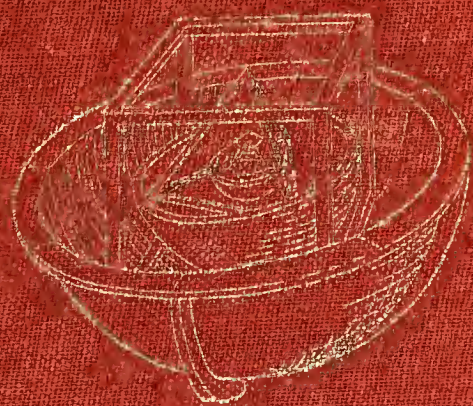




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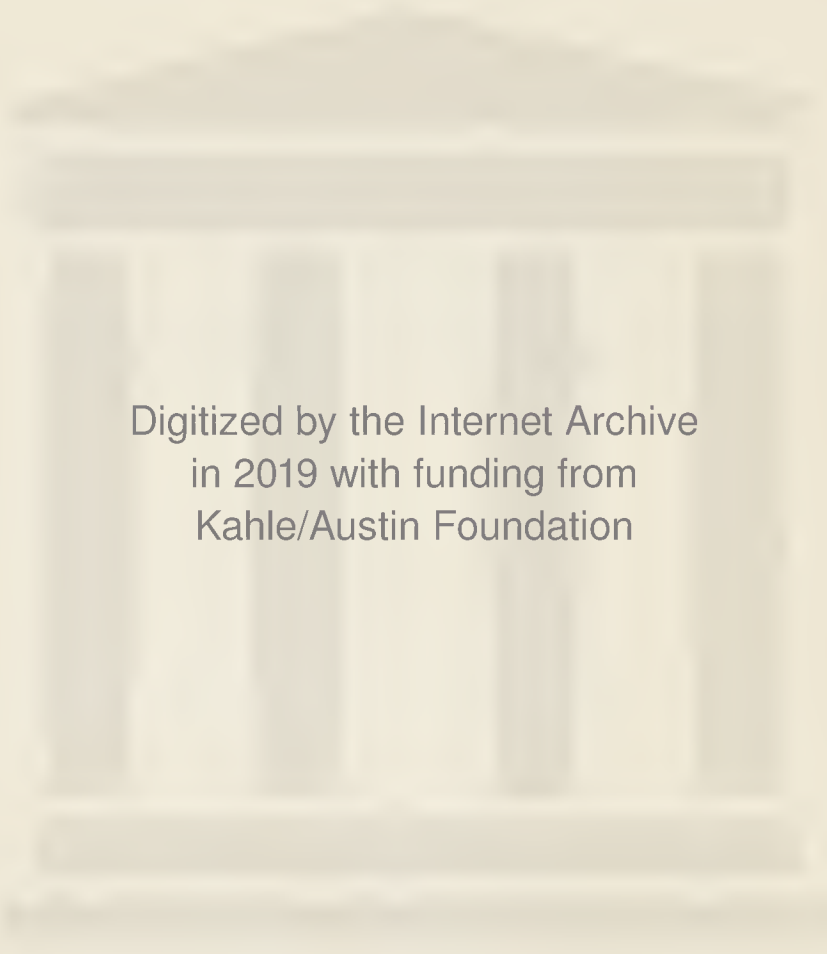
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THE ELEMENTS OF
SIR ISAAC NEWTON'S PHILOSOPHY



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THE ELEMENTS
OF
SIR ISAAC NEWTON'S
PHILOSOPHY

VOLTAIRE

TRANSLATED BY
JOHN HANNA



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This is an exact reproduction of the 1738 edition of Voltaire's *The Elements of Sir Isaac Newton's Philosophy*. An index, prepared under the General Editor's supervision, has been added.

T H E
E L E M E N T S
O F

Sir ISAAC NEWTON'S
PHILOSOPHY.

By Mr. VOLTAIRE.

Translated from the FRENCH.

Revised and Corrected

By J O H N H A N N A, M. A.

Teacher of the Mathematicks.

With Explication of some Words in Alphabetical
Order.

*Pulchre sibi disputare videntur, cum quod evertere
non possunt, tanquam ridiculum contemnunt.*

Horroccius.

L O N D O N :

Printed for STEPHEN AUSTEN at the
Angel and Bible in St. Paul's Church-Yard.

MDCCXXXVIII.

M. VOLTAIRE

TO THE

MARCHIONESS du CH**

IMMORTAL Emily, vast, pow'rful Mind,
 Pallas of *France*, and Glory of thy Kind,
 Surpassing Age, ev'n in thy Bloom of
 Youth,

The Pupil, Friend, of *Newton*, and of Truth.
 Thy Fires transpierce me, and thy Charms
 controul ;

5

I feel the Force, the Brightness of thy Soul !
 To Thee attracted, I renounce the Bays
 Sought on the Stage, while yet I liv'd on
 Praise.

My Wit, corrected, roves not as before,
 Of vain Applause, idolatrous no more !

10

Let Earth-born *Rufus* with Resentment
 rave,

And drag his senseless Fury to the Grave.
 In Rhyme still straining, coldly to enclose
 Some trivial Thought, that would depreciate
 Prose,

That

D E D I C A T I O N.

15 That harmless Thunder let him hurl at me,
Which first his Rage for others might decree.
To blast my Fame let Pedant *Zoilus* seek,
And spread unmeaning Malice once a Week.
With me their Envy withers in the Bud ;
20 I see no Tracts imprinted in the Mud.

Philosophy, all-charming, pow'rful Queen,
Lifts the wise Mind above corroding Spleen.
Happy on high, where *Newton* now remains,
Knows He on Earth if Enmity yet reigns?
25 Not more than He my Enemies I know,
While Truth august invites me from below.

