitants, this Motion is referred to the heavenly Bodies, as has been ſaid of the other Motions. Therefore whilſt the Poles of the World are moved about the Poles of the Ecliptic in *Antecedentia*, and paſs ſucceſſively thro' all the Points that are 23 Degr. 29 Min. diſtant from theſe Poles, theſe Points themſelves, or rather the

the fixed Stars that are in them, come towards the Poles of the World successively, and seem to be carried in *Consequentia*, and to describe Circles which are really described by the Poles of the World about the Poles of the Ecliptic, which, being placed in Centers, alone are at rest. For together with the Stars above-mentioned the rest of the Stars (because they keep the same Situation in respect to one another) * do also ap- *923
pear to be moved.

Therefore *the* whole *Sphere of the fixed Stars* 1185
seems to move, in Consequentia, *about an Axis passing through the Poles of the Ecliptic*; and each Star apparently describes a Circle parallel to the Ecliptic; by which Motion the Latitude of the Stars is not changed.

The Plane of the Æquator makes a right Angle with the Axis of the Earth; therefore, by the aforesaid Motion of its Axis, the Section of the
Plane of the Æquator, with the Plane of the 1186
Ecliptic, is moved round; wherefore *the first*
Points of Aries *and* Libra *, which are always op- *1085
posite, *move through the whole Ecliptic Line in the Space of about* 25000 *in* Antecedentia: Yet they they are looked upon as immoveable by the Inhabitants of the Earth, who imagine that the fixed Stars themselves are moved in *Consequen-* *1185
tia. *

CHAP. X.

Concerning the fixed Stars.

WE have said that the fixed Stars are lucid Bodies, removed so far off, that their Distances can be compared with no Distances in the

1187 the Planetary Syſtem. For *Aſtronomers have not been able, by their niceſt Obſervations, to obſerve the Poles of the World carried out of their Place in the annual Motion of the Earth*, although they deſcribe Circles in the Heavens which are equal to
952 the Earth's Orbit.

DEFINITION I.

1188 This Motion of the Pole is called *the Annual Parallax.*

That the fixed Stars are at an immenſe Diſtance, is alſo proved by Obſervations with the Help of
1189 Teleſcopes. *If any fixed Star*, even the lucid and conſpicuous, *be beheld with a Teleſcope*, through which the Diameter of the Sun would appear equal to the Diameter of the Earth's annual Orbit, *it will appear to be a lucid Point, without any ſenſible Magnitude*; for all the fixed Stars appear leſs when they are ſeen through Teleſcopes than they do to the naked Eye; for it is only their Twinkling which makes them appear to have any ſenſible Magnitude.

1190 *That the Stars may be diſtinguiſhed, they are referred to various Figures, which are imagined in the Heavens, and are called Conſtellations.*

1191 *Twelve Conſtellations are imagined to be in the Zodiac, which are called the Sines of the Zodiac*; they receive their Names from the Animals or
1192 Things which they repreſent: *Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, Piſces. Theſe* Signs have *given their Names to twelve Parts of the E-*
*999 *cliptic*, of which we have ſpoken before.*

In the Time of *Hipparchus*, the Sections of the Ecliptic and Æquator were between the Conſtellations of *Piſces* and *Aries*, and *Virgo* and *Libra*, and the Conſtellations gave their Names to thoſe Parts

Parts of the Ecliptic, which paſſed through each Conſtellation. *And the Parts of the Ecliptic, ſuppo-* 1193
ſing the Beginning of Aries *and* Libra, *in the Interſections of the Æquator and the Ecliptic, have kept the Names which they had* at that Time, *tho' theſe Interſections be carried from their old Places*; * *1186
whence the Sun is ſaid to be in *Taurus*, when it moves amongſt the Stars of the Conſtellation *Aries*.

The Zodiac ſeparates the North Part of the Heavens from the South Part.

In the Northern Region are the following Conſtel- 1194
lations; the leſſer Bear, the greater Bear, the Dragon, Cepheus, the Hounds, Bootes, the Northern Crown, Hercules, the Harp, the Swan, the Lizard, Caſſiopeia, Camelopardus, Perſeus, Andromeda, the Triangle, the leſſer Triangle, the Fly, Auriga, Pegaſus, or the Flying-Horſe, Equuleus, the Dolphin, the Fox, the Gooſe, the Arrow, the Eagle, Antinous, Sobiesky's Shield, Serpentarius, the Serpent, Mount Mænalus, Berenice's Hair, the leſſer Lion, the Linx.

In the Southern Region of the Heavens, are the following Conſtellations, many of which are inviſible 1195
to us: * *namely the Whale, the River Eridanus, the* *1131
Hare, Orion, the great Dog, Rhinoceros, the leſſer Dog, the Ship Argo, Hydra, the Sextant of Urania, the Cup, the Crow, the Centaur, the Wolf, the Altar, the Southern Crown, the Southern Fiſh, the Phœnix, the Crane, the Indian, the Peacock, the Bird of Paradiſe, the Southern Triangle, the Croſs, the Fly, the Chamæleon, King Charle's *Oak, the flying Fiſh, the* Toucan, *or* American *Gooſe, Hydrus, or the* Water-Serpent, *Xiphias, or* the Sword-Fiſh.

Definition II.

The Stars, which are between the Conſtellations, 1196
are called unformed Stars.

The Stars are not equally lucid, and they are 1197
referred by Aſtronomers *to ſix Claſſes*, the moſt lucid

cid are called Stars of the firſt Magnitude; others are ſaid to be Stars of the ſecond Magnitude, others of the third, &c. to the ſixth Magnitude.

1198 *Some are not referred even to this laſt Claſs, and are called Nebulous Stars.*

1199 *There is* alſo *a* certain *Zone* or Belt obſerved *in the Heavens, which* is not every where of the ſame Breadth, and goes round the whole Heavens, and in ſome Places is ſeparated, ſo as to become dou-
1200 ble. From its Colour it *is called the milky Way. It* is plain from Obſervations, by the Help of the Teleſcope, that this Way is *an Aſſemblage of innumerable fixed Stars, which cannot be ſeen by the naked Eye,* either becauſe they are leſs than the other Stars, or more diſtant.

1201 *Towards the Antarctic Pole there are two Nubeculæ, of the ſame Colour as the Milky Way, which are alſo Heaps of ſmall Stars,* and cannot be ſeen without a Teleſcope. Beſides the Stars, which are obſerved in theſe Nubeculæ, and in the Milky
1202 Way, *to whatſoever Part of the Heavens you point the Teleſcope, you may diſcover ſmall Stars in a great Number, which are not viſible to the naked Eye.* Very often an Heap of Stars appears to the naked Eye to be but one Star.

1203 *Amongſt the Stars, ſome are viſible and inviſible by Fits, and obſerve regular Periods*; others are ſucceſſively ſometimes more lucid, ſometimes of a duller Light, and to be ſeen only by the Help of a Teleſcope, and that at certain Times.

1204 Yet *they are not equally bright at every Period. Sometimes Stars have appeared ſuddenly, exceeding the brighteſt in Light, which afterwards, ſucceſſively decreaſing, have vaniſhed in a ſhort Time, and ſtill remain inviſible.*

1205 Beſides the Stars, *we obſerve in the Heavens ſeveral whitiſh Spots, which are in ſome Meaſure lucid, and*

and inviſible to the naked Eye; their Light is referred to the Stars which are in them, or they are looked upon as nebulous Stars.

What theſe Spots are, cannot be determined; perhaps they are a Congeries of Stars, which have the ſame Relation to the Teleſcopic Stars, as thoſe which form the Milky Way, have to thoſe which are ſeen to the naked Eye.

BOOK IV.

PART II.

The Phyſical Cauſes of the Celeſtial Motions.

CHAP. XI.

Concerning univerſal Gravity.

HAving explained the Motions of the heavenly Bodies, and the Phænomena ariſing from them, we muſt now examine by what Laws theſe Motions are performed.

We have before laid down the Laws according
124 to which the Motions of Bodies are directed.
125 If we add one to theſe, we ſhall ſee the whole
126 Contrivance by which that vaſt Machine, the
Planetary Syſtem, is governed.

1206 The Law, to be added to the reſt, is this. *All Bodies are mutually heavy* (or gravitate) *towards*
1207 *each other. This Gravity is proportional to the Quan-*
1208 *tity of Matter: At unequal Diſtances it is inverſly as the*

the Square of the Diſtance: That is, all Bodies mutually attract or tend towards each other, with the Force which belongs to each Particle of Matter acting upon each Particle; and the Force, with which a Body acts upon others, is compounded of the joint Forces of all the Particles of which the Body conſiſts; ſo this Force encreaſes in the ſame Proportion as the Quantity of Matter, and is unchangeable in every Particle; it is always the ſame at the ſame Diſtance; but the Diſtance encreaſing, the Force decreaſes as the Square of the Diſtance encreaſes.

We call this Force Gravity, when we conſider a 1209
Body which of itſelf tends towards another; becauſe this Force is called by this Name near the Earth's Surface.* *73

But when we conſider a Body, towards which an- 1210
other tends, we call this Force Attraction. We mean the ſame Effect by theſe Names, and nothing but the Effect; for ſince all Gravity is reciprocal, * it *126
is the ſame to ſay, all Bodies gravitate mutually towards one another, as that Bodies mutually attract one another, or mutually tend towards each other.

We look upon this Effect as a Law of Nature*, *4
becauſe it is conſtant, and its Cauſe is unknown to us, and cannot be deduced from Laws that are known, as we ſhall ſhew by and by. Now, that there is ſuch a Gravity, is to be proved from Phænomena.

All the Primary Planets are kept in their Orbits by Forces, which tend towards the Center of the Sun*; therefore there is a Force by which *944
the Planets are carried towards the Sun, and 226
whereby the Sun tends reciprocally towards each of them*: *That is, the Sun and Planets gravi-* 1211
tate mutually towards each other. *126

After

1212 After the ſame Manner it is plain, that *the Satellites of Jupiter and Saturn gravitate towards each*
*966 *other*; *as alſo that the Satellites of Saturn gravi-*
226 *tate towards their Primary Planet, and that towards*
126 *them.**

1213 *The Moon and the Earth* alſo *gravitate towards*
*966 *each other.**

226 *All the Secondary Planets gravitate towards*
126 *the Sun.* For they are all carried by a regular
1214 Motion about their Primary Planets, as if the Primary Planets were at reſt; whence it is plain, that they are carried about by the common Motion with the Primary Planets; that is, that the ſame Force, by which the Primary Planets are every Moment carried towards the Sun, acts upon *the Secondary ones*, and that they *are carried towards*
1215 *the Sun with the ſame Celerity as the Primary Planets.* Even the Irregularities of the Secondary Planets, which are ſo ſmall, as only to be ſenſible with reſpect to the Moon, confirm this Gravity of the Secondary Planets towards the Sun; for we ſhall ſhew hereafter, that all the Irregularities are cauſed by the Change of the Moon's Gravity towards the Sun, at a different Diſtance; and becauſe the Lines, in which the Earth and Moon tend towards the Sun, are not altogether parallel.

1216 From the Gravity of the Secondary Planets towards the Sun, it follows, that *the Sun gravitates*
*126 *towards them.**

1217 In reſpect of the Gravitation of the Primary Planets towards one another, Aſtronomers have obſerved, that *Saturn* changes its Way when it is neareſt to *Jupiter*, which is far the greateſt of all the Planets; ſo that it is plain from immediate Obſervations, that *Jupiter and Saturn gravitate towards each other.*

Jupiter

Jupiter alſo in this Caſe, as *Flamſteed* has ob- 1218
ſerved, diſturbs the Motion of *the Satellites of* Sa-
turn, attracting them a little to itſelf; which
proves that theſe Satellites *gravitate towards* Ju-
piter, *and* Jupiter *towards them.* From all which
Conſiderations * compared together, it follows, *1211
that the ſeventeen Bodies, of which the Planetary 1212,
Syſtem is made up, mutually gravitate towards 1213, 1214,
each other, although no immediate Obſervations 1216,
can be made concerning the Gravitation of each 1217,
particular one towards the reſt.* 1218. *7

The ſecond Part of the Law is,* that Gravity *1207
is proportional to the Quantity of Matter; that is, that all the Particles of Matter gravitate towards each other; and therefore that the Law of Gravity is univerſal, and that every Body acts upon all other Bodies; which is deduced from Phænomena.

The Forces of Gravity are as the Qualities of 1219
Motion which they generate, * and theſe Quan- *58
tities, in unequal Bodies that are equally ſwift, are
to one another as the Quantities of Matter;
therefore ſince unequal Bodies, at the ſame Di- *62
ſtance from the attracting Body, move equally
ſwift by Gravity, * it is evident, that the *1215
Forces of Gravity are proportional to the Quan-
tity of Matter. We find the ſame in all Bodies 1220
near the Earth's Surface, which have a Gravita-
tion towards the Earth, proportional to their
Quantity of Matter.* But *the mutual Gravity* *79
of all theſe *Bodies towards one another is not ſen-*
ſible; becauſe it is exceeding ſmall in reſpect of
their Gravity towards the Earth; and therefore
cannot diſturb their Motion ariſing from their
Gravity towards the Earth; * at leaſt, ſo as to *190
make any ſenſible Change in the Direction of
their Motions.

We ſhall preſently ſhew, by another Method, that this univerſal Gravity of all the Particles of Matter, whereby they act upon one another,
1222 may be proved from Phænomena.

The third Part of the Law, which we examine, is, that Gravity decreaſes when the Diſtance encreaſes, and is inverſly as the Square of the Diſtances, which alſo follows from Phænomena.

1221 Bodies, upon which Gravity acts according to their Quantity of Matter, as in our Syſtem, are moved with an equal Celerity in the ſame Circumſtances, as we ſaid before; ſo that it is no Matter, whether the Bodies are greater or leſs; and they are moved as if they were equal. But in this Caſe, if the Force towards a Point decreaſes in an inverſe Ratio of the Square of the Diſtance from that Point, and the Bodies move at various Diſtances from it, and are kept in Circles by that Force; the Squares of the Periodical Times will be to one another, as the Cubes of the Di-
239 ſtances. Which is demonſtrated by Geometers to obtain (in reſpect of the mean Diſtances) in Elliptic Lines, whoſe Forces are directed to their *Foci.* But this is the Caſe in Bodies which revolve about the *Sun*, *Saturn* and *Ju-*
*974 *piter*; * whence it follows, that the Force of Gravity, receding from the Centers of theſe Bodies, decreaſes in an inverſe Ratio of the Squares of the Diſtances.

1222 By this Reaſoning, ſuppoſing Gravity proportional to the Quantity of Matter, we demonſtrate, that it decreaſes in an inverſe Ratio of the Square of the Diſtance. And by the ſame Reaſoning, ſuppoſing the Diminution of Gravity to be in this Proportion, it follows, that Gravity is proportional to the Quantity of Matter, as is very evident.

But we prove by another Argument, that the Diminution of Gravity, so often mentioned, is in an inverse Ratio of the Square of the Distance; so that there can remain no Doubt concerning the two Laws of Gravity, which we now treat of.

The Planets are moved in Orbits at rest*; *1223
and are kept in them by Forces, which are di- *929
rected to an Excentric Point; * but it is plain, *931
that this would not obtain, if the central Force
did not encrease in an Inverse Ratio of the Square *141
of the Distance.* 243

It follows from the same Reasoning, that re- 1224
ceding from the Center of the Earth, Gravity de-
creases according to the same Law. For the
Moon is retained in its Orbit by a Force which
tends towards the Center of the Earth, that is,
to an Excentric Point.* And though the Line of *967
the Apsides is not carried by a parallel Motion, 966
its Agitation is so small, if we consider every 226
Revolution, that it may be looked upon here as quiescent: For if we compute the Force which keeps the Moon in its Orbit so agitated, we shall find the Diminution of the Force of Gravity, in respect of the Moon, to differ very little from an Inverse Ratio of the Square of the Distance; and we shalll shew hereafter, that this Difference depends upon the Action of the Sun.

And no Doubt will remain concerning this 1225
Diminution, if we consider, *that the Moon is kept in its Orbit by that very Force, wherewith Bodies are carried towards the Earth, near the Earth's Surface*; which is diminished, according to the Law of Diminution so often mentioned. The Mean Distance of the Moon is 60½ Semidiameters of the Earth: We have before shewn, that a Diameter of the Earth contains 3400669 *Rhynland* Perches; * whence knowing the Periodical Time, *976

we eaſily diſcover that the Moon, in one Minute
of Time, goes through 16425 $\frac{1}{2}$ *Rhynland* Per-
ches of her Orbit. This Arc is not the hun-
dredth Part of one Degree, and may be looked
upon as its Subtenſe; therefore the Diameter of
its Orbit is to this Arc, as the Arc itſelf is to its
Verſed Sine; which is diſcovered to be of 15,
736 *Rhynland* Feet; and it is the Space which
the Moon and Earth would go through in one Mi-
nute, coming to one another by their mutual
Attraction. The Celerity with which a Body
comes to another by the Force of Gravity, de-
pends upon the Force with which it is attracted
by that other, all whoſe Particles of Matter at-
tract it; therefore the Celerities of the Moon
and Earth, as they come towards each other,
are inverſly as the Quantities of Matter in them;
which is alſo deduced from the equal Quantity of
126 Motion that is in each Body. Therefore by
65 this Proportion we diſcover how much of the
aforeſaid Space (15, 736 Feet) is gone through
by the Moon: As the Quantity of Matter, in both
Bodies, is to the Quantity of Matter in the Earth;
ſo is the Space gone through by both Bodies, in
their mutual Acceſs towards each other, to the
Way gone through by the Moon only. The
Quantities of Matter in the Moon and in the
Earth, as we ſhall ſhew hereafter, are to one
another as 1, to 39, 37; and 40, 37, is to 39,
37, as 15, 736 to 15, 344, the Space gone thro'
by the Moon; which therefore would be gone
through in one Minute by any Body, which at the
Moon's Diſtance ſhould be impelled by Gravity
towards the Earth. This Force increaſing in an
Inverſe Ratio of the Square of the Diſtance
from the Center, the Space gone through in the
ſame Time at the Diſtance of a Semidiameter
of the Earth, that is, on its Surface, will be

60 $\frac{1}{2}$

$60\frac{1}{2}\times60\frac{1}{2}\times15{,}344$, (*viz.*) 56158 Feet; but because in every Motion equably accelerated, as here (for we consider the Force as removed from the Earth's Center to the Distance of its Surface) the Squares of the Times are as the Spaces gone through in the Fall;* by dividing the Number by *131 60 × 60, that is 3600; we have the Space gone through by a Body in one Second, near the Earth's Surface, by the Force with which the Moon is kept in its Orbit, which is discovered to be 15, 6. *Rhynland* Feet.