Already see ! she opes the Gate of Day !
The Lifts I enter, and pursue my Way !
The massy Whirlpools, heaving still for Place,
30 Heap'd without Rule, and moving without
Space,

Those learned Phantoms vanish from my
Sight,
And Day comes on me with her genuine Light !
That vast Expanse, of Being the Abode,
Space, which contains th' Infinity of God,
35 Sees in her Breast this bounded System move
Of Planets, Worlds, beneath us and above,
Whose whole Extent, so wondrous to our Sense,
Is but a Point, an Atom in th' Immense.

Go

DEDICATION.

v

God speaks, and Chaos at his Voice subsides;
In various Orbs the mighty Mass divides: 40
At once they gravitate, they strive to fall,
One Center seeking, which attracts them all.
That Soul of Nature, that all-moving Spring,
Lay long conceal'd, an unregarded Thing;
'Till *Newton's* Compass, moving thro' the 45
Space

Measures all Matter, all discover'd Place;
Finds Motion's Cause, Philosophy unleavens,
Lifts up the Veil, and open'd are the Heavens.

His learned Hand unfolds the glitt'ring
Robe,

That clothes yon lucid, animated Globe, 50
Who guides the Seasons, and who rules the
Day.

Mine Eyes distinguish each emitted Ray.
With Purple, Azure, Emerald, and Rose,
Th' immortal Tissue of his Habit glows.
Each Emanation, in pure Substance, bears 55
The various Colours that all Nature wears :
Those blended Taints illuminate our Eyes,
Give Life to Matter, fill th' expanded Skies.

Eternal Pow'rs, who, near the King of
Kings,
Burn with his Fires, and cover with your Wings. 60
His

DEDICATION.

His Throne; O tell us! viewing *Newton's* Plan,
Were you not jealous of that wond'rous Man?

The Sea too hears him. With stupendious
Dance

I see the humid Element advance !

65 Tow'rd's Heav'n it rises; Heav'n attracts it
high :

But central Pow'r, more potent, as more nigh,
Each Effort stops : The Sea recoils; it roars;
Sinks in its Bed, and rolls against the Shores.

Ye Comets, dreaded like the Bolts of Jove,
70 In vast Ellipses regularly rove !

Cease with your Motion Mortals to affright :
Remount, descend near the great Orb of Light :
E lance your Fires; fly ; and, as each appears,
Restore the Vigour of exhausted Spheres!

75 Thou, Sister of the Sun, who, in the Skies,
Of dazzled Sages mock'd the feeble Eyes
Newton has mark'd the Limits of thy Race:
March on ; illumine Night; we know thy
Place.

Earth, change thy Form; let the great Law
of Matter,

80 The Pole depressing, elevate th' Equator!
Pole, fix'd to Sight, avoid the frozen Car,
The Constellation of the Northern Bear :

Embrace,

Embrace, in each of thy immense Careers,
Almost two thousand Centuries of Years*!

How beautiful these Objects! how the Mind 85
Flies to these Truths, enlighten'd and refin'd!
Yes, in the Breast of God, from Matter free,
It hears the Voice of that eternal He.

Thou, whom that Voice familiarly invites,
Say, ev'n in Youth, the Season of Delights, 90
How hast Thou dar'd, in spite of Custom's
Force,

To move so boldly, thro' so vast a Course?
To follow *Newton* in that boundless Road,
Where Nature's lost, and ev'ry Thing but God?

Pursuing Thee, I venture to advance, 95
And bring home Truth, that Wanderer, to
France.

While *Algaroti* †, sure to please and teach,
Conducts the Stranger to the Latian Beach,
With native Flow'rs adorns the beauteous Maid,
And *Tyber* wonders at such Worth display'd; 100

* *Almost two thousand Centuries.*] Mr. *Voltaire's* Line is
Deux cens siecles entiers par delà six milleans.

But the Period he is speaking of, according to his own
Account of it, consists of 194000 Years, which is almost
two thousand Centuries.

† *Algaroti.*] A young *Venetian*, who is now printing at
Venice a Treatise on Light, in which he explains Attraction.

D E D I C A T I O N.

I grasp the Compass, and the Out-lines trace,
And with coarse Crayons imitate her Face.
Th' immortal Fair, all simple, noble, grand,
Should I attempt it, my unskilful Hand
105 To Her, as Thee, no Lustre could impart,
Above all Praise, and far above my Art.

T H E

THE P R E F A C E.

IT seems to have been the Design of the Author in the following Treatise to give only a Taste of Sir Isaac Newton's natural Philosophy to those who have heard his Works much commended, but had not enough of Mathematical Learning to read them; tho' there are in several Places several curious Things to entertain the more Learned.

*The Author himself hath observed several Errors in the French Edition, printed at Amsterdam; and therefore it was necessary in this Edition, which is taken from it, to make several Amendments, tho' perhaps some may be wanting still; particularly in Page 12. Line 10. where it's said the Distance of the Stars is as their apparent Magnitude inversly, some may think it should be the Square of their Distance; but even that would not be true, except
their*

their real Magnitudes were all equal, which is scarcely credible; a few others were marked with the Errata, which may be soon helped.

The Reader is at Liberty to pass over the few Remarks at the Bottom of some Pages, tho' they were inserted by one who is neither a rigid Newtonian nor Cartesian, and so no Party Man; for Amicus Plato, Amicus Aristoteles, sed magis amica veritas. There are not only the Prejudice of Education, but also Interest, the Estimation of others, and Selfconceit, that give a great Bias to the Judgment, and sometimes Decipimur specie recti. This Treatise may serve to rectify the Judgment of those that can bear to read any thing against it.

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- P** AGE 170. *Line ult. for directed read deceived.*
P. 170. l. ult. for suspended r. superadded.
P. 172. l. 9. for Eclipses r. Ellipses.
P. 173. l. ult. for good r. hold good.
P. 144. l. 8. at the Begiz. g, r. reflects, and dele nothing.
P. 160. l. 5 r. absolute Gravity.

T O T H E
MARCHIONESS of CH**

I N T R O D U C T I O N.