Now if we examine the Gravity which we daily find in all Bodies near the Earth's Surface,* *72 it is plain, from what has been said concerning the Motion of Pendulums,* and from Experi- *157 ments made upon Pendulums, that a Body in 158 falling goes through 15, 6. *Rhynland* Feet in one Second of Time, and therefore falls with the Force by which the Moon is kept in its Orbit.

In this Computation we have neglected to consider the Action of the Sun, because it is small, and sometimes encreases, sometimes diminishes the Gravity of the Moon towards the Earth.

We have considered the Centers of the Bodies in examining the Law of the Diminution of Gravity, although Gravity belongs to all the Particles of Bodies; because it is plain by Mathematical Demon-
stration, that *the Action of a spherical Body (in* 1226
which, in every Part, the Particles, that are equally distant from the Center, are homogeneous, and which is made up of Particles, towards which there is a Gravity that decreases, receding from each of them in an Inverse Ratio of the Square of the Distance) is directed towards the Center of the Body, and receding from it, is diminished in the same Inverse Ratio of the Square of the Distance: So that such a Body

acts, as if all the Matter, of which it consists, was collected in its Center. Whence we deduce the following Conclusions.

1227 That *on the Surfaces of Bodies, in which the Matter is homogeneous at equal Distances from the Center, the Gravity is directly as the Quantity of*
*1207 *Matter, and inversly as the Square of the Diameter*;*
1208 for in these Bodies the Distances from the Center are as the Diameters.

1228 That *on the Surfaces of Bodies that are spherical, homogeneous, and equal, the Gravities are as the Densities of the Bodies*; for the Distances from the Center are equal; in which Case the Forces of
1207 Gravity are as the Quantities of Matter; which,
228, in equal Bodies, are as their Densities.
79 That *on the Surfaces of the Bodies, that are sphe-*
1229 *rical, unequal, homogeneous, and equally dense, the Gravities are* inversly as the Squares of the Diame-
1208 ters; because the Distances from the Center are
*1207 *in the Ratio* of those Diameters,* the Gravities also are directly as the Cubes of their Diameters; for the Quantities of Matter in Spheres are in that Ratio: And the Ratio compounded of that direct Ratio of the Cubes of the Diameters, and the inverse Ratio of their Squares, in the direct Ratio *of the Diameters themselves.*

1230 Therefore *if both the Densities and the Diameters differ, the Gravities on the Surface will be in a*
*1228 *Ratio compounded of the Densities* and the Diame-*
*1229 *ters.** Therefore dividing the Gravity on the Surface by the Diameter, you will have *the Den-*
1231 *sity*; which consequently *is in a direct Ratio of the Gravity on the Surface, and an Inverse Ratio of the Diameter.*

1232 *If a Body be placed in a Sphere that is homogeneous, hollow, and every where of the same Thickness*, wheresoever it be placed, *it has no Gravity*, the opposite Gravities mutually destroying one another

another precisely: Whence it follows, that *in an* 1233
homogeneous Sphere, a Body, coming towards the
Center, gravitates towards the Center only from
the Action of the Sphere, whose Semidiameter
is the Distance of the Body from the Center,
which *Gravity decreases in coming towards the
Center, in the Ratio of the Distance from the Cen-* *1229
ter; for all Matter, which is at a greater Distance
from the Center, forms an hollow Sphere, in
which the several Actions on a Body destroy each
other.* *1232

We have said that the Gravity, which we have
hitherto explained, is to be taken for a Law of
Nature, because we don't know the Cause of
it; and because it depends upon no Cause that
is known to us, which will evidently appear, if
we attend to what follows.

(Viz.) That *Gravity requires the Presence of* 1234
the attracting Body; so the Satellites of *Jupiter*,
ex. gr. gravitate towards *Jupiter*, wheresoever it
be.* *1212

That *the Distance remaining the same, the Cele-* 1235
*rity with which Bodies are carried by Gravity, de-
pends upon the Quantity of Matter in the attract-* *1207
ing Body: And that the Celerity is not changed, let* 1236
*the Mass of the gravitating Body be what it will.** *1207

Besides that, *if Gravity depend upon any known* 1237
*Law of Motion, it ought to be referred to a Stroke
from an extraneous Body*; *and* because Gravity is
continual, *a continual Stroke would be required.*

If there be such a Sort of Matter continually
striking against Bodies, it must of Necessity be
fluid, and very subtile, so as to penetrate all Bo-
dies; for Bodies, that are any how shut up in
others, are heavy.

Now let a Mathematician consider, whether
a Fluid so subtile as freely to penetrate the Pores
of all Bodies, and so rare, as not sensibly to hin-

der the Motion of Bodies (for in a Place void of Air, the Motion of a Pendulum will be continued very long) can impel vaſt Bodies towards one another with ſo much Force? Let him explain how this Force increaſes in a Ratio of the Maſs of the Body towards which another is car-
1235 ried.

Laſtly, Let him ſhew, what ſeems moſt difficult to me, how all Bodies, in any Situation whatſoever (if the Diſtance, and the Body to-
1236 wards which the Gravitation is, remain the ſame) are carried with the ſame Velocity; that is, how a Liquid which can only act on the Surfaces, either of the Bodies themſelves, or their internal Particles, to which it is not hindered from coming by the Interpoſition of other Particles, can communicate ſuch a Quantity of Motion to Bodies, which in all Bodies exactly follows the Proportion of the Quantity of Matter in them; and which in this Chapter we have proved to obtain every where in Gravity, and which we have
*77 demonſtrated by a direct Experiment, in reſpect
1238 of the Gravity near the Earth's Surface.*

Yet we don't ſay, that *Gravity does not depend upon any Stroke*, but that it does not follow from that Stroke, *according to any Laws known to us*, and we confeſs that we are entirely ignorant of the Cauſe of Gravity.

CHAP. XII.

Of the Celeſtial Matter; *where* a Vacuum *is proved.*

HAVING explained the Laws whereby the whole Planetary Syſtem is governed, ſeveral Things muſt be firſt laid down, before we proceed to the Phyſical Explication of the Syſtem.

Syſtem. We muſt begin, by ſaying ſomething of the Celeſtial Matter, that is, of the Medium in which the Bodies that make up the Syſtem are moved, which would be done in few Words, if all Philoſophers agreed that there is a *Vacuum*.

We have before proved that a *Vacuum* is poſſible ;* now we are to demonſtrate that there is *13
really one. *From only conſidering Motion we can* 1239
deduce a Vacuum; and this is a very common and uſual Way of proving it: To ſee the Force of which Argument, we muſt conſider, that indeed all Motions are not impoſſible without a *Vacuum*, but moſt of thoſe which are daily obſerved; which might be fully evinced by a longer Diſcuſſion: But it ſeems to me to be ſo evident from the following Conſideration, that it would be uſeleſs to add much more.

The Figure of the leaſt Particles is unchangeable; for the Particle, whoſe Figure may be changed, conſiſts of ſmaller Particles, which are moved in reſpect to each other; and therefore if it has a changeable Figure, it is not one of the leaſt Parts.

But if the Figure of theſe Particles be unchangeable, and a Body can move between them, without ſuch a Separation of the Particles as to leave a void Space, this will depend on the Figure of the Particles, and the Relation which they have to one another, which a Mathematician will not deny: Therefore, if keeping Things in this State (as to their Figure and Relation) the Particles are encreaſed, even in that Caſe Bodies may be moved without a *Vacuum*.

Now ſuppoſing the ſmalleſt Particles encreaſed to the Bigneſs of a Cubic Foot, whatever be their Figure and Relation with the other Parts, which we ſuppoſe encreaſed in the ſame Proportion as the firſt; let any one conſider, whether

Bodies

Bodies of any Bigneſs can be carried between thoſe Parts in Right Lines, and in all ſorts of Curves, and yet never ſeparate the Particles ſo as to leave Vacuities between them.

We cannot conceive how the moſt ſubtile Parts are made, and therefore often attribute to them ſuch Properties as do not follow from their Figure; but theſe Errors will be corrected, by imagining the Particles encreaſed.

1240 *We alſo prove a* Vacuum *by an Argument taken from Reſiſtance.*

12 We have ſaid that Matter is inactive; ſome diſpute about the Word, but no Man denies the Thing; whence it follows, that a Body cannot move through a Fluid, without undergoing a Re-
319 ſiſtance, and conſequently a Retardation.* The
*330 Reſiſtance ariſing from the *Inertia* of the Matter (which Reſiſtance alone is here conſidered) depends upon the Quantity of Matter to be removed out of its Place, which is the ſame, whether the Parts of a Fluid be greater or leſs, if the Celerity of the Body remains the ſame: Whence it follows, that in determining what relates to the Reſiſtance, we muſt have no Regard to the Subtility of the Fluid, as long as it cannot go through the Pores of Bodies; for if we come to ſuch a Fineneſs of Parts, that a Fluid ſhall partly penetrate a Body, it will leſs reſiſt the Body.

Now let us ſuppoſe any Ball or ſpheric Body to be moved along in a Medium of the ſame Denſity as itſelf, and ſo cloſe, that the Parts of the Medium cannot paſs through the Pores of the Body; this Body will be retarded every Moment, ſo that its Velocity at laſt will be reduced to half (as may be proved by a Mathematical Demonſtration) before the Body has gone through twice the Length of its Diameter.

In

In order to apply this Propoſition to a Motion in a very ſubtile Fluid, which freely penetrates the Pores of all Bodies, and fills all Places, we muſt conceive a ſpherical Body without any Pores at all; and that ſuch a Body may be ſuppoſed by imagining all the Particles of Matter cloſely joined, no body will deny.

That the Reſiſtance of ſuch a Body in any Fluid does not depend upon the Bigneſs of the Parts of the Fluid, and is the ſame, whether the Parts of the Fluid be equal, or any how unequal, is evident.

If every thing be full of Matter, this Body can only move through a Fluid of the ſame Denſity as itſelf; for it muſt run againſt all the Matter which is in thoſe Places through which it paſſes, and in them the Matter is without Interſtices as it is in the Body; therefore it will loſe half its Velocity, before it has run through the Length of twice its Diameter.

Now let us ſuppoſe the Body to be encreaſed, the Quantity of Matter remaining the ſame, and the Body continuing homogeneous; that is, let there be Pores in the Body, through which the moſt ſubtile Particles of Matter may paſs very freely; and let theſe Pores be equally diſperſed all over the Body. If the Body, thus changed, be moved, the very ſubtile Fluid, of which we ſpeak, will not run againſt the whole Surface, but only thoſe Parts of the Surface which are between the Pores, which Parts being taken together, becauſe we ſuppoſe the Body homogeneous, are equal to the Surface of the Body in the firſt Suppoſition, when we conceived it to be without Pores; for the Body being encreaſed, the Surface has not been changed, but only dilated by the Interpoſition of Pores: So that in both Caſes the Body will undergo the ſame Reſiſtance

ſiſtance from the Impulſe upon the Surface; and the Reſiſtance on the dilated Body is greater from the Fluid running againſt the internal Parts of the Body. Wherefore this Body will ſooner loſe half its Motion in the ſecond, than in the firſt Caſe; that is, before it has run through the Length of two Diameters of the firſt ſuppoſed Bigneſs; and therefore it loſes a greater Quantity of Motion, in going through two Diameters of the Bigneſs ſuppoſed in the ſecond Caſe.

But this is contrary to Experience; for a homogeneous Ball of Gold, or Lead, *&c.* loſes a much leſs Quantity of Motion than what we have mentioned, in Water or Air; whence it follows, that the Suppoſition that all Things are full of Matter, is falſe. Therefore there is a *Vacuum.*

1241 *That there is a* Vacuum *does* alſo *agree with the Phænomena relating to Gravity*; by which it follows that it is proportional to the Quantity of Matter. If all was full of Matter, Gravity would act equally every Way, and the Forces which are directed towards oppoſite Parts would deſtroy one another; and therefore no ſenſible Gravity would be obſerved, which is contrary to Experience.

Theſe being premiſed, we muſt return to the Celeſtial Matter.

1142 The Motions of the heavenly Bodies do not depend upon the Motion of the Celeſtial Mat-
1238 ter, if there be ſuch a Matter;* *whereby is overthrown the Opinion of thoſe which ſay that the heavenly Bodies are carried along by the common Motion of the Matter which fills our Syſtem.* This Opinion is alſo overthrown by the Motion of the Comets: If there was a Medium in the Syſtem which carried about the Planets in its Motion, and alſo the Comets, it would at leaſt ſenſibly diſturb theſe laſt in their Motions, whilſt they

come almoſt directly towards the Sun, or directly recede from it, or are carried in *Antecedentia*; that is, in a Motion contrary to the Motion of that Matter. Now as this Motion is not diſturbed, but follows the Way which depends upon Gravity, as it is obſerved, it is plain, that if there be any Celeſtial Matter, and that it is in Motion, it does not exert a ſenſible Action on the Bodies of the Planetary Syſtem, which is alſo deduced from the ſmall Reſiſtance of ſuch a Medium; for by comparing the moſt ancient Obſervations with the modern, it does not appear that the Planets are ſenſibly retarded in their Motions. Yet in Air the Reſiſtance is ſenſible; wherefore the Denſity of the Medium, in which the Planets ſhould move, muſt be almoſt immenſly leſs; therefore *the Planetary Syſtem is not* 1243
filled, *unleſs* it be *by* ſuch *a ſubtile Medium*.

But we may from the Diviſibility of Matter deduce, that a Quantity of Matter, how ſmall ſoever it be, may be diſperſed all over the Planetary Syſtem, leaving but very ſmall Interſtices. * *29

CHAP. XIII.

Concerning the Motion of the Earth.

BESIDES the Queſtion that has been handled in the foregoing Chapter, there is alſo another to be examined, before we proceed to the Explication of the whole Syſtem.

That no Doubt may be made concerning the Syſtem, which has been explained in the firſt Chapter of this Book, we muſt here prove the Motion of the Earth, concerning which it is no Wonder that many have doubted; for the Celeſtial

leſtial Motions cannot be determined by us, but by Obſervations made by Obſervers on the Earth; and the ſame Phænomena appear, whether the Bodies themſelves be moved, or the Spectator
993 be moved; ſo that it is not to be proved by immediate Obſervations, whether the Motion of the Earth is to be referred to the heavenly Bodies or not.

1244 *That the Earth is carried about the Sun, is deduced from the Analogy of the Motions, and from an* Examen *of the Laws of Nature.*

As to what relates to the Analogy of the Motions, it is to be obſerved, that Satellites revolve about *Jupiter* and *Saturn*, which are leſs than the central Body; that the Moon revolves about the Earth, than which it is leſs. *Laſtly*, That the Sun has revolving about it leſs Bodies than itſelf, as *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*. Now if the Earth revolves with the
1245 reſt, then every where *in our Syſtem the leſſer Bodies move about the greater:* Now *there would be an Exception in this Rule, in reſpect of the Sun, if that* vaſt Body *was to go round ſo ſmall a Body as the*
*975 *the Earth.* *

About the Sun, *Jupiter* and *Saturn*, about which ſeveral *Bodies* revolve, thoſe *move the ſloweſt which*
1246 *are moſt diſtant from the central Body*, and according to this Rule, that the Squares of the Periodical Times follow the Ratio of the Cubes of the
974 Diſtances; *which Rule* may be applied to the Earth, if it be carried about the Sun with the reſt of the Planets, as appears, if its Periodical Time (namely the Time in which the Sun appears to perform an entire Revolution) and its Diſtance from the Sun be compared with the Diſtances and Periodical Times of the reſt of the Planets.

Now this Rule *has only one Exception, if the Sun be moved about, the Earth is at reſt.* In this

Caſe

Case *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*, are subject to this Rule in their Motions, as also the five Satellites of *Saturn*, and the four Planets that accompany *Jupiter*; only the Moon and the Sun would move above the Earth in a Proportion quite different; and then the Celerity of the Sun would not only be greater than is required by this Law, but its Velocity would at least be six and twenty Times greater than that of the Moon, though it be removed to a vast Distance from the Earth, in respect to the Moon's Distance: And therefore in this respect, the Analogy of the Celestial Motions would be disturbed.

To these Arguments I shall add others, whereby it will clearly appear, that the Motion of the Earth is a necessary Consequence of the Laws of Nature, which are deduced from Phænomena.