M A D A M,

NEITHER your Title, nor the Philosophy here treated, are imaginary. Your solid Study of many new Truths, and the Fruits of so meritorious an Application, are what I now offer the Publick for your own, and the Glory of your Sex, and for the Improvement of all such as desire to cultivate their Reason, and enjoy without difficulty the Benefit of your Enquiries. Graces and Beauties are not to be expected here. Every Hand is not capable of covering the Thorns of the Sciences with the Flowers of Wit and Fancy; and for my part I ought to make it my sole Endeavour in this Essay to conceive certain Truths aright, and to explain them with Order and Perspicuity: To attempt to adorn them, were encroaching upon your Province.

The

INTRODUCTION.

The Name of new Philosophy would be no more than the Title of a new Romance, if it implied only the Conjectures of a Modern in opposition to the Notions of the Ancients. A Philosophy, founded only upon accidental Explications advanced at a venture, would not in strictness deserve the least Examination. For the Methods of arriving at Error are innumerable, whilst there is but  one Way that leads to Truth ; it is therefore the odds of infinite to one, that a Philosopher, who supports his Principles only by Hypotheses, will advance nothing but Chimera's. Hence it is, that all the Ancients, who have treated Physicks without the light of Experiments, have been only the Blind explaining the Nature of Colours to the Blind.

This Tract will not be a compleat Course of Physicks. That were to make it immense ; a single part of Physicks employing the Lives of many Men, and often letting them die in Uncertainty.

You confine yourself in the Study, of which I treat, solely to forming a clear Idea of those subtle and powerful Springs, those primary Laws of Nature, discovered by *New-*
ton ;

ton; to examining how far others had gone before him, from whence he set out, and where he stopped. We shall begin like him with Light, which, tho' the most subtle of all Bodies, and that which approaches the nearest to infinitely little, is however the Body of which we know the most. It has been traced in its Motions and Effects; it has even been anatomized and separated into all its possible Parts. Of all Bodies, it is that which most explains the Secrets, and brings us the nearest to the first Springs, of Nature.

We shall endeavour to make these Elements easy and intelligible to those, who know no more of *Newton* and Philosophy than their Name. The Knowledge of Nature is a Good, to which all Men have an equal Right: all are for knowing their Good, which few have Time or Patience to calculate; this *Newton* has done for them. Here we must sometimes content ourselves with the total of those Calculations. A publick Man, a Minister, every day forms a just Idea of the result of Operations not in his own Power to execute; the Eyes of others have seen, the Hands of others have laboured for him, and
enable

enable him by faithful Reports to pass his Judgment. Every Man of Wit will be here almost in the same case with this Minister.

Newton's Philosophy has hitherto seemed to many as unintelligible as that of the Ancients; but the Darknefs of the *Greeks* proceeded from their having in reality no Light at all, whilst that of *Newton* arises from his Light's being too remote from our Eyes. He has discovered Truths; but he has searched for, and placed them in an Abyfs, into which it is necessary to descend, in order to bring them out, and to place them in full Light.

The Reader will find here all those Truths which tend to establish the new Property of Matter discovered by *Newton*. We shall be obliged to speak of some Singularities which occur in the course of our Design; but we shall not lose Sight of our End.

Those who desire to instruct themselves more at large, may read the excellent Physics of *Gravesande*, *Keil*, *Muschenbroek* and *Pemberton*, and approach to *Newton* by degrees.

C H A P. I.

*What Light is, and in what manner
it comes to us.*

THE *Greeks*, and after them all the barbarous Nations, who learnt of them to reason and to err, have said from Age to Age thro' a long series of Time; "Light is
" an Accident, which Accident is the act of
" Transparent as Transparent; Colours are
" what move transparent Bodies. Luminous and coloured Bodies have Qualities
" like those they excite in us, according to
" the Maxim, that nothing can give what it
" has not. In fine, Light and Colours are
" a mixture of the hot, cold, dry and humid;
" for the humid, dry, cold and hot,
" being the Principles of all Things, Colours
" must necessarily be composed of them."

This is the absurd Jargon, which the Professors of Ignorance, paid by the Publick, have made human Credulity revere for so many Ages; which manner of reasoning prevailed almost in all things down to the times of *Galileo* and *Descartes*. Even long after them

them the same Trash, the Disgrace of human Understanding, subsisted in many Schools. I dare aver that human Reason, so obscured, is far below the narrow indeed, but certain, Perceptions, which in Brutes we call Instinct. Hence we cannot congratulate ourselves too much on our good Fortune in being born at a Time, and amongst a People, in which, and with whom Mankind begin to open their Eyes, and to enjoy the noblest Inheritance of Humanity, the Use of Reason.

All the pretended Philosophers therefore having guest of Nature at a venture thro' the Veil, under which she lay concealed, *Descartes* at length came, and discovered a Corner of that great Veil. He said: Light is a fine and subtle Matter diffused universally, that strikes our Eyes. Colours are Sensations excited in us by God, according to the Motions which transmit that Matter to our Organs. Thus far *Descartes* was in the right, and ought either to have stopped there, or in advancing, to have taken Experiment for his

*The Fond-
ness for e-
stablishing
a System
misled Des-
cartes.*

Guide. But he was possessed with the desire of establishing a System. That Passion had the same effect on this great Man, as Passions

have

have on all Men ; they hurry them beyond their Principles.

He had laid down as the first Principle of his Philosophy, that nothing should be believed without Evidence ; and yet, in Contempt of his own Rule, he imagines three Elements formed of pretended Cubes, which he supposes to have been made by the Creator, and to have been broken to pieces in turning upon themselves, after they came out of the Hands of God. These three imaginary Elements are, as every body knows,

1. The most dense parts of these Cubes ; *His System*. of which gross Element, according to him, the solid Bodies of the Planets, the Seas, and even the Air are composed.

2. The imperceptible Dust, which the breaking to pieces of these Dice had produced, and which fills to Infinitude the Spaces of the infinite Universe, in which he supposes no Vacuum, or Void.

3. The Middles of these pretended Dice broken to pieces, equally attenuated on all sides, and at last made round into Balls, of which he thinks fit to make Light, and which he diffuses abundantly throughout the Universe.

The

False. The more wittily this System was imagined, the more the Reader will perceive it unworthy of a Philosopher. For, as nothing of all this is proved, it were full as reasonable to admit the cold and hot, the dry and humid. What does it signify which of the two Errors be preferred! We will not lose time in disputing this creation of Cubes and three Elements, or rather this Chaos. Let us content ourselves with observing here the Philosophical Errors into which the Systematical Spirit, or Fondness for System carried the sublime Genius of *Descartes*; and let us refute especially only those Errors, which having the air of Truth, have gained Credit, and deserved to be advanced.

According to *Descartes*, the Light does not proceed to our Eyes from the Sun, but is a globulous Matter diffused universally, which the Sun impels, and which presses upon our Eyes as a Staff pushed at one end presses the same instant at the other. This appeared plausible, but is not therefore the less false: *Descartes* however was so fully convinced of this System, that in his seventeenth Letter of the third Volume, he positively says and repeats

peats it: *I confess that I know nothing of Philosophy, if the Light of the Sun is not transmitted to our Eyes in an instant.* And indeed, we must own, that as great a Genius as he was, he knew very little of true Philosophy; and wanted the Experiments of the succeeding Age. That Age is as much superior to *Descartes*, as *Descartes* was to Antiquity.

1. If Light were always diffused, and always existing in the Air, we should see as clearly in the Night as we do in the Day, because the Sun below the Hemisphere would continually impel the Globules on all sides, and the Impression equally affect our Eyes.

2. It is demonstrated, that Light flows from the Sun, and we know, that it is very near seven or eight Minutes in coming to us from so immense a distance, which a Cannon-bullet retaining its force could not do in five and twenty Years.

The Author of the *Spēctacle de la Nature*, a Work of great Merit, has fallen in this point into a small Mistake, which no doubt he will correct in the next Edition of his Work. He says, that Light, according to *Newton*, is seven Minutes in coming to us from the Stars; he

Of the progressive Motion of Light.

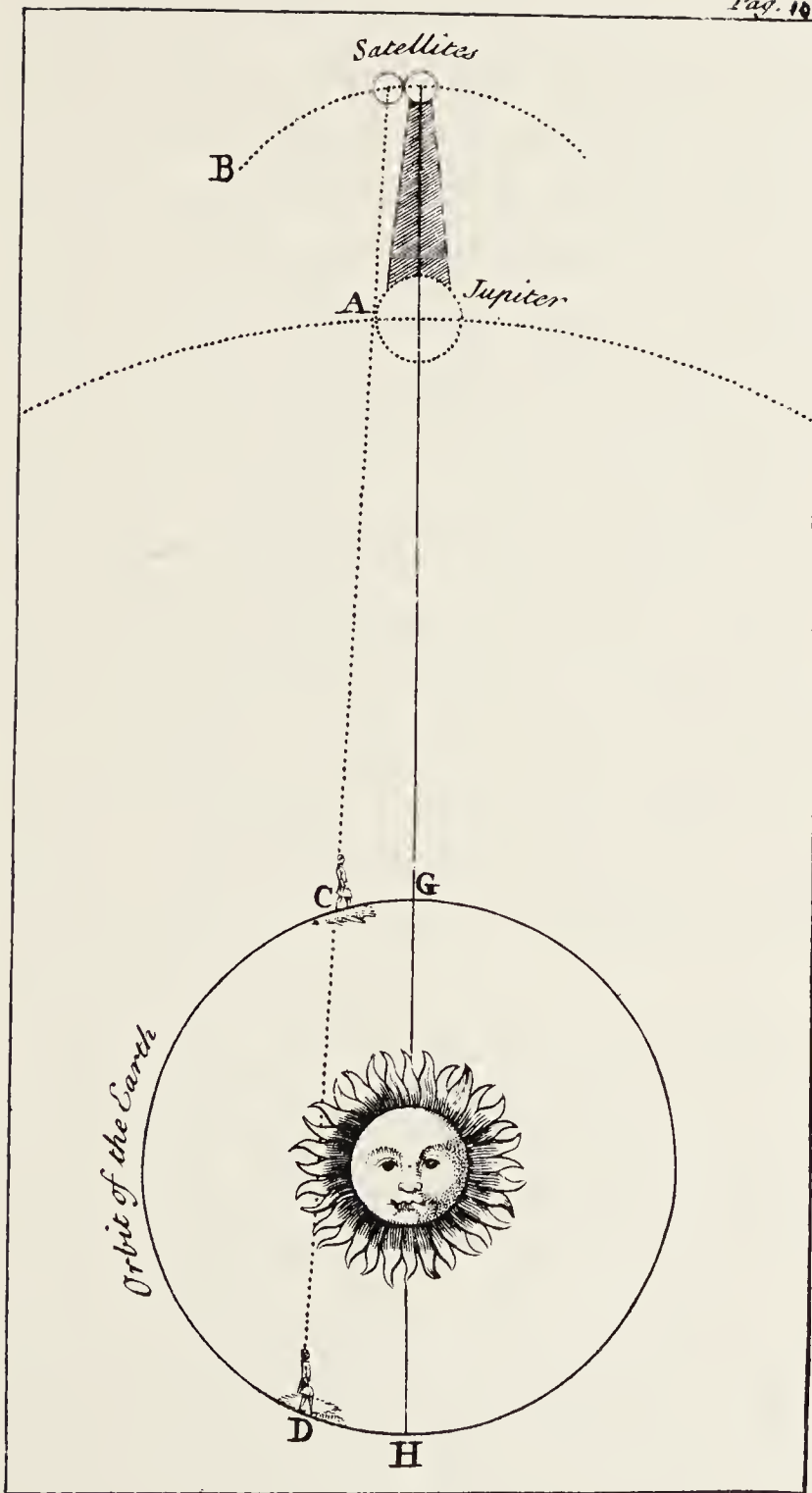
Error in Spēctacle de la Nature.