All Bodies gravitate towards one another,* 1247
therefore the Sun and Earth do; but the Mo- *1206
tion, whereby these Bodies tend towards one
another, is deduced from direct Observations.
Whichsoever of these Bodies moves about the
other, describes Area's by Lines drawn to the
Center of it, proportional to the Times, which
is evident from Astronomical Observations;
therefore the Body moved is retained in a Curve
by a Force, which is directed towards the Center
of the other.* Now as Re-action is always *226
equal to Action,* unless the Laws of Nature, *126
which obtain constantly every where, be wholly
overturned, these two Bodies tend towards one
another with equal Motions; that is, with Cele-
rities that are inversly as their Masses;* which *65
is also immediately deduced from the Law of
Gravity.* *1235

The Quantity of Matter in the Earth is next to nothing, in comparison to the Quantity of

Matter in the Sun, as we ſhall ſhew in the following Chapter; wherefore the *Sun muſt move very ſlowly whilſt the Earth comes towards it very ſwiftly.*

Whence it follows, that the Earth is carried round the Sun, leſt it ſhould fall upon the Sun by that very violent Motion whereby it is retained in its Orbit.

This Motion of the Earth is alſo deduced from the ſame Principles another Way.

Two Bodies, that are carried towards one another by any Force, will at laſt concur, or continually recede from one another, unleſs each of them be ſo moved, as to have a centrifugal Force equal to the Force whereby it is carried towards the other Body; but as the Bodies, which gravitate towards one another, tend towards
126 each other with equal Forces, or what is the
65 ſame, with Celerities that are inverſly as the
1235 Quantities of Matter; theſe Bodies cannot per-
1248 ſevere in their Motions about one another, unleſs both of them be ſo moved, as to have equal centrifugal Forces, which does not happen, unleſs they both revolve in equal Times about their common Center of Gravity: That is, if this Propoſition be applied to the Sun and Earth, unleſs they both move about a Point, whoſe Diſtance from the Center of the Sun is to its Diſtance from the Center of the Earth, as the Quantity of Matter in the Earth is to the Quantity of Mat-
*234 ter in the Sun, they cannot perſevere in their
235 Motions about one another:* This Point or Center of Gravity muſt of Conſequence be very near to the Sun's Center. Now ſince whichſoever of theſe Bodies moves, it perſeveres in its Motion about the other, it follows, that both of them are affected by the Motions above-mentioned, and that the Sun is moved but

but a little, whilſt the Earth deſcribes a very great Orbit. Whence it follows, that the Motion of the Earth cannot be denied by any one, who reaſons from the Laws of Motion that are deduced from Phænomena.

Having proved *the* annual *Motion of the Earth* 1249
and brought back the Earth amongſt the Planets, there remains but little Difficulty in relation to the Motion of it *about its Axis*; for no body, that believes the annual Motion, doubts of this; a great many, which allow of the Motion about the Axis, deny the annual Motion; therefore it will be enough to obſerve by the By, that all the Planets, concerning which any Obſervation could be made in reſpect of this Motion, do move about their Axes; and that the Earth has ſuch a Motion, *the uniform diurnal Motion in Bodies, at any Diſtances, does plainly enough ſhew.* To which we muſt add, that the Celerity of the fixed Stars, going through one whole Revolution leſs than 24 Hours, can hardly be more probable than it is conceivable.

This Motion alſo is diſagreeable to the Nature
of all *the heavenly Bodies*; for, *if they are car-* 1250
ried round, they muſt every Day, with an equable Motion, deſcribe Circles that have the Earth for their Center; that is, they muſt, by Lines drawn to the Center of the Earth, ſweep through Area's proportionable to the Times, and be retained in their Orbits by Forces which are directed
towards the Center of the Earth,* and by *226
which (by reaſon that Action and Re-action * *126
are equal) *the Earth* muſt alſo be continually attracted towards thoſe Bodies; ſo that it *muſt neceſſarily be agitated by a very violent Motion*; whence it appears that the diurnal Motion muſt not be referred to the heavenly Bodies, but to the Rotation of the Earth about its Axis.

1251 Thoſe that obſtinately affirm that the Earth is at Reſt, object that Bodies, upon the Surface of the Earth, muſt (on account of their centrifugal Force) recede from the Earth, along a
217 Tangent to a Circle parallel to the Æquator. We anſwer, that the Bodies in the Places where they are, are carried round with the ſame Motion as the Surface of the Earth; and therefore that, in reſpect of the Points of the Surface, they endeavour to recede in Lines perpendicular to the
223 Axis; but alſo that Bodies by Gravity tend to the
1226 Center of the Earth; and therefore by a Motion compounded of both theſe, the Body is continu-
190 ally moved, or endeavours to move; but becauſe
198 the firſt Motion is extremely ſmall in reſpect of the other, a heavy Body is turned but very little out of its Direction towards the Center, and the Gravity is a little diminiſhed, ſo much the more as the Place is more diſtant from the Pole; which agrees with Experience. We ſhall hereafter ſhew, when we come to ſpeak of the Figure of the Earth, that the above-mentioned Direction of heavy Bodies is every where directed perpendicularly to the Surface of the Earth. A Body, which is thrown upwards, is acted upon, not only by the Motion wherewith it is thrown up; but it is alſo carried by the Motion that is impreſſed to the Perſon or Machine that impels the Body; that is, it is carried by the Motion which is common with the Surface of the Earth; and therefore the Body moves in the ſame Line (the Line being carried on with the Surface of the Earth) as it would do if the Earth was at Reſt.

CHAP.

CHAP. XIV.

Concerning the Density of the Planets.

BEFORE we proceed to the Physical Explanation of the System, we must determine the Quantities of Matter in some Bodies, and their Diversities; which being known, the Effects of the Laws, by which these Bodies are governed, will more easily appear.

The Quantities of Matter, in different Bodies, are to one another, as the Gravities at the same Distance from these Bodies;* which Gravities *1207
are to one another inversly as the Squares of the Periodical Times of the Bodies revolving about those different Bodies at the same Distance.* *236
By multiplying the Quantities which are in this Ratio by the same Quantity, (*viz.*) by the Cube of this Distance, the Ratio of these Quantities will not be changed; which are therefore to one another as the Quotients of the Divisions of the above-mentioned Cube, by the Squares of the Periodical Times aforesaid: But the Quotient of such a Division is found for any Body, by dividing the Cube of the other Distance; let it be what it will, by the Square of the Periodical Time of the Body revolving at that Distance; for such Quotients are equal to one another, for all Bodies that revolve about the same Body at any Distances; as follows from the Equality of the Ratio between the Cubes of the Distances, and the Squares of the Periodical Times at those Distances.* From which we deduce, that *the* *974
Quantities of Matter, in any Bodies in our System, 1252
are to one another directly as the Cubes of the Distances at which other Bodies revolve about these,

and inversly as the Squares of the Periodical Times of these revolving Bodies.

These Things are demonstrated by setting aside the Agitation of the Central Body, whose Quantity of Matter is enquired after.

By reason of the Sun's Magnitude, in respect of *Venus*, *ex. gr.* which alone we consider of the Planets, the Sun is scarce moved by the Action
2135 of that Planet. And *Venus* may be considered as moving about a quiescent Body.

The Satellites of *Jupiter* and *Saturn* are indeed carried by the common Motion along with the Primary Planets, but by reason of the Magnitude of the Primary Planets, they are carried about them as about Bodies that are at rest.

But the Moon acts sensibly enough upon the Earth and moves it; wherefore before we can compute the Motion of the Moon by the Help of the
1252 aforesaid Rule, in order to compare the Quanti-
1253 ty of Matter in the Earth with the Quantities of Matter in the Sun, *Jupiter*, and *Saturn*, we must determine *the Distance at which the Moon would move about the Earth*, if it was at Rest (that is, *not carried about by the Action of the Moon*) *in the same Periodical Time in which it now performs its Revolution.* Here also we don't take Notice of the Motion that is common to the Earth and Moon, by which they are both carried about the Sun.

The Moon perseveres in its Motion about the Earth; therefore the Earth and Moon are moved about a common Center of Gravity; as follows from what has been demonstrated concerning the
1248 Earth and the Sun, and the Moon (with that Force with which it tends towards the Earth) revolves in an Orbit whose Semi-Diameter is the Distance of the Moon from the aforesaid common

mon Center of Gravity of the Moon and the Earth.

Let L be this Diſtance of the Moon from the common Center of Gravity; T the Diſtance of the Earth from the ſame Center; L + T therefore is the Diſtance of the Moon from the Earth, and is 60 $\frac{1}{2}$ Semi-Diameters of the Earth; for here we conſider the mean Diſtance. Let D be the Diſtance which we would have, at which the Moon, by its Gravity towards the Earth, would move about the Earth, if it was at Reſt, in the ſame Time in which it is now moved about the common Center of Gravity at the Diſtance L.

By reaſon of this Equality of the Periodical Times, the Force, whereby the Moon would be kept in its Orbit at the Diſtance D, is to the Force whereby it is kept in its Orbit at the Diſtance L, as D to L.* *232

But the Force whereby the Moon would tend to the Earth, and be kept in its Orbit at the Diſtance D, is to the Force whereby it is now kept in its Orbit at the Diſtance L + T, as $\overline{L+T}^q$ to D^q*. Therefore *1208

$$D, L :: \overline{L+T}^q, D^q$$

Conſequently $D^c = L \times \overline{L+T}^q$, and $D^c \times \overline{L+T} = L \times \overline{L+T}^c$: Whence we deduce the following Proportion:

$$\overline{L+T}, D^c :: L+T, L.$$

Therefore L + T, D :: L + T, is to the firſt of two mean Proportionals between L + T and L.

L + T is to L, as the Quantity of the Matter in the Earth and Moon taken together, to the Quantities of Matter in the Earth alone;* *234
which Quantities of Matter, as we ſhall ſhew 235
hereafter, are to one another, as 40, 37. to

39, 37. and the firſt of two mean Proportionals to theſe Numbers is 40,035; therefore 40, 37. is to 40,035. as 60½ to the Diſtance required, which is found to be 60 Semi-Diameters of the Earth.

Concerning this Operation it is to be noted, that the Diſtance D cannot be diſcovered, unleſs the Ratio between the Maſs of the Moon and the Earth be known, which cannot be determined unleſs the Ratio between the Denſity of the Sun and the Earth be found: To diſcover which, it is neceſſary that the Diſtance D be known. Wherefore D is diſcovered at firſt by Trials, and is exactly determined by Approximation. But it is certain, that this is 60 Semi-Diameters of the Earth; becauſe, this being ſuppoſed, it is found that the Ratio between the Quantities of Matter of the Moon and the Earth is as 1 to 39, 37. as we ſhall ſee hereafter; by making uſe of which Proportion, this Diſtance is diſcovered to be 60 Semi-Diameters, as we have ſhewn.

Theſe Things being premiſed, we proceed to the Computation.

The Diſtance of *Venus* from the Center of the Sun is 723, and its Periodical Time is 5393
*959 Hours.

The Fourth Satellite of *Jupiter* is diſtant from the Center of *Jupiter* 12, 507. ſuch Parts of which *Venus* is diſtant from the Sun 723. The Periodical Time of this Satellite is 402 Hours,
971 5 Minutes.

The Fourth Satellite of *Saturn* is diſtant from the Center of *Saturn* 9, 292. of the ſame Parts;
972 and its Periodical Time is 382 Hours 41 Min.

Laſtly, the Diſtance of the Moon is 60 Semi-Diameters of the Earth from its Center, and

2,909.

2,909. of the aforesaid Parts. Its mean Periodical Time is 655 Hours, 43 Min.

If you divide the Cubes of these Distances re- 1254
spectively by the Squares of the Periodical Times, you will have, in the Quotients, Numbers which are to one another as the Quantities of Matter in the aforesaid Central Bodies; * *1252
which Quotients are to one another as the following Numbers:

	In the Sun.	In Jupiter.	In Saturn.	In the Earth
Quantities of Matter.	10000.	9, 248.	4, 223.	0, 0044.

We have also the Proportion of the Diameters 1256
of these Bodies from Astronomical Observations, as follows.

	Of the Sun.	Of Jupiter.	Of Saturn.	Of the Earth
Diameters	10000.	1077.	889.	104.

If the Quantities of Matter abovesaid be di- 1257
vided by the Squares of the Diameters, the Quotients will be to one another as the Weights on the Surfaces of the aforesaid Bodies;* and these *1227
Quotients are as the following Numbers.

	Of the Sun.	Of Jupiter.	Of Saturn.	Of the Earth
Gravities on the Surfaces	10000.	797, 15.	534, 337.	407. 832.

1258

If you divide these Numbers by the Diame- 1259
ters, you will have the Proportion of the Densities of those Bodies.* *1231

The Quotients, found by these Divisions, are as the following Numbers.

	Of the Sun.	Of Jupiter.	Of Saturn.	Of the Earth
Densities	10000.	7404.	6011.	39214.

1260

We ſhall determine the Denſity of the Moon in the laſt Chapter.

It is not probable that the aforeſaid Bodies are homogeneous. We ſhall ſhew in relation to the Earth, in the 17th Chapter, that it is denſer towards the Center than towards the Surface; from whence it follows, that the Denſities cannot be exactly determined: Wherefore *we* only *determine the mean Denſities*, that is, *which the Bodies would*
1261 *have, if the ſame Bodies, keeping the ſame Quantity of Matter and Bulk which they now have, ſhould become homogeneous.*

1262 *The above-mentioned Proportion* * *between the*
*1260 *Denſities, in reſpect of all the Bodies, and the reſt of the Computations in reſpect of the Sun, Jupiter, and Saturn, are free from any ſenſible Error: When they are compared with the Earth there may be ſome Error*, which muſt be corrected by Obſervations to be made hereafter; for we ſuppoſe the Diſtance of the Moon (which is 60 Semi-Diameters of the Earth) to be 2, 909 ſuch Parts, of which *Venus* is diſtant from the Sun 723, that is of which the
959, 960 Earth is diſtant from the Sun 1000; which Diſtance of the Moon is diſcovered by ſuppoſing the Horizontal Parallax of the Sun 10″, which cannot be looked upon as abſolutely true, although it be deduced from the moſt exact Obſervations that have hitherto been made, of the Parallax of *Mars*, when it is neareſt of all to the Earth, which is too ſmall to leave us without Suſpicion of
1108 ſome Miſtake.

But the Error, in not determining truly the Proportion between the Semi-Diameter of the Earth and the Diſtance from the Sun, does not change the determined Denſity of the Earth, as is deduced from Computations made about it.

For it follows from theſe, that the Denſities of Bodies are to one another in a Ratio compounded

pounded of the direct Ratio of the Cubes of the Diſtances of the Bodies carried about, and the inverſe Ratio of the Squares of the Periodical
Times of theſe revolving Bodies ;* as alſo of *1254
the inverſe Ratio of the Cubes of the Diameters of the Central Bodies whoſe Denſities are requi-
red ;* the Ratio, compounded of theſe, is com- *1257
pounded of the direct Ratio of a Fraction whoſe 1259
Numerator is the Cube of the Diſtance of the revolving Body, and whoſe Denominator is the Cube of the Diameter of the Central Body, and the inverſe Ratio of the Square of the Periodical Time of the Body carried about. But you have ſuch a Fraction, if you know the Ratio between the Diameter of the Central Body and the Diſtance of the revolving Body from that Center, although this Diſtance can be compared with no other ; but this Ratio is given in reſpect of the Earth and Moon, as well as in reſpect of the other Bodies ; wherefore alſo the Ratio of the Denſity of the Earth to the Denſities of the other Bodies is exactly diſcovered.

CHAP. XV.

The Phyſical Explanation of the whole Planetary Syſtem.

IN the firſt Part of this Book we have ſhewn,
what are the Motions of the Bodies in the *124,
Planetary Syſtem; now we muſt explain how 125,
theſe Motions follow from the Laws of Nature ;* 126,
that is, how theſe Bodies, being once put in Mo- 1206,
tion, perſevere in thoſe Motions which we obſerve. 1207, 1208
Let us conceive the Sun and *Mercury* to be left 1263
to themſelves, and they will come together ;* *1206
but if they be projected, they may revolve about

a common Center of Gravity in equal Times,
*1248 and deſcribe immoveable Elliptic Lines, * and
1208 perſevere in that Motion; for it is plain, by Ma-
241 thematical Demonſtration in that Caſe, that the Bodies will deſcribe Ellipſes about the common Center of Gravity, ſimilar to that which the one of them could deſcribe with the ſame Forces about the other, if it was at Reſt: This Center,
*235 on account of the Sun's Magnitude, * is very little diſtant from the Center of the Sun itſelf.

Let us conceive beſides, *Venus* to be projected at a greater Diſtance from the Sun, it will a little diſturb the Motion of *Mercury*, which alſo, by its Action upon *Venus*, will turn it a little out of the Way, and both will draw the Sun, ſometimes the ſame Way and ſometimes different Ways; but we find all theſe Irregularities are inſenſible, if we conſider the Magnitude of the Sun; and therefore that theſe three Bodies tend towards a Point that is between them near the Sun, which therefore is very little diſtant from the common Center of Gravity of them all.

If the Earth, *Mars*, and the other Planets be ſucceſſively projected at different Diſtances from
1264 the Sun, the ſame Reaſoning will hold good. Whence it follows, that *all the Planets are revolved about the common Center of Gravity of all the Bodies which compoſe the Syſtem*, which is but little diſtant from the Sun, and that the Planets do not
1265 ſenſibly diſturb one another in their Motions; wherefore *they all deſcribe the ſame Line ſingly, which they would deſcribe about the Sun, if every one of them was alone with the Sun in the Planetary Syſtem*, that is, immoveable Ellipſes: For it is plain, that theſe will be deſcribed by the Force
*1208 of Gravity; * and it is proved by Mathematical
241 Demonſtration, that no other immoveable ex-

centric Lines can be described by a Central Force acting equally at equal Distances.

It will also more plainly appear, that all the Planets tend to a Point near the Sun, if we consider that the Quantity of Matter in the Sun is a thousand times, and more, greater than the Quantity of Matter in *Jupiter*, which is far the greatest of all the Planets.* *1255

When all *the Planets move*, though they move 1226
the Sun but little, yet they do move it, and draw it differently according to their different Situation in respect of one another; whence there arises a small Motion in the Sun, which always depends upon the Motion already acquired, and the Change which happens in it from the Action above-mentioned, which varies every Moment.

It is owing to this Agitation of the Sun, that the 1267
Planets disturb one another less in their Elliptic Motions round the Sun, than if the Sun was at Rest in the Middle of the System. If *Jupiter*, *ex. gr.* was equally distant from *Mercury* and the Sun, it would attract both those Bodies to itself with an equal Celerity;* whence the Situation, in respect *1235
of the Sun, is less changed than if the Sun was not agitated by this Motion, and *Mercury* only was attracted by *Jupiter*: According to the various Distances of *Mercury* and the Sun from *Jupiter*, the one or the other is more attracted, and there is always a less Change in their respective Situation when both are carried the same Way, than if (the Sun being at Rest) *Mercury* only should be carried towards *Jupiter*.

This Reasoning may be applied to all the Actions of the Planets, that are more distant from the Sun, upon those that are less distant. As to what relates to the Action of those that are nearer, upon those that are farther from the Sun, according to the different Situation they

draw

draw a Planet to the Sun, or drive it from the
Sun, and in conſidering one whole reſpective Re-
volution, that is, the Motion from one Conjunc-
tion to another, the Diſturbance is leſs than
if the Sun was immoveable.

1268 The Magnitude of the Sun, compared with
the reſt of the Bodies of our Syſtem, is the Rea-
ſon (as appears by what has been already demon-
ſtrated) that the Planets diſturb one another but
little; but ſince the Magnitude is not infinite,
theſe mutual Actions muſt not be wholly over-
looked.

We have ſaid, that it appears by Aſtronomi-
cal Obſervations, that *Jupiter* alters the Way of
*1217 *Saturn* when it is neareſt to it; * why this Di-
ſturbance is more ſenſible than the reſt, is deduced
from the Law of Gravity.

1269 The Actions of *Jupiter* upon *Saturn* when it
is neareſt to it, and of the Sun upon the ſame
Planet, by which it is kept in its Orbit, are to
one another directly as the Quantities of Matter in
*1207 *Jupiter* and the Sun,* (*viz.*) as 9, 248. to 10000,*
*1255 and inverſly as the Squares of the Diſtances of
Jupiter and the Sun from *Saturn*; that is, directly
as 81 to 16; for the Diſtances of *Saturn* and
1270 *Jupiter* from the Sun are almoſt as 9 to 5; where-
fore, *when Jupiter is neareſt to Saturn, the* Diſtances
of *Saturn* from *Jupiter* and the Sun are as 4
to 9. The Ratio compounded of the two afore-
ſaid Ratio's is as 749 to 160000, or as 1 to 214.
This *Action of* Jupiter *conſpires with the Gravity of*
Saturn *towards the Sun, and* therefore *encreaſes* $\frac{1}{214}$
Part: Whence it is no Wonder that the Diſtur-
bance is ſenſible.

We don't here conſider the Force by which
Jupiter attracts the Sun, for the Orbit of *Saturn*
is not changed by it, and what we had to ex-
plain was, why Aſtronomers obſerve *Saturn* to
be

be turned out of the Way; yet by the Action of
Jupiter upon the Sun, the Sun is brought nigher
to *Saturn*, and the respective Situation of these
Bodies is more disturbed, than is discovered by
Astronomical Observations. The Force with
which *Jupiter* in the aforesaid Position attracts
the Sun, and with which therefore the Sun is at-
tracted towards *Saturn*, is to the Force with which
Jupiter attracts *Saturn*, as 16 to 25;* that is, *1208
as 479 to 749, which Number expresses the
Force with which *Saturn* tends towards *Jupiter*,
when the Gravity of *Saturn* towards the Sun is
expressed by 160000. If we collect into one
Sum the Forces of *Jupiter*, by which it attracts
Saturn and the Sun; the Force, by which, from
the Interposition of *Jupiter*, these Bodies tend
towards each other, will be to the Gravity of *Sa-
turn* towards the Sun, as 1228 to 160000; but
this Gravity is to the Gravity of the Sun towards
Saturn, as 160000 to 67, 5.* wherefore *the* *1207
mutual Access, or Approach of the Sun and Saturn 1255
is to the Encrease of this Approach by the Action of 1271
Jupiter *interposed*, as 160067 to 1228, or, *as* 130
to 1.

This Disturbance is remarkable, and far the greatest of any that happens in the Motion of any of the primary Planets: This also obtains only in this one Case of the Conjunction; for when *Jupiter* recedes from *Saturn*, the Disturbance of the Motion of *Saturn*, in a short Time, becomes insensible.

In the same Position of *Jupiter*, when it is
nearest to *Saturn*, the Force of *Saturn*, although
it be the greatest of all in this Case, does not so
sensibly alter the Way of *Jupiter* about the Sun.
The Action of *Saturn*, attracting *Jupiter*, is to its
Action by which it attracts the Sun, as 81 to
16;* therefore it attracts *Jupiter* with greater *1208
Celerity; and since they are both attracted the
same

ſame Way, the Difference of theſe Forces is the Force with which (from the Action of *Saturn*)
*175 *Jupiter* and the Sun are ſeparated from each other*; which is therefore to the Gravity of the Sun towards *Saturn*, as 65 to 16; but this Gravity of the Sun towards *Saturn* is to the Gravity of *Jupiter* towards the Sun, as 4, 223. to
1207 10000, and as 25 to 81*; that is, as 106 to
1255 810000, or as 16 to 122756; therefore the di-
*1208 ſturbing Force of *Saturn* is to the Gravity of *Jupiter* towards the Sun, as 65 to 122756, or
1272 as 1 to 1888; therefore *by the greateſt Action of* Saturn, *the Gravity of* Jupiter *towards the Sun is diminiſhed only by* $\frac{1}{1888}$ *Part*, which Diſturbance is inſenſible.

The other mutual Diſturbances of the Planets are much leſs, as will appear by determining that, which is the greateſt of them all, (*viz.*) that of *Mars* by *Jupiter*, which is diſcovered by the ſame Sort of Computation as the foregoing.

The Diſtance of *Jupiter* from *Mars* and the Sun, when *Mars* is between the Sun and *Jupiter*
961 in the ſame Line, are as 7 to 10; wherefore
962 the Forces with which *Jupiter* attracts theſe
1280 Bodies, are as 100 to 49, the Difference of which Forces is to the Gravity of the Sun towards *Jupiter*, as 51 to 49. This Gravity of the Sun towards *Jupiter*, is to the Gravity of
*1207 *Mars* towards the Sun, as 9, 248 to 1000*, and
1255 as 9 to 100*; that is, as 83 to 1000000; or as
*1208 49 to 590443; and the diſturbing Force of *Jupiter* is to the Gravity of *Mars* towards the Sun, as 51 to 590443; or as 1 to 11577: wherefore
1273 *the Gravity of* Mars *towards the Sun, is diminiſhed only* $\frac{1}{11577}$ *Part by the Action of* Jupiter *when neareſt to it.*

Although

Although theſe Diſturbances, ariſing *from the* 1274
Actions of the Planets upon each other, be very
ſmall, and although thoſe which happen in a differ-
rent Poſition of the Planets do in ſome Meaſure
compenſate each other, yet the Proportion in which
the Force, which keeps the Planets in their Or-
bits decreaſes, is a little changed by theſe Actions,
ſo that it does not decreaſe exactly in an inverſe
Ratio of the Square of the Diſtance : Therefore
although the Orbits are at Reſt as to Senſe, *after
a great many Revolutions, a ſmall Change is ob-* *243
*ſerved in their Situation.** 929

From all this it follows, that if we ſuppoſe the 1275
Planets at firſt once projected at the Diſtances from
the Sun at which they are moved, they will, by
the Laws already explained, perſevere in thoſe
Motions ; and the Excentricity of the Orbits de-
pends upon the Celerity and Direction of the firſt
Projection. But theſe Motions may be preſerv-
ed very long, by reaſon of the ſmall Reſiſtance
of the Celeſtial Matter.

It is alſo plain, why, by Lines drawn to the
Center of the Sun, they deſcribe *Areas* propor-
tionable to the Times ; namely, becauſe all other
Gravities, in the Syſtem, are very ſmall in reſpect
to the Gravity towards the Sun* ; therefore by this *1265
Gravity alone, it is that they are retained in their
Orbits ; whence follows this Proportion of the
*Areas**. And alſo the Motion in Elliptic Lines, *225
which are carried on very ſlowly, follows from the
Law of Gravity ; and theſe Lines would alſo be
immoveable, if the Planets gravitated only to-
wards the Sun * ; but this ſlow Motion of the *241
Orbits is deduced from the Action of the Pla- 1208
nets upon one another.* Now in reſpect to the *1214
Proportion which is obſerved between the Cubes
of the Diſtances, and the Squares of the Periodi-
cal Times, it is alſo deduced from the Law of
Gravity

239 Gravity ; ſo that if we add to theſe what we
1208 *1217 have ſaid of the Deflection of *Saturn*,* nothing
1270 will remain to be explained in reſpect to the primary Planets.

1276 That *the Motion of Comets depends upon the Law of Gravity*, is alſo deduced from Obſervations ; and in reſpect of them, as has been ſaid concerning the Planets, the Sun's Gravity prevails, and by that Gravity they deflect from a rectilinear
980 Courſe ; but that the Curvature of their Way
226 depends upon the ſame Gravity, follows from this ; That a Body, by that Gravity, will deſcribe an Ellipſe, or a Parabola, or an Hyper-
241 bola ; which Lines it appears that thoſe Comets
1208 have deſcribed, whoſe Trajectories have been determined.

1277 *The Satellites of* Jupiter *and* Saturn *are moved*
*944 *by the ſame Laws about their Primaries, as the*
966 *Primaries are moved about the Sun ;** wherefore the
974 Explication of thoſe Motions * may be alſo refer-
*1275 red to them ; for in theſe three Caſes, ſmaller Bodies are revolving at different Diſtances about a much greater Body : Namely, Satellites about *Jupiter* and *Saturn* and Primary Planets about the Sun.

1278 *Whilſt ſecondary Planets are moved about a Primary one, it is evident that they may all be moved with one common Motion*, whereby the reſpective Motions with which they are moved, in reſpect of each other, will not be diſturbed, becauſe a Body may at the ſame Time be moved by different Im-
*125 preſſions : * The Motion that a Primary Planet has, in common with its Satellites, is the Motion of a Primary Planet about the Sun.

1279 Yet *the Motion of the ſecondary Planets is diſturbed by the Action of the Sun*, towards which they are carried ſometimes faſter, and ſometimes ſlower, according to the different Poſition of the Primary ; and they

they alſo often concur towards the Sun's Center in different Directions. Theſe Irregularities, which are very ſmall, cannot be obſerved in the Satellites of *Jupiter* and *Saturn*, though they be really like thoſe which are obſerved in the Motion of the Moon: The leaſt Deviation of this laſt is very ſenſible to us. But that the Irregularities of the Moon exactly follow from the Theory of Gravity, will appear in the next Chapter.

CHAP. XVI.

The Phyſical Explication of the Moon's Motion.

IT is certain that the Moon and Earth having 1280
once a projectile Motion given them, they
can perceive in their Motion about their common
Center of Gravity;* if they be carried any Way *1263
by a common Impreſſion directed in parallel Lines,
as was ſaid of the Satellites *Jupiter* and *Saturn*,* *1278
this Motion will not diſturb the Motion about
the common Center of Gravity, which will follow that Direction only, becauſe in reſpect of the two Bodies it is at Reſt. But the Bodies are carried by a Motion compounded of that Impreſſion, and of the Motion about the common
Center of Gravity; * that is, they are whirled *190
about that Center as it is carried along, as before its Motion when it was at Reſt. If every Moment new Impreſſions common to both the Bodies act upon them, the Way of the Center of Gravity may be changed every Moment, which Change will be like that which the Bodies themſelves would undergo, if they had no reſpective Motion.

Hence we deduce, that if whilſt the Moon and Earth are whirled round their common Center of Gravity, they be both projected, the Way of the Center of Gravity, by the Action of the Sun acting upon both Bodies, is the ſame as a Body, projected in the ſame Manner, would deſcribe about the Sun.

1281 Whence it follows, *that the Moon diſturbs the Motion of the Earth, and that the common Center of Gravity of thoſe Bodies deſcribes that Orbit about the Sun, which we have hitherto ſaid, that the Earth deſcribed*; becauſe we looked the Action

1282 of the Moon; but *the Earth deſcribes an irregular Curve.*

1283 *Fig.* 4. *Plate* XXIV.] Let the Sun be at S; and the common Center of Gravity of the Moon Q, and the Earth at M, at the Time of the full Moon, be at F: After one whole Lunation, that is, the next full Moon, let that Center be at A; and let F D A be the Orbit which we call that of the Earth; but in which it is the Center of Gravity above-mentioned that does really move.

If this Lunation be divided into four equal Parts, after the firſt, the Center of Gravity will be at E, the Moon at P, and the Earth at L; after the ſecond Part of the Time, at New-Moon, the Center of Gravity will be at D, the Moon at R, and the Earth at I; in the following Quadrature, the Center of Gravity will be at B, the Moon at O, and the Earth at H. Laſtly, at Full-Moon the Center of Gravity being at A, the Moon will be at N, the Earth at G: All which follows from the Revolution of the Earth and Moon about their common Center of Gravity, whilſt it is carried in the Orbit about the Sun.

Therefore we ſee the Earth moves in the Curve M L I H G, which is twice inflected in each Lunation; which Curve also does not return into itself, because the Inflections in the several Revolutions about the Sun do not coincide; for 12 Lunations, and a third Part of another, are performed every Year.

This Irregularity of the Motion of the Earth, 1284
which is deduced from the Laws of Nature, *is too small to become sensible in Astronomical Observations*; wherefore we may without any Error say, that the Center of the Earth itself describes the Orbit F D A; for M F, or D I, the greatest Distance of the Earth from that Orbit, is about the 40th Part of the Distance I R, which Distance itself is not the 300th Part of the Distance F S.

In explaining what relates to the Moon, we also 1285
neglect the Consideration of the Motion of the Earth about the common Center of Gravity above-mentioned, but we suppose it to revolve at the Distance of 60 *Semidiameters from the Center of the Earth*; because, as we have before demonstrated,* such is the Distance at which, in its periodical Time, it could revolve about the Earth at Rest, or be carried along in an Orbit in which it should not be disturbed by the Moon's Action. By this Method, the Moon's Irregularities will be much more easily discovered; for they are the same; as is evident, whether the Moon moves about the common Center of Gravity of the Moon and Earth, or about the Center of the Earth itself.

*1253

Plate XXV. *Fig.* 1.] Let S be the Sun; T the 1286
Earth; and the Orbit of the Moon A L B *l*; and last of all, let the Moon be at A in the Quadrature; it tends towards the Sun in the Direction A S, in the same Manner, and with the same Force that the Earth is carried towards S along T S, because the Distances A S and T S are equal: This Force may be represented by T S or A S,

whereby the Moon endeavours to deſcend along AS, and is reſolved into two Forces, by drawing the Parallelogram ADST; ſo that the Moon will endeavour to move in the Directions AD and AT, by Forces repreſented by thoſe
192 Lines.

By the Force which acts along AD, the Moon is carried with the ſame Celerity and the ſame Way of the Earth; by reaſon of the equal and parallel Lines TS and AD: Wherefore by this Motion, the Relation between the Moon and Earth is not changed; but the Force along AT
1287 conſpires with *the Gravity of the Moon towards the Earth*, and this Gravity *is encreaſed by the Action of the Sun, when the Moon is in the Quadratures; and the Augmentation or Addition is to the Gravity of the Earth towards the Sun, as* AT *the Moon's Diſtance from the Earth is to* TS, *the Earth's Diſtance from the Sun.*

1288 TS *the Earth's Diſtance from the Sun remaining the ſame, the* above-mentioned *Addition of Gravity encreaſes, and diminiſhes in the Ratio of the Line* AT, *the Diſtance of the Moon from the Earth.*

But this Diſtance of the Moon from the Earth AT, if it remains the ſame, and TS be encreaſed, then AT will be leſs in reſpect of AS: Therefore though there ſhould be no Change in the Force, whereby the Earth and Moon fall towards the Sun, the Addition will be leſs, and ſo much leſs as TS is greater; that is, it will be inverſly as TS; but the Force of Gravity does not remain the ſame, when TS is encreaſed, but is diminiſhed; wherefore alſo in that reſpect, the above-mentioned Addition is diminiſhed, and in the ſame Ratio with that Force of Gravity; therefore it is the inverſe Ratio of the Square of the
1208 Diſtance TS; if this Diminution be added to that above-mentioned, we ſee that the *Addition* of which

which we speak, *follows the inverse Ratio of the Cube of the Distance of the Earth from the Sun.* 1289

The Distance of the Earth from the Sun remaining the same, the Gravity of the Moon towards the Earth decreases more slowly in the Quadratures, than according to the inverse Ratio of the Square of the Distance from the Center of the Earth; for if the Addition in that Case should follow the inverse Ratio of the Square of the Distance, as the Gravity from the Action of the Earth does,* this Ratio would not be disturbed; but the Addition encreases when the Gravity itself is diminished; wherefore the Addition, when the Distance is encreased, is always greater than is required, and consequently the Diminution the less. 1290 *1208

This Addition is determined *in the mean Distances of the Moon from the Earth, and of the Earth from the Sun:* Let A T and T S be these mean Distances; the *Addition* required is to the Gravity of the Earth towards the Sun, as A T to T S*; the Gravity of the Earth towards the Sun, *is to the Gravity of the Moon towards the Earth* (because these Bodies are retained by these Gravities in their Orbits) directly as T S to T A, and *inversly as the Squares of the Periodical Times of the Earth about the Sun, and of the Moon about the Earth:** Therefore the Addition required is to the Gravity of the Moon towards the Earth, in a Ratio compounded of these Ratio's; *that is*, the abovementioned inverse Ratio of the periodical Times of the Earth and Moon, the other Ratio's destroying one another. These Times are given, and their Squares are inversly *as* 1 *to* 178,73. 1291 *1287 *237 1236

Now if the Moon be at L, [*Plate* XXV. *Fig.* 1.] in which Situation the Sun attracts the Moon and Earth in the same Line, but not equally; the Moon it draws with a greater Force, because it is less distant from it: The Difference of those 1292 those Forces is the Force by which the Moon is drawn back from the Earth, and by which the Gravity of the Moon towards the Earth is diminished.