he has taken the Stars for the Sun. Light is six Months in coming to us from the nearest of them, according to a certain Calculation, founded upon Experiments very delicate, and at the same time very imperfect. It is not *Newton*, but *Huygens* and *Hartsoeker*, who have advanced this Supposition : he says also, to prove that God created Light before the Sun, *That Light is diffused throughout all Nature, and makes itself sensible, when the luminous Stars impel it* ; but it has been demonstrated to be very long in coming from the fixed Stars to us. Now, if it comes so far, it was not diffused before. It is necessary to be aware of these Errors, which are every day repeated in abundance of Books, that are a kind of Ecchoes to each other.

The following is in a few words the Substance of *Romer's* sensible Demonstration, that Light employs seven or eight Minutes in its Passage from the Sun to the Earth.

*Demon-
stration of
the Motion
of Light.*

From the Earth at C, a Satellite of *Jupiter* is observed to be eclipsed regularly once in two and forty Hours and an half. If the Earth were immoveable, the Observer at C would see thirty Emerfions of that Satellite in thirty times



two and forty Minutes and an half ; but at the end of that time the Earth is come to D, and then the Observer sees no longer that E-merfion exactly at the end of thirty times two and forty Hours and an half ; but must add the time, which Light takes in paffing from C to D, which time is manifefly confiderable. But this fpace C D is lefs than the fpace G H, for C D is a Chord of the Circle, and G H its Diameter. This Circle is the great Orbit defcribed by the Earth around the Sun in the Center ; Light in coming from the Satellite of *Jupiter* paffes the Chord C D in ten Minutes, and G H in fifteen or fixteen. The Sun is between G and H ; the Light therefore is feven or eight Minutes in coming from the Sun.

Mr. *Bradley*, in the laft place, has obferved by reiterated and certain Experiments, that many Stars viewed at different times, appeared fometimes a little more towards the South, and fometimes a little more towards the North ; which difference, he has proved, could arife only from the annual Motion of the Earth, and the Progreflion of Light. He obferves, that if thefe Stars have a Parallax, it can be only of one Second. Admit-

Admitting this, I proceed to reason in the following manner : a Star, whose annual Parallax is no more than of one Second, is four hundred thousand times more remote from us than the Sun ; if Light be eight Minutes in coming from the Sun to us, as Mr. *Bradley* believes, it will in consequence be six Years, and above a Month, in coming to us from those Stars. But this is not all. These are Stars of the first Magnitude, those therefore of the sixth, being six times more distant, cannot transmit their Light to us in less than thirty six Years and an half.

3. The Rays, diverted and forced to take a new Course by a Prism, demonstrate, that Light actually moves, and is not a Quantity of Globules or Balls simply prest.

4. If Light consisted of Globules existing every where in the Air, a small hole cut in a dark Chamber ought to illuminate it entirely : for Light impelled in every manner thro' the little Hole would act on all sides, as Balls of Ivory disposed in a circular or square Form would disperse themselves on all sides, if only one of them were strongly moved ; but directly the contrary happens. For the Light
received

received at a small Hole, which admits but few Rays to pass thro' it, scarce illuminates half a Foot of the place upon which it falls.

5. The Light always enters a Hole in a right Line, in whatever manner the Hole can be contrived; but if the Balls were simply pressed, it would be impossible for that Pressure to be in a right Line. It is evident therefore, that *Descartes* is mistaken as well in regard to the Nature of Light, as the manner in which it is transmitted to us.

Father *Mallebranche*, whose Genius was F. Mallebranche's Error. more subtile than true, and who always consulted his Meditations, but not always Nature, adopted the Elements of *Descartes* without Proof; but he made some Alterations in that enchanted Castle. He imagined without other Proof another Explanation of Light.

The Vibrations of luminous Bodies impress, according to him, Strokes or Motions upon small and gentle Whirlings, capable of Compression, and entirely composed of subtile Matter. But had *Mallebranche* been asked, in what manner these small and gentle Whirlings transmitted Light to our Eyes; how the Sun's Action could pass in an instant thro'

thro' so many small Bodies compressed upon one another, of which a very small number were sufficient to intercept that Action ; and lastly how it happened, that those gentle Whirlings did not mingle in turning upon one another : What would that Father have replied ? Upon what Foundation did he build this imaginary Superstructure ? Should Men who talked of nothing but *Truth*, have wrote nothing but Romances !

*Definition
of Light.*

What then at length is Light ? It is *Fire itself*, which burns at a small distance when its Parts are less attenuated, or more rapid, or more united ; and which gently illuminates our Eyes, when it acts from a greater distance, and its Particles are more rare, and less rapid, and less united.

Thus a lighted Candle would burn the Eye at the distance of only some Lines (twelfths) of an Inch, and gives it Light at that of some Inches. Thus the Rays of the Sun, diffused thro' the Spaces of the Air, illuminate Objects, and collected by a Burning-Glass melt Lead, Gold, &c.

This Fire is darted on all sides from the Point irradiating : which is the cause of its
being

being seen on all sides ; it is therefore always to be considered, as Lines issuing from a Center to a Circumference. Thus every Irradiation, or Groupe of Rays, from the Sun or any Fire whatsoever, should be considered as a Cone, of which the Base is upon our Eye, and the Vertex at the Fire that darts it.

This Matter of Fire is thrown from the Sun to us, and as far as *Saturn*, &c. with a Rapidity that amazes the Imagination.

The Calculation of it shews, that if the Sun is four and twenty thousand Semi-diameters of the Earth from us, Light in its Progression to us from that Star, is but a Second in coming about a thousand million of Feet. Now a Bullet of a Pound Weight, discharged with half a Pound of Powder, flies but six hundred Feet in a Second ; so that a Ray of the Sun (to make the Numbers even) is one million, six hundred and six thousand, six hundred times more rapid than a Cannon-ball.

I shall not enter here into the famous Dispute *De vivis viribus* ; I refer the Reader for that to the learned and profound Dissertation of Mr. *Mairan*, See Memoirs of the Academy, &c. 1728.

I hope that Philosopher, and those who most oppose the Doctrine of living Powers, will permit me with the utmost Rigour to advance the following Proposition.

The Effect produced by the Force of a Body in motion, at least when uniform in its Rapidity, is the Product of its Quantity by the Square of its Acceleration; that is to say, that a Body, if it has ten Degrees of Swiftnefs, will (*cæteris paribus*) make an hundred times as much Impression as it would do, if it had only one Degree of Swiftnefs.

If therefore a single Particle of Light acts in proportion to the Square of its Swiftnefs, and if that Force is about sixteen hundred thousand to that of a Bullet, that Square will be 2560000000000, it follows then, if that Atom is only two billions, five hundred and sixty thousand millions of times less than a Pound, it will however have the same Effect as a Cannon-ball. Suppose this Atom still a thousand millions of times less; one Moment's Emanation of Light would destroy all the Vegetables upon the Face of the Earth. Imagine how small a Particle of Light is, which passes so easily through Glafs; and to have

*Extreme
minuteness
of the Par-
ticles of
Light.*

have some Idea of Infinite, conceive what that Matter still a million of Degrees more subtile must be, that enters the Pores of Gold and the Loadstone, and penetrates the Rocks and the Bowels of the Earth.

The Sun which darts this luminous Matter to us in seven or eight Minutes, and the Stars, those other Suns, which transmit it to us in several Years, supply us eternally without wasting almost in the same manner, as the Creature that produces Musk, perpetually emits odoriferous Bodies around it, without any sensible diminution of its Weight.

In fine the Rapidity, with which the Sun projects its Rays, is in proportion to its Magnitude, which is about a million to one, to that of the Earth, and to the Swiftneſs of the Motion, with which that immense Body of Fire turns round upon its own Axis in twenty five Days and an half.

The Force, Illumination, Intenſeneſs and Denſity of all Light is calculated. This Calculation ſhews, that this Force is exactly in proportion to the Force, with which Bodies fall, and with which *Newton* proves all the heavenly Bodies attract one another. This

Propor-

Proportion is called the inverse Rule of the Square of the Distances. It will be necessary to familiarize ourselves with this Expression.

*Proportion
in which
all Light
acts.*

Its Signification is simple and intelligible : it is, that a Body at the distance of four Feet from any Fire, will be sixteen Times less heated and illuminated, than a Body at the distance of one Foot, sixteen is the Square of Four. Now Four is the distance of the Body less illuminated ; the Light therefore transmits to this Body distant four Feet, not four but sixteen Times less Rays. And this is called the Ratio, or Rule, inverse of the Square of the Distances, which ought to be well understood ; for this Proportion will be one of the Principles, on which the New Philosophy is founded, which we shall endeavour to make easy.

*Progression
of Light.
Proof of the
Impossibility
of a Ple-
num.*

We may here take occasion to conclude from the Rapidity, with which the Substance of the Sun transmits itself to us in this manner in a right Line, how chimerical the Plenum of *Descartes* is. For first, how could it come to us in a right Line, thro' such immense Spaces of Matter moved in a curve Line, and thro' such an Infinity of different Motions? 2. How could so rare a Body in
seven

seven or eight Minutes pass thro' the Space of thirty millions of Leagues between us and the Sun, if it was to penetrate a resisting Matter all the way. In that Case every Ray must displace thirty millions of Leagues of subtile Matter in a Moment. Besides which, we are to remember, that this pretended subtile Matter would resist in the absolute Plenum, as much as the most solid Matter. For a Pound of Gold-dust, pressed close in a Box, resists as much as a piece of Gold weighing a Pound. So that it would be necessary for a Ray of the Sun to have much greater Force, than if it were to penetrate thro' a Cone of Gold, of which the Axis should be thirty millions of Leagues.

Experience, that true Guide of Philosophy, further shews us, that Light in coming from one Element into another, from one Medium into another, does pass through entire, as we shall observe : a great Part of it is reflected ; the Air repelling more of it than it transmits ; so that it would be impossible for the Light of any of the Stars to reach us ; it would be wholly repelled and absorbed, before a single Ray could come half way to
our

our Atmosphere. But in the Chapters, where we shall explain the Principles of Gravitation, we shall prove by a multitude of Arguments, that this pretended Plenum was a Romance.

Let us here stop a Moment to observe how slowly Truth establishes itself amongst Mankind.

It is almost fifty Years since *Romer* demonstrated by Observations upon the Satellites of *Jupiter*, that Light is transmitted from the Sun to the Earth in about seven Minutes and an half, notwithstanding which the contrary is not only maintained in many Books of Physicks ; but in a Collection upon that Subject in three Volumes extracted from the Observations of all the Academies in *Europe*, printed 1730, pag. 35, Vol. I. there is this Passage.

“ Some have pretended, that a luminous
 “ Body as the Sun, emits continually an
 “ Infinity of small insensible Particles, which
 “ bring the Light to our Eyes ; but this
 “ Opinion, which still favours a little of
 “ the old Philosophy, cannot be maintain-
 “ ed.”

This

This Opinion is however demonstrated in more than one manner, and is so far from favouring of the Old Philosophy, that it is directly contrary to it; for can any thing be more contrary to Words void of Sense, than Measures, Calculations and Experiments?

C H A P. II.

The Property, which Light has of reflecting itself, was not truly known. It is not reflected by the solid Parts of Bodies as vulgarly believed.

HAVING seen what Light is, from whence derived, and how long it is in coming to us, let us proceed to its Properties and Effects, unknown till our Days. The first of its Effects, is its seeming to rebound from all Objects to bring the Images of them to our Eyes.