The Forces whereby the Moon at L, and the Earth at T, tend towards the Sun, are to one
1208 another as the Squares of the Lines S T and S L:
and the Difference of the Forces, that is, the disturbing Force, is to the Force by which the Earth descends toward the Sun, as the Difference of those Squares to the Square of the Line L S; that is, nearly as double L T to L S or T S; for
1293 these Lines do but very little differ from one another; and *the Difference of the Squares, whose Roots differ but little, is keeping the Proportion double that which is between the Roots.*

If therefore T S, as before, represents the Force whereby the Earth descends towards the Sun, L *l* will represent the disturbing Force and diminishing Gravity, when A T represents the disturb-
1286 ing Force in the Quadratures. Let the Moon be
1294 at *l*; it is again (together with the Earth) attracted by the Sun in the same Line; but the Earth, because less distant, moves more swiftly to-
1208 wards the Sun; so that there is a Force which separates the Earth from the Moon, namely, the Difference of the Forces which attract the Moon and the Earth; which Force always acts contrary to the Gravity of the Moon towards the Earth, and diminishes it, in the same Manner as has been demonstrated from the greater Gravity of the Moon towards the Sun, supposing it at L. At *l* also the separating Force scarce differs from the separating Force at L; for this Force, as we have shewn, is proportional to the Difference of the Squares of the Lines T S and L S; and that (as appears by such another Demonstration) proportional to

I the

the Difference of the Squares of the Lines *l* S and T S; which Difference, by reason that L *l* is very small in respect of T S, scarce differ among themselves; so that the Force which diminishes the Moon's Gravity at *l*, is also represented by L *l*.

Yet *the Disturbing Force is something greater at* 1295
the Conjunction L, *than at the Opposition l*; for supposing the Differences between the Roots to be equal, the Squares, keeping the Proportion, will differ so much the more, the less they are; and so keeping the Proportion, the Forces differ more at L and T, than at T and *l* which also are less.* *1208

From this we conclude, that *the Force which* 1296
diminishes the Gravity of the Moon in the Syzygies, is double that which encreases it in the Quadratures; namely, as L*l to* A T. Wherefore in the Syzygies, the Gravity of the Moon from the Action of the Sun is diminished by a Part, which is to the whole Gravity, *as* 1 *to* 89, 36; for in the Quadratures, the Addition of Gravity is to the Gravity, as 1 to 178,73.* *1291

In the Syzygies, the disturbing Force follows the 1297
same Proportion with half added to it; that is, with the disturbing Force in the Quadratures*; *1296
it is therefore *directly as the Distance of the Moon from the Earth,** *1288 *and inversly as the Cube of the Distance of the Earth from the Sun.** *1289

At the Syzygies the Gravity of the Moon towards 1298
the Earth, receding from its Center, is more diminished, than according to the inverse Ratio of the Square of the Distance from that Center; for it would be diminished in that Ratio, if the Force to be taken away followed the same Ratio; but on the contrary, as it encreases when the Distance becomes greater,* the Diminution is always *1297
greater than in that Ratio.

1299 *Plate* XXV. *Fig.* 1.] Laſtly, let the Moon be at F, in any intermediate Place between the Syzygy and Quadrature, it is drawn towards the Sun along F S; by which ſince it is leſs diſtant than the Earth T, it is attracted with more Force than the Earth: Let the Force, with which the Moon tends to the Sun, be to the Force, with which the Earth is carried towards it, as F M to T S, which alſo before has been made uſe of to expreſs the ſame Gravity of the Earth. Draw the Parallelogram F H M I, whoſe Diagonal is F M, and whoſe Side F H is parallel and equal to the Line T S. The Motion of the Moon towards the Sun is reſolved into two Motions, one along F H, the other along F I, and theſe Lines denote the Forces whereby the Moon endeavours
192 to move along them. The Motion along F H is common to the Moon and the Earth, which with an equal Force, and in a Line parallel to it, does alſo tend to the Sun: So that by this Motion of the Moon, the Situation of it, in reſpect of the Earth, will not be changed, and the diſturbing Force will be only the Motion along F I.

By reaſon of the immenſe Diſtance of the Sun, the Part M S of the Line M F is ſmall, in reſpect of the Whole, and the Angle F S T, where it is the greateſt, as A S T, is hardly more than the 6th Part of a Degree: Whence it follows, that the Lines M I and S N are very near one another, and that the Points I and N are ſcarce ſenſibly diſtant, and may without any ſenſible Error be confounded together; which Error, notwithſtanding how little ſoever it need be regarded, in Conſideration of one whole Revolution, is compenſated by a contrary Error when the Moon is at E. Therefore the diſturbing Force is expreſſed by F N.

It

It is to be observed, when only the Part E F 1300
of the Line E S is considered, that it is to be look-
ed upon as parallel to the Line L *l*, because of
the small Angle which these Lines make. From
the Point N, draw N Q perpendicular to the 1301
Line F T, continued if Need be, in which the
Moon gravitates towards the Earth; and let
the Rectangular Parallelogram E P N Q be
drawn: Let us conceive the Force along F N re-
solved into two others, acting in the Directions
F Q and F P, and represented by these Lines:* *192
By the Force along F Q, the Force of Gravity is
diminished, in the Case represented by this Figure;
but it is encreased when the Point Q falls be-
tween F and T; but by the Force along F P,
the Moon in its Orbit is drawn towards the next
Syzygy L, and the Motion of the Moon is acce-
lerated or retarded, according as this Force con-
spires with, or acts contrary to the Moon's Mo-
tion.

Near a Syzygy, the Gravity of the Moon is diminished, and the Line F Q, which follows the Proportion of this Diminution, grows less, receding from the Syzygy till it vanishes, at the Distance of about 54 Degr. 44 Min. from it: At a greater Distance of the Moon from the Syzygy, Q falls in between F and T; and the Gravity of the Moon towards the Earth is encreased by the Sun's Action. The Force along F P vanishes in the Syzygy L; receding from it, it encreases quite to the Octant, which is the middle Point between the Syzygy and the Quadrature; and then it diminishes again till it vanishes quite at B.

Between B and *l*, or *l* and A, the disturbing 1302
Motions are determined in the same Manner, as
in A L B, the opposite inferior Part of the Or-
bit; at E and F, the Diminution of Gravity is
equal,

equal, and in that Poſition it is drawn in the Orbit with an equal Force towards the Syzygy *l*, with that with which at F it is impelled towards the Syzygy L.

1303 Hence it follows, *that in the Motion of the Moon from the Syzygy to the Quadrature*, between L and B, as alſo between *l* and A; *the Gravity of the Moon towards the Earth is continually encreaſed,*
1304 *and the Moon is continually retarded in its Motion.* But *in the Motion from the Quadrature to the Syzygy*, between B and *l*, as alſo between A and L, *every Moment the Moon's Gravity is diminiſhed, and its Motion in its Orbit is accelerated.*

You may determine the Forces upon which theſe Effects depend, by comparing them with the known Force, whereby Gravity is encreaſed in the
1291 Quadratures, and which is repreſented by the Moon's Diſtance from the Center of the Earth.

1305 The Lines M I, H F, S T, are equal by Conſtruction; therefore when the Points I and N are confounded, M N is equal to S T, and M S is equal to N T. The Lines M F and S T repreſent the Forces, whereby the Moon at F and the Earth at T are carried towards the Sun S; therefore they are as the Square of the Line T S
1208 to the Square of the Line F S; wherefore as F G is the Difference of thoſe Lines, F M and T S differ from one another double the Line
229? G F, and adding G F to the Line F M, the Difference between G M and T S, that is, M S will be triple the Line F G; and therefore this is alſo the Quantity of the Line N T: Now as F E
1300 is double F G; therefore N T will be to F E as Three to Two.

Let F T be continued, if Need be, and from E draw E V perpendicular to it; the Triangles E V F and N Q T, which are rectangular, will be ſimilar, by reaſon of the alternate Angles

V F E

V F E and Q T N : * Therefore N T is to F E, *1300
that is, Three is to Two, as N Q, equal to F P, is to E V ; which therefore is proportional to two third Parts of the Force, which is expressed by F P ; but E V is the Sine of the Angle E T V at the Center, which is double the Angle E F V at the Circumference, equal to the Angle F T L, which is the Distance of the Moon from the Syzygy. Therefore, *as the Radius* T A, or T E, 1306
is to a Sine and an half of double the Distance of the Moon from the Syzygy, namely, F P, *so the Addition of Gravity in the Quadratures* (which is expressed by the Radius T A) *is to the Force which accelerates or retards the Moon in its Orbit.*

The Computation of this Diminution of Gravity, and of its Encrease at a less Distance from the Quadratures, is deduced from the same Principles.

This Diminution is represented by the Line F Q, which is equal to Q T, *minus* the Radius ; but from the Consideration of the Triangles abovementioned, V F taken once and an half is equal to Q T ; therefore V T and an half, with half the Radius added to it, expresses the required Diminution of Gravity ; and *the Radius is to the* 1307
Sum or Difference of once and a half the Co-sine of double the Distance of the Moon from the Syzygy and half the Radius : As the Addition of Gravity in the Quadratures, to the Diminution or Encrease of Gravity in that Situation of the Moon, concerning which the Computation is made.

We make use of the Difference of the Co-sine from half the Radius, when the Angle, whose the Co-sine is, is greater than a right Angle ; because in that Case we make use of the Co-sine of the Complement of the Angle to two right Angles : When in this same Case the Co-sine and a half, which we make use of, is greater

greater than half the Radius, the Quantity found is to be added; that is, encreases the Gravity, which obtains every where between the Quadrature, and 35 Degr. 16 Min. from it.

1308 *These Forces, whatever is the Figure of the Moon's Orbit, are exactly determined*; for they are compared with the Addition of Gravity in the Quadratures, supposing the Moon in the Quadrature to be at the same Distance from the Earth, at which it really is in the Place which is considered; but this Addition is discovered in every
1291 Case.
1288,
1289, Though it be foreign to the Purpose of this Work, to give a Computation of the Moon's Motion, I thought it necessary to explain in a few Words, what is the Method whereby to discover the Forces that govern the Moon; because the more exactly we know the Forces, the more easily we shall conceive their general Effect.

Now to examine the Moon's Motion, we must singly consider its several Irregularities; which to do without Confusion, we must remove several Irregularities, and conceive the Moon as moving in a Circle about the Earth, in which Curve it is plain, that it can be retain-
241, ed by Gravity. This Motion is disturbed by
1208 the Action of the Sun, *and the Orbit is more con-*
1309 *vex in the Quadratures than in the Syzygies.* The Convexity of a Curve, which a Body describes by a central Force, is so much the greater, as the central Force does more strongly every Moment turn the Body out of the Way; it is also the greater, the more slowly the Body moves; because the central Force, acting the longer, has a greater Effect in inflecting the Way of the Body. From contrary Causes the Convexity of the Curve is diminished. Both concur in encreasing the

the Convexity of the Orbit in the Quadratures,* *1303
and diminiſhing it in the Syzgies.* *1304

From this it follows, that the circular Figure of the Moon's Orbit is changed into an Oval, whoſe greater Axis goes through the Quadratures; ſo that the more convex Parts are in the Quadratures. Wherefore *the Moon is leſs diſtant from the Earth at the Syzygies, and more at the Quadratures*, and it is no Wonder that the Moon comes towards the Earth, when its Gravity is diminiſhed; becauſe the Acceſs is not the immediate Effect of this Diminution, but of the Inflexion of the Orbit towards the Quadratures. 1310

The Motion of the Moon, taking away the Action of the Sun, is not in a Circle, but in an Ellipſe, one of whoſe Foci coincides with the
Center of the Earth;* for the Orbit of the *967,
Moon is Excentric, and it is retained in it by the 241,
Force of Gravity. 1280

Therefore what has been demonſtrated cannot be exactly applied to the Moon's Motion; for as the Forces, which generate the Deviations explained, do really act upon the Moon, the Ellipſe, which the Moon would deſcribe if the Sun was taken away, is changed, *and cæteris paribus, the Propoſitions of* N° 1309, 1310, *may be applied to the Moon's Motion.* 1311

In the Quadratures and Syzygies, the diſturbing Force acts in the ſame Line as the Force of Gra- 1312
vity towards the Earth;* therefore the Force which *1286
continually acts upon the Moon, and retains it 1292,
in its Orbit, is directed towards the Center of 1294
the Earth, and *the Moon deſcribes Area's by Lines drawn to the Center, of the Earth proportional to the Times.* *215

Plate XXV. *Fig.* 1.] *In other Points of the Orbit*, as F, beſides the Force which acts in the Line F T, there is alſo another, whoſe Direction 1313

*1301 ction is perpendicular to F T, * which is here re-
presented by F P: The Direction of the Force
compounded of both, is directed sometimes side-
wise to the Line F T, and does not tend to the
190 Center of the Earth ; wherefore *the Area's, by
Lines drawn to the Center of the Earth, are not ex-*
*226 *actly proportional to the Times.** In the Octants,
F P is the greatest of all; and the Force, which is
represented by that Line, is to the Gravity of the
Moon towards the Earth, in that Point, in the
Mean Distances of the Sun and Moon, as 1 to
1306 119,49. Wherefore the Direction of the Force,
1307 compounded of the Actions of the Sun and Earth
upon the Moon, makes an Angle of above half a
Degree with the Line F T.

The Motion of the Moon is subject to several
other Irregularities; so that it describes a Curve
wholly irregular; which *Astronomers*, in order
to subject it to the most exact Computations
1314 that can be made, do *reduce to an Ellipse which
they conceive to be agitated by various Motions, and
also to be changeable, lest the Moon should go out
of it.*

In respect to central Forces we have observed,
that a Body does not describe an Ellipse, if the
central Force, by which it is retained in its Or-
bit, decreases in any other Ratio than the Inverse
Ratio of the Square of the Distance; but that the
*243 Curve may be often reduced to a moveable El-
1315 lipse : * Concerning which it is to be observ-
ed, that *the Ellipse*, in that Motion, *turns about*
1316 *one of its Foci, and the Motion of the Ellipse is
directed the same Way as the Motion of the Body in
it, when the central Force decreases faster than in the
Inverse Ratio of the Square of the Distance.* But *if
the central Force decreases slower as you recede from
the Center, the Ellipse is carried the contrary Way*;
as these Things may be demonstrated Mathema-
tically.

Hence

Hence it follows, the Orbit of the Moon cannot be referred to an Elliptic Orbit, unless you suppose it agitated by four Motions every Revolution; that is, unless the Line of the Apsides, which goes through the Center of the Earth, goes forwards twice, and backwards twice.

The Apsides of the Moon go forward when the 1317
*Moon is in the Syzygies,** or rather whilst the *1315
Moon moves between the Points, which are 54 1298
Degr. 44 Min. distant from them. * *In the Qua-* *1307
dratures, and between the Points distant from
them 35 Degr. 16 Min. *The Apsides go backwards,* 1318
that is, move in *Antecedentia.** *1316

The Forces, upon which *the Progress* and Re- 1290
gress *of the Apsides* depend, are the Forces which 1307
disturb the Motion of the Moon, which have 1319
been before explained; therefore, since the disturbing Force in the Syzygies, is double the disturb-
ing Force in the Quadratures;* the Progress, *1296
considering one entire Revolution of the Moon, exceeds the Regress, cæteris paribus.

In a Circle whose Center is in the Center of the Forces, the Diminution of the Force, in receding from the Center, produces no Effect; because in such a Line the Body does not recede from the Center; therefore the Effect of this Diminution is so much the greater, as the Curve described by the Body differs more from such a Circle.

In an Elliptic Orbit, one of whose Foci co- 1320
incides with the Center of the Forces, the Curvature in *the Apsides* differs most of all from such a Circle, and *the Effect of the Diminution of the Force, in receding from the Center of the Forces,*
is the greatest of all. If this Orbit is but a little 1321
Excentric at the Ends of the lesser Axis, the Ellipse differs very little from the Circle above-mentioned, and *the Effect of the Diminution is the least of all.*

The

1322 The *Progreſs and Regreſs of the Apſides* depend upon the Proportion, according to which the Force of Gravity decreaſes, receding from the
1315 Center of the Earth; it *is* therefore *the Effect of*
1316 *the Diminution of the Central Force.*

1323 *Plate* XXV. *Fig.* 2.] This Motion of the Apſides, which we have explained, undergoes ſeveral Changes; *the Apſides go forward faſteſt of all in a Revolution of the Moon, ſuppoſing the Line*
*1317 *of the Apſides in the Quadratures;* * *and in that*
1322 1320 *very Caſe, they go back the ſloweſt of all in the ſame*
*1318 *Revolution,* * becauſe, by reaſon of the ſame Ex-
1321 centricity of the Moon, the Quadratures are but
1322 very little diſtant from the Ends of the leſſer Axis of the Orbit.