All Men, all Philosophers, *Descartes*, *Mallebranche*, and such as are most remote from vulgar Opinion, have equally believed, that the solid Surfaces of Bodies are what actually reflect Light to us. The more smooth and solid a Surface is, the more, they say, it causes the Light to rebound from it; the larger, and the more direct the Pores of the Body are, the more the Rays of Light pass thro' its Substance. Thus the Looking-glass, covered at bottom with a Surface of Quick-silver, reflects all the Rays; and the same

Glass

Glaſs without Quickſilver, having direct and large Pores in great number, lets great part of the Rays paſs thro' it. The more large and direct Pores a Body has, the more tranſparent it is : ſuch is, ſaid they, the Diamond, ſuch the Water itſelf ; and theſe were the Ideas generally received, which no-body called in queſtion.

Yet all theſe Ideas are entirely falſe, ſo remote often is the Likeneſs of Truth from the Truth itſelf. The Philoſophers gave into this Error, in the ſame manner the Vulgar entirely miſtake, when they imagine the Sun no larger than it appears to the Eye. In this conſiſted the Error of the Philoſophers :

There is no Body, whoſe Surface we can really make even. However the Surfaces of many ſeem perfectly ſmooth and poliſhed : and whence do they appear ſo to us ? The moſt ſmooth Superficies, in reſpect to the Particles, of which Light is compoſed, is no more than a great number of Mountains, Cavities, and Spaces, ſo that the Microſcope diſcovers, that the Point of the fineſt Needle actually abounds with Eminences and rugged Parts.

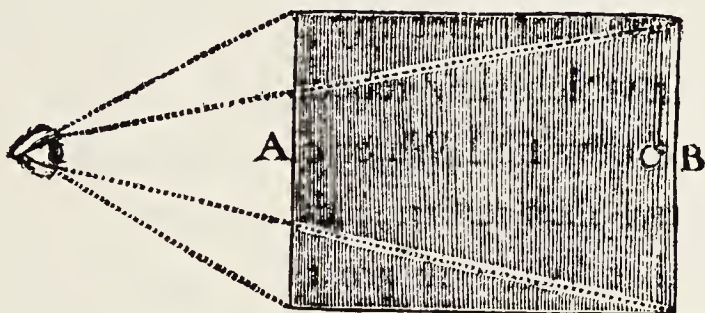
The Elements of

All the various Rays of Light, which should fall on these unequal Parts, would be reflected according as they should fall, and falling unequally, would never be regularly reflected, for which reason we could never see ourselves in a Glass.

The Light therefore, which presents us our Image in a Looking-glass, undoubtedly does not proceed from the solid Parts of the Superficies of that Glass; neither is it the Effect of the solid Parts of the Mercury Pewter spread upon its Back. Those Parts are not more even or more smooth than the Glass itself. The solid Parts of the Pewter and Mercury are incomparably larger than the constituent solid Parts of Light, therefore if the small Particles of Light fall upon the gross Parts of the Mercury, they will spread and scatter themselves on all sides, like Grains of Lead falling upon Rubbish. What unknown Power then is it, that causes Light to rebound towards us with so much Regularity? It appears already, that Bodies do not return it in this manner. What seemed the most known and incontestible amongst Mankind, becomes a greater Mystery than

than the Weight of the Air was formerly. Let us examine this Problem of Nature, and our Wonder will encrease. We cannot inform ourselves in it without Surprize.

Take a small piece, a Cube of Crystal, and you will find the Rays of the Sun fall on this solid transparent Body in this manner.



1. A small part of the Rays rebound to the Eye from the nearest Surface A, even without touching that Surface, as will be proved more at large.

2. Part of the Rays are received into the Substance of this Body, where they play, lose themselves, and extinguish.

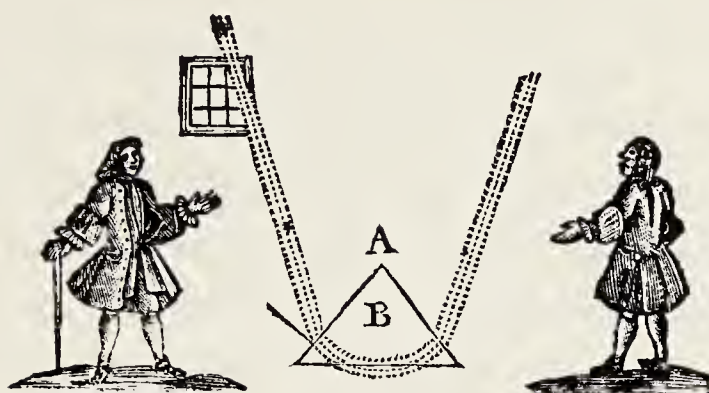
3. A third Part reach to the Inside C of the Surface B, and from near the Surface B return into A, from whence some come to the Eye.

4. A fourth Part passes into the Air.

5. A

5. A fifth Part, which is the most considerable, returns from beyond the farthest Surface B into the Crystal, which it repasses, and comes to reflect itself to the Eye. Let us here examine these latter Rays, which having passed the farthest Surface B, and come to the Air, fly back from that Air towards us, re-entring thro' the Crystal. They undoubtedly have not met any solid Parts in that Air, on which they rebounded; for instead of Air, if they find Water on that Surface, few of them then return; they enter and penetrate that Water in great abundance. Now Water is about eight hundred Times heavier, more solid, and less rare than Air. These Rays however do not rebound from this Water, but they rebound from that Air into the Glass; therefore the Light is not reflected by the solid Parts of Bodies.

The following is a more singular and more decisive Observation. Expose in a dark Chamber this Crystal A B, to the Rays of the Sun in such a manner, that the Light coming on the Superficies B, makes an Angle of above forty Degrees with the Perpendicular.