1324 *Suppoſing the Line of the Apſides to be in the Qua-*
*1317 *dratures, the Apſides are carried in* Conſequentia,
1322 1321 *the leaſt of all in the Syzygies;* * *but they return the*
*1318 *ſwifteſt in the Quadratures;* * *and in this Caſe,*
*1322 *in one entire Revolution of the Moon, the Regreſs*
1320 *exceeds the Progreſs.*

1325 Whilſt the Earth is carried along in its Orbit, the Line of the Apſides does ſucceſſively go through all Situations in reſpect of the Sun; wherefore, *conſidering a great many Revolutions of the Moon*
*1319 *taken together, the Apſides go forwards;* * and it is plain from Obſervations, that in the Space of about eight Years, the Line of the Apſides performs one entire Revolution.

We have alſo ſaid that the Excentricity of the Orbit is not conſtant.

1326 *The Excentricity of a Body is encreaſed, if the central Force,* the Diminution being continued, *decreaſes faſter than before,* whilſt the Body is carried from the lower to the upper Apſis; for then it is every Moment leſs attracted, than if the Force did not decreaſe; and therefore it recedes the more. The Excentricity of the Orbit is alſo thereby encreaſed, in the ſame Caſe, in the

the Motion from the upper to the lower Apsis, because in this Case, coming towards the Center, the Force encreases so much the faster, as the Body descends more towards the Center; so that in each Case, the Difference between the greatest and least Distance from the Center of the Forces, may become greater, and the Excentricity be thereby encreased. By the same 1327
Reasoning it appears, that *the Excentricity is diminished, when the Central Force* is encreased, in the Motion of the Body from the lower to the upper Apsis; and likewise when that Force is diminished in the Motion from the upper Apsis to the lower; that is, when *it decreases more slowly than before, in the receding from the Center.*

Applying this to the Moon's Motion, it ap- 1328
pears, that *the Excentricity of the Orbit, every Revolution, undergoes various Changes. That it is* 1329
the greatest of all, when the Line of the Apsides is in the Syzygies; because the Forces in the Apsides, being compared, do decrease faster than in an inverse Ratio of the Square of the Distance,* *1298
whence this Addition follows,* which prevails *1326
in this Position:* But *the Orbit is the least Ex-* *1320
centric of all, when the Line of the Apsides is in the Quadratures, the Diminution of the Excentricity prevailing.* *1290

We have said that the Moon moves in a Plane 1327
inclined to the Plane of the Ecliptic; that the 1321
Line of the Nodes is carried round in *Antecedentia*;* and that the Inclination of the Orbit is *970
not constant;* these Effects are also deduced from *969
the Action of the Sun upon the Moon.

By reason of the small Inclination of the Moon's Orbit, the Forces which we have hitherto considered acting in the Plane of the Ecliptic, not regarding the Inclination of the Orbit, may (without any sensible Error) be referred to the Plane

of the Orbit; and the Moon in it is ſubject to the
1330 Motions before explained: But *there is a Force which removes the Moon from the Plane of the Orbit*;* ſo that we muſt conceive that Plane to be agitated, otherwiſe the Moon would go out of the Orbit.

*1314

1331 *Plate* XXV. *Fig.* 1.] Let the Moon be at F; if we attend to what has been ſaid above concerning the Actions of the Sun,* it is plain, that the Plane of the Parallelogram FHMI goes through the Line TS, which joins the Centers of the Earth and Sun; and therefore it is in the Plane of the Ecliptic; ſo that the Point N, to which is directed the Force FN, diſturbing on account of the Action of the Sun, is in that Plane.

*1299

1332 *Plate* XXV. *Fig.* 4.] Let the ſame Force be repreſented by FI; at F let FR be raiſed perpendicular to the Plane of the Orbit; and imagine the Parallelogram FRI*i*, whoſe Side F*i* is in the Plane of the Orbit, and whoſe Diagonal is FI; the diſturbing Force along FI is reſolved into two, in the Directions FR and F*i* which theſe Lines repreſent,* and of which this laſt acts in the Plane of the Orbit: So that we muſt refer to this what relates to the diſturbing Force, of which we have treated in N° 1299; for the Lines F*i* and FI ſcarce differ, and the Plane of the Parallelogram FRI*i* is perpendicular to the Plane of the Moon's Orbit.

*192

1333 The Line FR muſt be determined, which repreſents the Force that acts perpendicular to the Plane of the Orbit, and removes the Moon from that Plane: Now the Relation of the Line FR or I*i*, to the Radius ET, is the Ratio of the diſturbing Force, which is ſpoken of here, to the Encreaſe of Gravity in the Quadratures.*
In

*1276

In the Case of this Figure, in which the Line 1334
of Nodes N *n* is in the Quadratures, we find out FR; because I T (which is N T of *Fig.* 1.) is given,* and because I T is to *Ii*, or to F R, as *1325
the Radius to the Sine of the Inclination of the Orbit.

But in every Case the Force must be determin- 1335
ed which drives the Moon out of the Plane; let us therefore suppose the Line of Nodes carried to the Situation M *m*, whereby, every thing else remaining as before, I *i* is changed. To M *m* continued, if Need be, let *i* X and I X be drawn perpendicular, which make an Angle equal to the Inclination of the Plane of the Orbit.

The Ratio between E T and I *i*; that is, *the* 1336
Ratio between the Addition of Gravity in the Quadratures, and the Force, which we seek, *which removes the Moon out of its Orbit*, is compounded of the Ratio's of the Line E T to T I, of the Line T I to I X, and lastly of the Line I X to I *i*. The first is the Ratio between the Radius and three Times the Sine of the Distance of the Moon from the Quadrature;* the second is the Ratio of the *1305
Radius to the Sine of the Angle I T X, that is, of the Distance of the Node from the Syzygy. *Lastly*, the third is the Ratio of the Radius to the Sine of the Inclination of the Orbit: And the Ratio, compounded of these, *is the Ratio of the Cube of the Radius to three times the Product of the Sines of the Distances of the Moon from the Quadrature, and of the Node from the Syzygy, as also of the Inclination of the Plane.* To this Force is also to be referred N° 1308.

This Force vanishes in the Quadratures, because 1337
the Point I coincides with the Point T, which is the Center of the Earth, and the Line I *i* vanishes; the Lines F I and F *i* concurring in the Plane of the Orbit, which also follows from the Computation above-mentioned;* the Sine of *1136

the Diſtance of the Moon from the Quadrature vaniſhing, and conſequently, the whole Product which is multiplied by that Sine.

1331 That ſame Product vaniſhes alſo, and with it *the Force* which it repreſents, when the Sine of the Diſtance of the Node from the Syzygy *vaniſhes*, that is, *ſuppoſing the Line of the Nodes in the Syzygies*: It is alſo deduced from this, that the Line of Nodes N *n* (*Plate* XXV. *Fig.* 5.) continued goes through the Sun, wherefore the Sun is in the Plane of the Orbit itſelf, and therefore cannot draw the Moon but in that Plane.

1339 *The Force* alſo, *which we examine*, *is increaſed as the Moon advances towards the Syzygy*, *and as* *1336 *the Node recedes from it.**

1340 *Plate* XXV. *Fig.* 6.] Let P *p* be the Plane of the Ecliptic, P A the Orbit of the Moon; when the Moon is come to A, that is, is receded a little from the Node, it is removed out of the Plane of the Orbit, and in the ſecond Moment it is not carried along A B (the Continuation of the Orbit P A) but along A *b*; becauſe it comes towards the Plane of the Ecliptic along B *b*; therefore it is moved as if it came from a more di-
1341 ſtant Node *p*. Whence it appears, that *the Nodes go backward*, *whilſt the Moon moves in its Orbit*, as long as it recedes from the Node: The Nodes alſo go back, whilſt the Moon is going to the oppoſite Node; becauſe as the Moon is continually driven out of its Orbit towards the Plane of the Ecliptic, it is continually directed to a Point leſs diſtant, and comes ſooner to the Node, than if, not being agitated by ſuch a Motion, it had continued in Motion with the ſame Celerity.

1342 *Conſidering one entire Revolution of the Moon* cæteris paribus, *the Nodes move in* Antecedentia
*1339 *ſwifteſt of all*, *when the Moon is in the Syzygies*,*
then ſlower and ſlower, *till they are at Reſt*, *when*
*1337 *the Moon is in the Quadratures.* Whilſt

Whilſt the Earth is carried round the Sun (even when we do not attend to the above-mentioned Motion of the Nodes) *the Line of Nodes* 1343
does ſucceſſively acquire all poſſible Situations in reſpect of the Sun; and *every Year goes twice through the Syzygies, and twice thro' the Quadratures.*

If now *we conſider ſeveral Revolutions of the* 1344
*Moon, the Nodes in one whole Revolution go back very faſt, the Nodes being in the Quadratures;** *1339
*then ſlower, till they come to reſt, when the Line of Nodes is in the Syzygies.** *1339

By the ſame Force with which the Nodes are 1345
moved, *the Inclination of the Orbit* is alſo changed; it *is increaſed as the Moon recedes from the Node; and diminiſhed as it comes to the Node.*

Plate XXV. *Fig.* 6.] For the Angle bpL is 1346
leſs than the Angle A P L, and for the ſame Cauſe it is continually diminiſhed, and the Inclination becomes greater; but when the Moon is come to the greateſt Diſtance from the Plane of the Ecliptic, and is going towards the oppoſite Node, the Direction of the Moon is continually inflected towards the Plane of the Ecliptic, and leſs inclined to it than if it continued in Motion in its Orbit: Let Npn be the Plane of the Ecliptic; the Curve Nn the Orbit of the Moon; by the Force whereby the Moon is continually removed out of it, the Way of the Moon is changed, and it goes in the Curve Np, which is more inclined to Npn at N than at p; ſo that we muſt conceive the Inclination of the Plane of the Orbit to be twice changed;* whilſt the Moon *1314
moves from one Node to the other; therefore this happens four times *in each Revolution of the Moon,* 1347
it is twice diminiſhed, and twice again encreaſed.

Plate XXV. *Fig.* 4.] *Suppoſing the Nodes* N n, 1348
to be *in the Quadratures,* the Forces which *in one Revolution* encreaſe *the Inclination,* and diminiſh it, are equal to one another; for by reaſon of the

equal Diſtance of each Node from the Syzygies, the Forces that change the Inclination at N D and *n* E are equal to the Forces in the correſpon-
*1336 dent Points in the Arcs D *n* and E N :* By the former the Inclination is encreaſed, by the latter
1345 it is diminiſhed ; the Diminution of the Angle of Inclination, on account of the firſt, is reſtored by the Action of the ſecond, and here it *is not*
*1343 *changed.* In the Motion above-mentioned* of the Line of Nodes in reſpect to the Sun, which depends upon the parallel Situation of this Line, the Node N is carried to the Syzygy E. When (*for Ex.*) the Line of Nodes is come to the Situation M *m*, the Moon in its Receſs from the Nodes goes through the Quadratures N *n*, in which the Force which changes the Inclination
1337 vaniſhes, and near which it is the leaſt of all :*
*1336 but in coming towards the Nodes, the Moon is every where diſtant from the Quadratures, and
1336 a greater Force acts upon it ; therefore *con-*
1349 *ſidering one entire Revolution*, the Encreaſe of the
1345 Angle of Inclination exceeds its Diminution ; that is, that Angle is encreaſed, or which is the ſame, *the Inclination is diminiſhed*; which obtains every where *in the Motion of the Nodes from the Quadratures to the Syzygies.*

1350 *When the Nodes are come to the Syzygies, the In-*
1351 *clination of the Plane of the Orbit is the leaſt of all*; for *in the Motion of the Nodes from the Syzygies to the Quadratures*, the Plane of the Orbit is continually more and more inclined; for in that Caſe as the Moon goes to the Node, it paſſes through the Quadratures ; in its Receſs from them the Moon is diſtant from the Quadratures, and *in one whole Revolution of the Moon*, the Force which
*1337 encreaſes the Inclination * exceeds that which
1345 diminiſhes it ; therefore *the Inclination is en-*
1352 *creaſed* ; and *it is the greateſt of all when the Nodes are in the Quadratures*, where the Diminution of the

the Angle made by the Plane of the Orbit with
the Plane of the Ecliptic is terminated.* *1349

All the Errors in the Moon's Motion, that we have 1353
explained, *are something greater in the Conjunction*
*than in the Opposition.** *1295

All the disturbing Forces are determined by dis- 1354
covering their Relation with the Addition of
Gravity in the Quadratures ;* for which Reason *1306
they all undergo the same Changes as that Ad- 1307
dition does; that is, they *are inversly, as the* 1336
Cube of the Distance of the Sun from the Earth,* *1289
which when it remains the same, they are as the
*Distance of the Moon from the Earth.** *Consider-* *1288
ing all the disturbing Forces together, the Diminu- 1355
tion of Gravity prevails ;* which follows immedi- *1296
ately from the Progress of the Apsides ; for it ap- *970
pears from thence, that considering several Revolu- 1325
tions together, the Effect of the Diminution of *1317
Gravity exceeds the Effect of the Encrease of it.* 1318

Therefore *the Motion of the Moon being consider-* 1356
ed in general, the Gravity of the Moon towards the
Earth is diminished, coming near the Sun ;* there- *1355
fore when it is less attracted by the Earth, it re- 1354
cedes more from it than it would recede, if there was
no such Diminution of Gravity: Therefore in
that Case the Moon's Distance is encreased, as 1357
also *the Periodical Time* ;* and that Time *is the* *224
greatest, as also the Distance of the Moon (*cæteris pari-*
bus) *the greatest, when the Earth is in the Perihelion*,* *1354
because then it is least distant from the Sun.

C H A P. XVII.

Concerning the Figures of the Planets.

IF we consider the Figures of the Planets, we shall find that they have such Figures, which follow from these very Laws by which

the System is governed; which is very agreeable
to that admirable Order which we observe every
where, that no Forces act upon the Planets to
1358 destroy them; that is, that *the Figure of a Planet,*
whether it be a Primary or Secondary Planet, is such
as it would acquire, if it wholly consisted of fluid
Matter; which agrees with the Phænomena.

1359 Whence it follows, that *all the Primary and*
Secondary Planets are Spherical; for they consist
of a Matter whose Particles gravitate towards one
1206 another; from which mutual Attraction a Sphe-
1207 rical Figure is generated in the same Manner, as a
Drop becomes round from another Sort of At-
24 traction of the Parts.

1360 *This Spherical Figure of the Planets is not changed*
from their Motion round the Sun, or from the Motion
of the Secondary Planets about their Primary ones;
because all the Particles are carried by the same
Motion: But this Figure undergoes some Change
by the Motion round the Axis, and so much the
greater as this Motion is swifter.

1361 *Plate* XXV. *Fig.* 7.] Let P P be the Axis
of a *Planet*; E *e* the Diameter of the Æquator
perpendicular to the Axis; let there be a Canal
P C E filled with a Liquid; this Fluid will de-
scend by its Gravity in both Legs towards C,
and will not be at rest, till the Pressure in both
Legs be equal. If the Planet be at rest, the
1359 Height of the Fluid in both Legs will be equal:
but if the Planet be moved about its Axis P*p*,
all the Liquid in the Leg C E will endeavour to
217 recede from the Center by its centrifugal Force,
223 which Force acts contrary to Gravity, and
therefore diminishes the Gravity; so that there
is no *Æquilibrium* till C E exceeds C P. Now
if the Canal be taken away, the lateral Pressure
of the Fluid, of which the Planet consists, does
not change the Gravity towards C, nor the Dif-
ference

ference between the Heights of the Columns C E, C P;* therefore the Planet is every where higher *280
in the Æquator than in the Poles, and *acquires, by its Motion round its Axis, the Figure of a* 1362
Spheroid depressed in its Poles; for the Elevation is continually diminished as you go towards the Pole, because the centrifugal Force is diminished by reason of the Diminution of the Distance from the Axis.* *232

If what has been demonstrated be compared with the Phænomena, it will appear why all the Bodies in our System are spherical;* but that *924
this Figure is not exact, but a little changed by their Motion round their Axis,* though this can- *1362
not be observed in most of them, may be deduced from Observations made upon *Jupiter* and the Earth. *Astronomers have observed that the Axis of* 1363
Jupiter *is shorter than its Æquatorial Diameter*; although this Planet be the greatest of all the Planets, it is moved the swiftest about its Axis;* *962
and therefore this Difference may be observed.

The Elevation of the Earth at the Æquator is 1364
determined by us, although perhaps to the Inhabitants of the other Planets, if there are any, it may not be more sensible than the Elevations on *Mars* and *Venus* are to us, which are so small that we cannot perceive them.

Suppose the Earth to be fluid, it will acquire 1365
the aforesaid spheroidical Figure:* If the Parts *1361
cohere towards the Center, the Position of the other Parts will not be changed thereby, nor will it be changed, if in some Places the Parts cohere together quite to the Surface; so that the Surface of the Sea must necessarily acquire a spheroidical Figure depressed at the Poles. But since the Shores are every where but a little elevated above the Surface of the Sea, it is certain that the Continent acquires the same Figure.

Now

Now to meaſure this Elevation, that is, how much the Diameter of the Æquator of the Earth is longer than the Axis, we muſt conſider its Motion round its Axis in the Space of 23 Hours,
960 56 Min. 4 Sec. and ſuppoſing the Earth homogeneous, the Computation will be made in the following Manner.

1366 The Periphery of the Earth is 128,202,185 *Rhynland* Feet; therefore in one Second of Time, a Point of the Æquator goes through 1488 Feet; the verſed Sine of which Arc is 0,054, a Space which could be gone through by a Body in ſuch a Time by the centrifugal Force.

By a Gravity, a Body, in one Second, as we have ſhewn before, falls through 15,607 *Rhynland* Feet; but theſe Experiments were made at the Diſtance of 48 Degr. from the Æquator E *e* (*Plate* XXV. *Fig.* 7.) at the Point A, the centrifugal Force at E is to the centrifugal Force at A, as C E to C A, for theſe Lines are very little dif-
232 ferent at A B: Let this centrifugal Force be A *b*; having drawn the Perpendicular *b a* to C A continued, let the Force through A *b* be reſolved into two other Forces directed along A *a*
*192 and *a b*;* the Gravity is diminiſhed only by the former, and A *b* is to the Force diminiſhing it, as C A to A B, by reaſon of the ſimilar rectangular Triangles A *b a* and A B C, which have their oppoſite vertical Angles equal at A; therefore the centrifugal Force at the Æquator, with which a Body in one Second goes through 0,054; is to the Force which diminiſhes the Gravity at A, in a duplicate Proportion of the Radius A C to A B, which is the Co-ſine of the Latitude A E of 48 Degr. So that from this diminiſhing Force the Body in one Second goes through 0,0243; wherefore, if the Earth was at reſt, in falling it would not go through 15, 607 Feet, but 15,632; with

with which Gravity a Body falls under the Poles, becauſe theſe Points are not moved. At the Æquator, by the centrifugal Force, a Body goes through 0, 054. and falls as much in the ſame Time from the Height of 15, 578 Feet; whence it appears that the Gravity under the Poles is, to the Gravity under the Æquator, as 289 to 288.

If *Fig.* 7. repreſents the Figure of the Earth, the Weight of a Column of Liquid C E will be to the Weight of a Column of Liquid C A, the Earth being at reſt, as 289 to 288; for otherwiſe, the Earth moving, there will not be an *Æquilibrium*; becauſe $\frac{1}{289}$ of the Column C E is ſuſtained by the centrifugal Force; for the centrifugal Force decreaſes as you come towards the Center, in the Ratio of the Diſtance,* in which Ratio alſo the *232
Gravity decreaſes;* ſo that in all the Points of *1233
the Column, the ſame Part of the Weight is ſuſtained, as towards the Surface.

Whence we deduce, that *the Height* C P *at the* 1367
Pole is, to the Height E C *at the Æquator, as* 229 *to* 230; for ſuppoſing this Ratio between the Axis and the Æquatorial Diameter, if a Computation be made of the Gravities in the Places P and E, the Earth being at reſt, they are found to be to one another, as 1121, 71. to 1120, 71; which Ratio obtains every where in correſpondent Points, that is, which are diſtant from the Center as C P to P E; becauſe in both Legs the Gravity decreaſes in Proportion to the Diſtance from the Center.* You have the Weight *1233
by multiplying the Quantity of Matter by the Gravity; for the Weight encreaſes in a Ratio of both: By multiplying 1121, 71. by 229, and 1120, 71. by 230. the Products are to one another as 288 to 289; which is the Ratio of the Weights before diſcovered. The mean Diameter of

976 of the Earth is 3,400,669 Perches, therefore the Axis P P is 3,393,261, and the Æquatorial Diameter E *e* is 3,408,078 Perches, which exceeds
1368 the Axis by 14,817 Perches (*viz.*) $\frac{1}{230}$, and *the Æquator is more elevated by* 7408,5.

1369 In this Computation, as we have said, we have looked upon the Earth as homogeneous; but if it be more dense towards the Center, the Matter which is added to it may be looked upon as a separate Body, from whose Center the Points P and E are unequally distant, and towards which therefore the Bodies P and E have a dif-
1226 ferent Gravity; and the Difference is so much the greater as these Differences are greater; and it will be also so much the greater in respect of the whole Gravity, as the Quantity of Matter which is added, or which is the same, as the Density is greater towards the Center.

It is plain that the Forces of Gravity, at the Poles and the Æquator, differ from one another more than $\frac{1}{289}$ Part, by comparing together Experiments made at several Distances from the Æquator, by the Help of Pendulums, by which the Forces of Gravity may be compared together,
164 as we have shewn; and which Difference is truly
165 nearly double that which is found by Computa-
1370 tion; whence it follows, that *the Elevation of the Æquator is nearly double that which we have de-*
*1368 *termined to be* 7408, 5 *Perches.**

Now if we consider the spheroidical Figure
1371 of the Earth, we shall see that *heavy Bodies do not tend directly to the Earth's Center*, unless at the Poles and the Æquator, *but every where perpendicularly to the Surface* of the Spheroid; for a Liquid will not be at rest, unless its upper Surface forms a right Angle with the Direction of heavy
272 Bodies; and the Figure of a Spheroid is formed by the Surface of a quiescent Fluid. We

also

also deduce this Direction of heavy Bodies from 1372
the centrifugal Force (*Plate* XXV. *Fig.* 7.) The Body A, by its Gravity, tends towards C, and is carried by its centrifugal Force along A *b*: This Force at the Point A is to the Gravity along A C, as 1 to 430, 8. having formed a Parallelogram with the Sides A *c* and A *b*, supposing these to one another, as 430, 8. to 1, the Diagonal will shew the Direction of heavy Bodies,* *190
forming a small Angle with the Line A C. The Force along A *b* encreases as you go towards the Æquator, whereby this Angle is encreased, but is diminished by the Encrease of the Angle C A *b*; so that in the Æquator, where the centrifugal Force is greatest, the Direction of heavy Bodies coincides with E C; at the Pole it coincides with P C; because there is no centrifugal Force there.

In this spheroidical Figure, *the Latitude of the* 1373
Place is determined by an Angle, as A C E, *which is made with the Æquator, by a Line drawn from the Place of the Center.* Dividing this whole Arc P A E, by this Method, into 90 Parts, that is, into Degrees, it will easily appear, that *going* 1374
towards the Poles, the Degrees are encreased on the Surface; but this Difference is so very small, that in measuring Degrees that are not very distant, it cannot be discovered; because the Error, arising from the Make and Use of the Instruments, exceeds this Difference. Whence Degrees measured at the South and North of *France*, as also in *England*, differ little from one another, and the middle one is the least of all; wherefore *nothing can be concluded concerning the Earth's* 1375
Figure from these Measures.

CHAP.

CHAP. XVIII.

The Physical Explanation of the Motion of the Axis of the Earth.

THAT the Nodes of the Moon go back,
*1341 that is, are moved in *Antecedentia*,* and
that the Inclination of its Orbit is liable to
1347 Change, we have already demonstrated; let us conceive several Moons to be at the same Distance, revolving in equal Times about the Earth, in a Plane inclined to the Plane of the Ecliptic; it is plain they will all be agitated by the same Motions: Let us conceive the Number of the Moons to be encreased, so as to touch one another, and form a Ring, whose Parts cohere; whilst one Part of the Ring is attracted, to encrease the Inclination, the other Part is
1376 agitated by a contrary Motion, to diminish its
1345 Inclination; the greater Force in this Case pre-
1377 vails, that is, *in the Motion of the Line of Nodes, from the Quadratures towards the Syzygies, the Inclination of the Ring is diminished in each of its*
*1349 *Revolutions;* and it is the least of all, when the*
*1350 *Line of Nodes is in the Syzygies.** On the contrary, *its Inclination is encreased, when the Line of Nodes is carried from the Syzygies towards the Quadra-*
*1351 *tures;* and it is the greatest of all, when the Line of*
1378 *the Nodes is in these last.* The Line of the*
*1352 *1341 *Nodes is continually carried in* Antecedentia, *un-*
1344 *less when it is at rest in the Syzygies.**

1379 *If the Quantity of Matter in the Ring be diminished, its Motions will not be changed*; because they depend upon Gravity, which acts equally up-
1027 on every Particle of Matter.

If

If the Diameter of the Ring be diminiſhed, theſe 1380
Motions are diminiſhed in a Ratio of this Di-
minution,* but none of them wholly vaniſh; and *1354
it is agitated by the ſame Motions.

Let us conceive the Earth to be ſpherical; and 1381
in the Plane of the Æquator, which makes an
Angle of 23 Degr. 29 Min. with the Plane of
the Ecliptic, let there be a Ring, revolving in
the ſame Time as the Earth; let it be diminiſhed
ſo as to touch the Earth, and cohere with it;
by this the aforeſaid Motion of the Ring will
not be deſtroyed; for ſince the Earth is kept in
a determinate Situation by no Force, it yields to
the Impreſſions of the Ring, whoſe Agitations
are yet diminiſhed, the Matter to be moved be-
ing encreaſed, and the moving Power remaining
the ſame.

And this is truly the Caſe, for the Figure of
the Earth is ſpherical, encompaſſed with a Ring
at the Æquator, whereby the Earth is more ele-
vated towards the Æquator,* the Line of Nodes *1370
of which Ring is the Section of the Planes of
the Æquator and Ecliptic. Whence we deduce
the following Concluſions.

In the Æquinoxes, the Inclination of the Æ- 1382
quator is leaſt of all;* and therefore *the Incli-* *1377
nation of the Axis is the greateſt; for it makes a
right Angle with the Plane of the Æquator.* *1075
The Inclination of the Æquator is encreaſed, that
is, *the Inclination of the Axis is diminiſhed, till* 1383
the Sun comes to the Solſtices, where this Inclination
of the Axis is leaſt of all, and that of the Æquator
the greateſt.* Therefore *twice in a Year the In-* *1377
clination of the Axis of the Earth is diminiſhed, and
twice encreaſed. And *the Section of the Plane of the* 1384
Æquator with the Plane of the Ecliptic, which *is* 1385
at reſt in the Æquinoxes, the reſt of the Time is
moved in Antecedentia.*

*1378

The

1386 The Plane of the Æquator is enclined to the Plane of the Moon's Orbit; for it makes a ſmall
969 Angle with the Plane of the Ecliptic: And therefore the Moon acts in the ſame Manner upon the Ring as the Sun; and although the Moon be leſs, yet, becauſe it is much leſs diſtant than the Sun, it exerts a greater Action upon the Ring.
1387 Wherefore alſo *the Inclination of the Axis of the*
*1384 *Earth to the Plane* of the Moon's Orbit* (and conſequently to the Plane *of the Ecliptic*) *is twice changed in every Revolution, and twice reſtored by the Action of the Moon: And the Section of the Plane of the Æquator*, with the Plane of the Moon's
1385 Orbit, *is carried in* Antecedentia: From which Motion neceſſarily follows, that the Section of the Plane of the Æquator, *with the Plane of the Ecliptic, changes its Place.*

1388 *The Changes of the Inclination of the Axis are too ſmall to be obſerved; but the change of Place of the*
1389 *Line of the Equinoxes, and the Motion of the Axis* which follows from it, being always carried the ſame Way, *at laſt become ſenſible*; and from theſe
1185 1186 follow the Phænomena before explained.

CHAP. XIX.

Concerning the Tides.

THAT we may explain the Tides from the Principles already laid down, we muſt conſider, that the Earth, as alſo all Bodies near it,
1206 gravitate towards the Moon; therefore the Particles of Water in the Earth's Surface which tend towards the Center of the Earth (for here we neglect the Conſideration of N° 1371.) are carried with it towards the Moon. Since alſo the ſolid Maſs of the Earth is carried towards the Moon, according to the Laws, which would obtain

obtain, if all the Matter of which it consists was collected in its Center ;* *what has been demon- strated in* Chap. 16. *of the Action of the Sun upon the Moon* falling towards the Earth, whilst with the Earth it goes towards the Sun, *may be applied to the Action of the Moon upon the Particles of Water in the Earth's Surface*, which do not cohere with the Mass of the Earth, but tend towards its Center, and continually with its Mass fall towards the Moon; by which Force, as we have shewn,* the Earth is kept in its Orbit, about the common Center of Gravity of the Earth and the Moon.

*1126 1390 *1280

1391 *Plate* XXV. *Fig.* 1.] Let S be the Moon; ALBL*l* the Surface of the Earth, whose Mass tends towards the Moon, as if it was all collected at T ; by the Action of the Moon, the Particles of Water, A and B, acquire a greater Gravity towards T ;* on the contrary, the Particles at L, *l*, lose of their Gravity ;* whence we deduce, that if the whole Earth was covered with Water, there would not be an *Æquilibrium*, unless this Water was more elevated in the Points L and *l*, than in a whole Circle 90 Degrees distant from these Points; and therefore passing through the Points A and B. Therefore *by the Action of the Moon, the Water acquires a spheroidical Figure, formed by the Revolution of an Oval about its greater Axis, which, being continued, goes through the Moon.*

*1287 *1296 1392

Let us suppose the Moon in the Æquator ; all the Sections of the Earth which are parallel to the Æquator, as they are also parallel to the Axis of the Spheroid* are Oval, whose greater Axes pass through the Meridian of the Moon ; whence it follows, that *the Earth being at Rest, in any Circle of Latitude, the Water is more elevated*

*1392 1393

in the Meridian in which the Moon is, and in the opposite Meridian, than in the intermediate Places.

DEFINITION.

1394 The Lunar Day *is the Time spent between the Moon's going from the Meridian and coming to it again.* This Day is divided into 24 Lunar Hours: It is 50 Minutes longer than the Natural Day.

From the Motion of the Earth round its Axis, every Lunar Day, every Place passes through the Meridian of the Moon and the opposite Meridian, that is, twice passes through that Place,
1395 where the Water is raised *by the Action of the Moon*, and twice through that Place, where the
1393 Water is dispersed by the same Action; and so *in a Lunar Day the Sea is twice elevated, and twice depressed, in any assigned Place.*

1396 By the Motion of the Earth round its Axis, the elevated Water continually recedes from the Meridian of the Moon; yet by the Action of the Moon, the Axis of the Spheroid passes
1392 through the Moon; therefore the Water is continually agitated, that the Elevation, which (on Account of the Motion of the Earth) is removed, may be brought under the Moon. Therefore the Water continually flows from A and B (*Plate* XXV. *Fig.* 1.) towards L and *l*, whilst, by the Motion of the Earth, the Elevation is carried from L towards B, and from *l* towards A; that is, between L and B, as also between *l* and A, there are two contrary Motions, by which the Water is accumulated; so that the greatest Elevations are between these Points (*viz.*) not directly under the Moon, but on one Side of that Point, and likewise aside of
1397 the opposite Point. That is, in any Place, *the Water most elevated, two or three Hours after the Moon*

Moon has passed the Meridian of the Place, or the opposite Meridian.

The Elevation towards the Moon a little exceeds 1398
*the opposite one.** *The Ascent of the Water is dimi-* *1390
nished, as you go towards the Poles, because there 1295
is no Agitation of the Water there.

What has been demonstrated, in relation to 1399
the Moon, may be applied to the Sun; therefore 1400
from the Action of the Sun, every natural Day, the 1401
*Sea is twice elevated, and twice depressed**. *This* *1395
Agitation is much less, on account of the immense
Distance of the Sun, *than that which depends upon the Moon*; yet *it is subject to the same Laws.* 1402

The Motions, which depend *upon the Actions of* 1403
the Moon and Sun, are not distinguished, but confounded; and from the Action of the Sun, *the Lunar Tide is only changed*; *which Change varies*
every Day, by reason of the Inequality between 1404
the Natural and Lunar Day*. *1394

In the Syzygies, the Elevation, from the Actions 1405
of both Luminaries, concur, and *the Sea is more elevated*; *the Sea ascends less in the Quadratures*; for where the Water is elevated by the Action of the Moon, it is dispersed by the Action of the
Sun, and so on the contrary. Therefore, *whilst* 1406
the Moon passes from the Syzygy to the Quadrature, the daily Elevations are continually diminished: On the contrary, *they are encreased when the Moon*
moves the Quadrature to the Syzygy. *At a New* 1407
Moon also, *cæteris paribus*, *the Elevations are*
greater, and those that follow one another the same *1398
*Day, are more different than at a Full-Moon.** 1402

The greatest and least Elevations are not observed, 1408
till the second or third Day after the New or Full Moon; because the Motion acquired is not presently destroyed from the Attrition, and other Causes, by which acquired Motion the Ascent of the Water is encreased. Although the Action by which

which the Sea is raiſed be diminiſhed; ſomewhat like to what we have demonſtrated elſewhere con-
1174 cerning Heat.

1409 If now we conſider the Luminaries receding from the Plane of the Æquator, we ſhall perceive that *the Agitation* is diminiſhed, and *becomes leſs, according as the Declination of the Luminaries becomes greater.* Which plainly appears, if we conceive them to be in the Poles; for then the Axis of the ſpheroidical Figure coincides with the Action of the Earth; and all the Sections that are parallel to the Æquator, are perpendicular to the Axis of the Spheroid; and therefore circular. So that the Water, in every Circle of Latitude, will have every where the ſame Elevation; and ſo in the Motion of the Earth, the Height of the Sea is not changed in particular Places. If the Luminaries recede from the Poles, it is eaſy to find, that the Agitation will be more and more encreaſed, till it be the greateſt of all, the Spheroid revolving about a Line perpendicular to the Axis, the Axis of the Spheroid being ſuppoſed in the Plane of the Æquator.

1410 Hence it is plain, why *in the Syzygies, near the Æquinoxes, the Tides are obſerved to be the greateſt*, both Luminaries being in or near the Æquator.

1411 *The Actions of the Moon and Sun are greater, the*
*1354 *leſs thoſe Bodies are diſtant from the Earth**; but
*1390 when the Diſtance of the Sun is leſs, and it is in the South Signs, often both the greateſt Æquinoctial Tides are obſerved in that Situation of the Sun; that is, before the Vernal, and after the Autumnal Æquinox, which yet does not happen every Year; becauſe ſome Variation may ariſe from the Situation of the Moon's Orbit, and the Diſtance of the Syzygy from the Æquinox.

Plate

Plate XXV. *Fig.* 8.] *In Places distant from the* 1412
Æquator, as the Luminaries recede from the Æquator, the Elevations, that happen the same Day, are unequal. Let P P be the Axis of the Earth, E E the Æquator, L *l* a Circle of Latitude; A B the Axis of the spheroidical Figure which the Water forms: When a Place in the Circle L *l* is given at L or *l*, it is given in the same Meridian with the Axis of the Spheroid, and the Water is most elevated, in both Cases; yet at L it is more elevated than at *l*; for C l exceeds C *l*, which Lines measure the Heights of the Waters, that is, the Distances from the Center: These Lines would be equal if A L and B *l* (which are the Distances from the Axis of the Spheroid) were equal. But C *l* is less, because B *l* exceeds A L, which arises from the Inclination of the Axis of the Spheroid to the Æquator.

As long as the Moon is on the same Side of the 1413
Æquator in any Place, that is, towards the Line
C A continued, *the Elevation of the Water is ob-* 1414
served to be greatest every Day, after the Moon has passed the Meridian of the Place; for there is the greatest Elevation when the Place is come to L; but *if the Æquator* separates, or *is between* the *Moon and the Place*, of which we speak, that is, if the Moon be towards the Line C B continued, the Water again at L will come to the greatest Height, and, *every Day, the greatest Elevation of the Sea will be, after the Moon has passed through the opposite Meridian.*

All Things, which have been hitherto explained, would exactly obtain, if the whole Surface of the Earth was covered with Sea; but since the Sea is not every where, some Changes arise from thence, not indeed in the open Sea; because the Ocean is extended enough to be subject to the Motions we have spoken of. But

1415 *the Situation of the Shores, the Streights, and many other Things depending upon the particular Situation of the Places, disturb these general Rules.* Yet it is plain from the most general Observations, that the Tide follows the Laws which we have explained. What remains is, to determine the Forces with which the Sun and Moon act upon the Sea, that it may appear, that they are able to produce the Effects which we have mentioned; and that the Actions of those Bodies, upon Pendulums and other Bodies, are insensible.

1416 The Encrease or Addition to the Gravity of the Moon in the Quadratures, from the Action of the Sun, is to the Gravity of the Moon to-
1291 wards the Earth, as 1 to 178, 73. In which Computation we have supposed the mean Distance of the Moon from the Center of the
1285 Earth to be 60 Semidiameters of the Earth: Therefore the Gravity of the Moon is to the Gravity of the Earth's Surface, as 1 to 60 × 60
1208 =3600. Therefore the above-mentioned Encrease is to the Gravity on the Earth's Surface, as 1 to 643428, in which Computation there is an Error to be corrected.

This Computation would be exact, if the Encrease, of which we speak, was to the Force, with which the Earth descends towards the Sun, as the Distance of the Moon (which is 60 Semidiameters of the Earth) to the Distance of
1287 the Earth from the Sun; but it is as the true mean Distance of the Moon, which is 60½ Semidiameters of the Earth to the Distance of the Earth from the Sun. Wherefore the Encrease, that we have just determined, ought to be $\frac{1}{120}$ Part encreased, and will be to the Force of Gravity on the Earth's Surface, as 1 $\frac{1}{120}$ to 643428, or as 1 to 638110, 4.

This Encrease of the Gravity of the Moon, in the Quadratures from the Action of the Sun,

is to the Encreaſe of the Gravity of the Water on the Earth's Surface, in Places which are 90 Degr. diſtant from the Sun (from the ſame Action of the Sun) as 60½ to 1*. Therefore this *1288
Encreaſe of the Gravity is to the Gravity of the Water, as 1 to 38605679. The Diminution of the Gravity, under the Sun, and in the oppoſite Place, is double this Encreaſe *; therefore it is to *1296
the Gravity as 1 to 1930 839, and *the* whole 1417
Change in the Gravity, ariſing from the Action of the Sun, is to the Gravity itſelf, as 1 *to* 12868560.

In order to compare the Action of the Moon 1418
with the Action of the Sun, we muſt make Experiments in Places, in which, by reaſon of the Narrowneſs, the Sea is ſenſibly raiſed. Near *Briſtol* at the Autumn and Spring, at which Times the Agitation of the Sea is greateſt*, the *1410
Water aſcends in the Syzygies about 45 Feet, more or leſs, in the Quadratures about 25 Feet, more or leſs. Which Numbers are to one another as 9 to 4.

The Determination of the Forces, which we would find, if the greateſt and leaſt Elevations were exactly at the Time of the Syzygies, would be very eaſy, which we have ſhewn before not to happen ſo*. *1408

The Diſtance of the Moon from the Syzygy, or the Quadrature, is not always the ſame in the greateſt or leaſt Elevation; for this Diſtance varies, becauſe the Moon is ſometimes more, and ſometimes leſs diſtant from the Meridian, when it goes through the Syzygy or Quadrature. The mean Diſtance of the Moon from the Syzygy, or Quadrature, to which the aforeſaid Obſervations ought to be referred, is about 18 Degr. 30 Min. ſo that the whole Action of the Sun neither conſpires with the Action of the Moon in the Syzygies, nor acts contrary to it in the Quadratures. Alſo in ſuch a Caſe, if at

the Syzygy, both the Luminaries be in the Æ-
quator, in the ſaid Diſtance from the Quadrature,
the Declination of the Moon is 22 Degr. 13 Min.
more or leſs; whereby the Force of the Moon to
1409 move the Sea is diminiſhed. Beſides, *cæteris pa-
ribus, the Diſtance of the Moon from the Earth
1310 at the Syzygies is leſs than at the Quadratures;
1311 whence alſo the Action of the Moon is diminiſh-
1411 ed at the Quadratures: By attending to all which
Things we may diſcover, that *the mean Force of*
1419 *the Sun, to move the Sea, is to the mean Force of the
Moon to move the ſame, as* 1 *to* 4,4815. But the
Force of the Sun is to the Force of Gravity, as
1417 1 to 12868560; wherefore *the Force of the Moon
is to the* ſame *Force of Gravity as* 1 *to* 2871485.
1420 From whence it follows, that theſe Forces of the
Moon and Sun are too ſmall to be ſenſible in
Pendulums and other Experiments; but it is eaſily
proved, that they are capable of agitating the
Sea.

By diminiſhing the Gravity $\frac{1}{289}$ Part, the Sea
*1368 is raiſed to the Height of 88902 *Rhynland* Feet*.
1417 For each Perch contains 12 Feet; whence, by the
1421 Rule of Proportion*, we find that *the Action of*
1422 *the Sun changes the Height of the Sea two Feet,*
*1419 *and that the Action of the Moon changes it* 8, 95;*
*and that from the joined Action of both, the mean
Agitation is of about eleven Feet*, which agrees pret-
1423 ty well with Obſervations; for in the open Ocean,
as the Sea is more or leſs open, the Water is
raiſed to the Height of Six, Nine, Twelve, or
Fifteen Feet; in which Elevations alſo there
is a Difference ariſing from the Depth of the
Waters. But thoſe Elevations, which far exceed
theſe, happen, *where the Sea violently enters into*
1424 *Streights or Gulphs*; where *the Force is not broken,
till the Water riſes higher.*

CHAP.

CHAP. XX.

Of the Moon's Density and Figure.

THE Forces of the Sun and Moon, for 1425
giving Motion to the Sea, are to one another, in a Ratio compounded of the Ratio of the Quantities of Matter in these Bodies* (for all the *1207
Particles of Matter act) and the inverse Ratio of the Cubes of the Distances of the Sun and Moon from the Earth * *1390

The Quantities of Matter are in a Ratio com- 1402
pounded of the Ratio of the Bulks, that is, of 1354
the Cubes of the Diameters, and the Ratio of the Densities;* wherefore the Forces above- *288
mentioned are directly as the Densities and the 79
Cubes of the Diameters, and inversly as the Cubes of the Distances.

The apparent Diameters of Bodies, that is, the Angles under which they are seen, encrease as the Diameters themselves, and diminish as the Distances; that is, they are directly as the Diameters, and inversly as the Distances; therefore the Ratio compounded of the Ratio's of the Cubes of the apparent Diameters *of the Sun and Moon*, and of the Ratio of the Densities, will be the Ratio of the Forces, whereby those Bodies act upon the Sea. Therefore the *Densities* of those 1426
Bodies *are directly as the Forces, whereby they move the Sea, and inversly as the Cubes of their apparent Diameters*; and dividing the Forces by the Cubes of those Diameters, you have the Ratio of the Densities.

The Force of the Sun is to the Force of the
1419 Moon, as 1 to 4, 4815; the mean apparent
Diameter of the Sun is 32 Min. 12 Sec. and the
mean apparent Diameter of the Moon is 31 Min.
$16\frac{1}{2}$ Sec. That is, they are to one another, as
1427 3864 to 3753. Therefore *the Denſity of the Sun
is to the Moon's Denſity, as* 10000 *to* 48911 : which
Denſity of the Moon may be compared with the
*1260 Denſities of *Jupiter*, *Saturn*, and the Earth*, and
the Moon is denſer than the Earth.

The Quantities of Matter in two Bodies are
to one another, in a Ratio compounded of the
79 Denſities and Bulks; that is, if the Body be a
Sphere, in a Ratio compounded of the Denſities
and the Cubes of the Diameters.

1428 *The Denſites of the Moon and Earth are to one*
*1427 *another*, as 48911 to 39214*; the Diameters
1260 as 11 to 40, 2. therefore the *Quantities of Matter*,
in thoſe Bodies, *are as* 1 *to* 39, 13. Though the
Denſities be diſcovered, if you ſuppoſe the Bodies
to be homogeneous; yet the Quantities of Matter
will be rightly defined, though the Bodies are not
homogeneous; for we determine the Denſity which
that Body would have, if the Matter, of which
the Body really conſiſts, was equally diffuſed all
over it.

1429 *The Gravities, on the Surfaces of the Earth and
Moon, are* determined, by multiplying the Denſi-
1230 ties by the Diameters, that is, they are to one
another, as 2, 93 to 1, or *as* 407,8 *to* 139, 2.
Which Number alſo does expreſs the Relation of
Gravity on the Surface of the Moon, with the
Gravity on the Surfaces of the Sun, *Jupiter* and
*1258 *Saturn*.*

1430 *The common Center of Gravity of the Moon and
Earth*, about which both Bodies are moved, is
determined; for its Diſtance from the Center of
the

the Earth, *is to the Distance* between the Centers
of both Bodies, as the Quantity of Matter in the
Moon to the Quantity of Matter in both Bo-
dies ;* therefore 40, 13. is to 1 : as the Distance *234
of the Moon from the Earth, is to the required 235
Distance of the Center of Gravity, *from the Center
of the Earth*, which is found to be *of* 5126950
Perches, as is deduced from the known Diame-
ter of the Earth*, and the Distance of the *976
Moon.

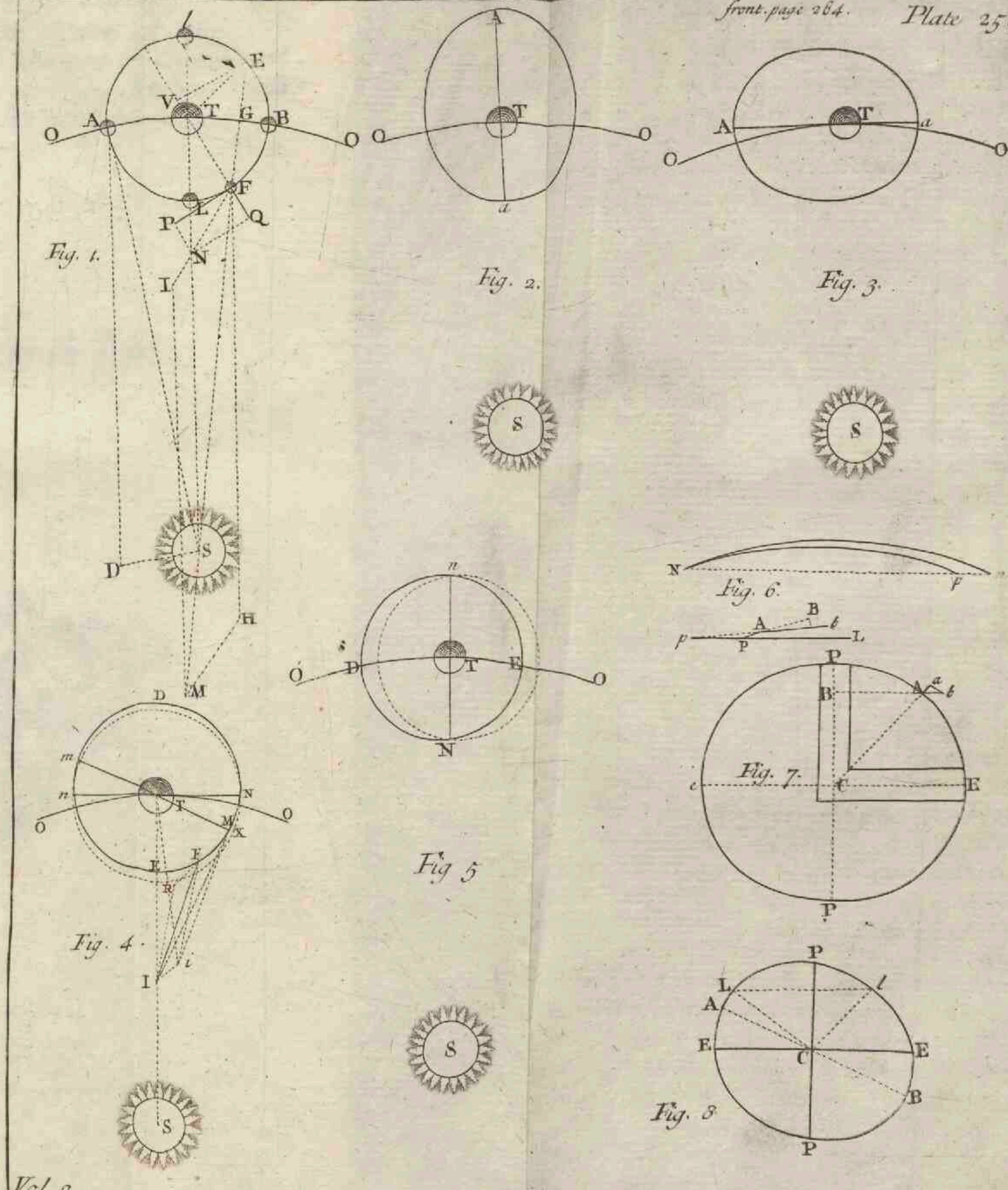
To determine the Figure of the Moon, we 1431
must examine what Figure it would have, if it
was fluid*. If we consider the Moon alone at *1358
rest, it would be spherical :* If we consider the *1359
Action of the Earth upon the Moon, the Moon
would acquire the Figure of a Spheroid, whose
Axis would go through the Earth*. The Force *1392
of the Earth, for changing the Figure of the
Moon, is to the Force of the Moon upon the
Earth, as 39, 13. to 1.* and as the Diameter of *1418 1207
the Moon to the Earth's Diameter,* which are *1390
to one another as 11 to 40, 2. and it is a Ratio 1354
compounded of these 10 7. to 1. This Force
of the Moon is to the Gravity upon the Earth's
Surface, as 1 to 2871485 ;* which Gravity, on *1420
the Earth's Surface, is to the Gravity on the
Surface of the Moon, as 407, 8, to 139, 2.* or *1429
as 2871485, to 980028 : Wherefore *the Action of
the Earth, for changing the Moon's Figure, is to the
Gravity upon the Moon's Surface, as* 10, 7. to 1432
980028, *or as* 1 *to* 91524, the Gravity being
changed on the Earth's Surface, by $\frac{1}{2871485}$ Part
the Water is raised 8, 95 Feet ;* and therefore if *1420
Gravity was to be changed $\frac{1}{915}$ Part, the Eleva- 1422
tioned would be of 280, 7 Feet, as it is found by the
Rule of Three. If, keeping this Diminution of
Gravity, we consider a less Body, this Height
must

must be diminished, in Proportion to the Diameter: Therefore, from the Action of the Earth, the Elevation of the Moon is of 76, 8 Feet; and if the
1433 Moon be homogeneous, *there will not be an Æquilibrium, unless the Axis of the Spheroid exceeds the Diameter, which is perpendicular to it*, 153, 60 Feet.

1434 *The Elevation of the Moon*, from the Action *of the Earth*, may be discovered by one single Proportion, by knowing the Elevation of the Sea from the Moon's Action; for these Elevations *are in a duplicate inverse Ratio of the Gravities on the Surfaces of those Bodies.*

1435 If, supposing this to be the Figure of the Moon, we conceive the Parts to cohere, *there will not be an Æquilibrium between the Parts of the Moon, unless* the Axis of the Spheroid be directed towards the Earth; whence we see the Reason, why *the Moon always turns the same Face towards the Earth*; by which continual Agitation, the Moon
1436 has at least acquired *the Motion about its Axis* of
970 which we have before spoken; which Motion
1092 *must necessarily be performed in the same Time, as the Moon performs one Revolution*; for from the Action above-mentioned, it must necessarily adapt itself to such a Celerity; for if the Celerity was greater, it would be continually retarded by the Force, whereby the same Face is always directed towards the Earth; and, if this Celerity was less, it would be continually accelerated. Yet this Force is not great enough, sensibly to disturb the Æquibility of the Motion acquired a-
1437 bout the Axis, every Revolution: Therefore *the Motion about the Axis is equable, though the Moon*
*966 *be moved in its Orbit by an unequal Motion**. The Position also of the Moon's Axis cannot be so changed by the Force above-mentioned, as to become

front. page 264. Plate 25.



become perpendicular to the Plane of the
Orbit, when its Inclination is changed;* there- *1345
fore *the Axis of the Moon is sometimes inclined* 1438
to the Plane of the Orbit, as we have before
shewn*. *1093

The End of the Fourth Book.

A N

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