*Decisive
Experi-
ments.*

Most of the Rays then penetrate into the Air no longer, they re-enter the Crystal the instant they quit it, they return, as you see, but in a Curve not Perceptible.

It certainly is not the solid Surface of the Air that repels them into the Glass; many of those Rays entered the Air before, when they fell less obliquely; why therefore with an Obliquity of forty Degrees, nineteen Minutes, do most of those Rays pass no longer? Do they find more Resistance, more Matter in the Air at this Degree, than in the Crystal they had penetrated? Are there more solid Parts in the Air at forty Degrees and one third, than at 40? The Air is almost two thousand four hundred Times more rare, less weighty, and less solid than the Crystal, those Rays therefore ought to pass into the Air with two thousand

thousand four hundred Times more Facility, than they penetrated the Substance of the Crystal. However, notwithstanding this prodigious appearance of Facility they are repelled; but then repelled here by a Force two thousand four hundred Times greater than that of the Air; they therefore are not at all repelled by the Air; again, the Rays are not reflected to our Eyes by the solid Parts of Matter. For Light rebounds so little from the solid Parts of Bodies, that in reality it rebounds from Vacuity.

We have just seen, that Light falling in an Angle of 40 Degrees 19 Minutes upon the Crystal, rebounds almost entirely from the Air, which it finds at the farthest Surface of the Crystal. Let Light fall on it, in an Angle less only one Minute, still less of it will pass beyond that Surface into the Air. Remove the Air, and no Rays at all will pass. This is a thing demonstrated.

Now when there is Water upon this Surface, many Rays enter that Water, instead of being reflected by it. When there is only Air fewer Rays enter that Air. When there is

no Air, no Ray passes; it is therefore from the Vacuum that Light is reflected.

Here then are undoubted Proofs, that it is not a solid Superficies that reflects Light to us: there are many other Proofs still of this new Truth; of which the following is one, we shall explain in its Place. Every opaque Body reduced to a thin Plate, suffers Rays of a certain kind to pass through its Substance, and reflects other Rays: now, if Light were reflected by Bodies, all the Rays which should fall upon these Plates, would be reflected by them. To conclude, we shall see that so astonishing a Paradox never had a greater variety of Proofs. Let us begin then by familiarizing ourselves with these Truths.

1. This Light, which is imagined to be reflected by the solid Surface of Bodies, returns in Effect without having touched that Surface.

2. Light is not reflected from the Back of a Looking-glass by the solid Surface of the Quicksilver, but from the very Pores of the Looking-glass and the Quicksilver.

3. It is not necessary, as it has hitherto been thought, that the Pores of that Quicksilver should

should be very small to reflect Light; on the contrary, it is necessary that they should be large.

To those who have not studied this Philosophy, it will be new matter of Surprize to hear it said, that the Secret of rendering a Body opaque, is often to enlarge its Pores, and that the Means to make it transparent, is to make them small. The Order of Nature appears entirely changed: what seemed the necessary Cause of Opacity, is directly the Cause of Transparence; and what appeared to render Bodies transparent, is become what makes them opaque. Nothing however is more true, as the grossest Experiment demonstrates.

A piece of dry Paper, of which the Pores are very large, is opaque, no Ray of Light passing thro' it: reduce those Pores, by making it imbibe Water or Oil, it becomes transparent; as will also Linen, Salt, &c.

There are then certain unknown Principles, which produce these Wonders, certain Causes, which occasion Light to rebound, before it touches a Surface, which reflect it from the Pores of transparent Bodies, and which re-
pel

pel it from the very midst of Vacuity ; we are inevitably obliged to admit these Facts, whatever the Cause of them may be.

Let us then apply ourselves to the other Mysteries of Light, and let us see whether these surprizing Effects may be traced to some incontestbile Principle, which we must necessarily admit as well as the Effects themselves.

C H A P. III.

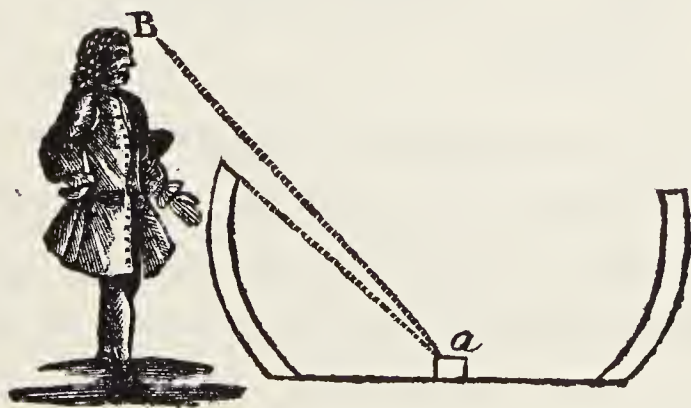
Of the Property which Light has of refracting in passing from one Substance into another, and of taking a new Course in its Progression.

THE second Property of the Rays of Light, which it is necessary to examine well, is that of taking a new Direction in its Passage from the Sun into the Air, from the Air into Glass, from Glass into the Water, &c. It is this new Direction in these different Mediums, or breaking of the Light, which is called Refraction, by which Property an Oar in the Water appears crooked to the Rower; it is that occasions our seeing the Object in a Bowl, by putting Water in it, which we could not see before at the same Place.

In short it is by the means of this Refraction that our Eyes enjoy Sight. The admirable Secrets of Refraction were unknown to the Ancients. Notwithstanding its being before their Eyes, and their perpetual Use of it, they have not left us a single Tract,

to induce us to believe that they had guessed the reason of it. Thus to this Day we still continue ignorant even of the Cause of the Motions of our Bodies, and of the Thoughts of our Souls; but this Ignorance is of a different kind. We neither have nor ever shall have Instruments of so exquisite a Frame, as to enable us to inspect the first Springs, the vital Principles of ourselves; but human Industry has formed itself new Eyes, which has supplied us with the means of prying into the Effects of Light, almost as far as it is permitted for Man to know concerning them.

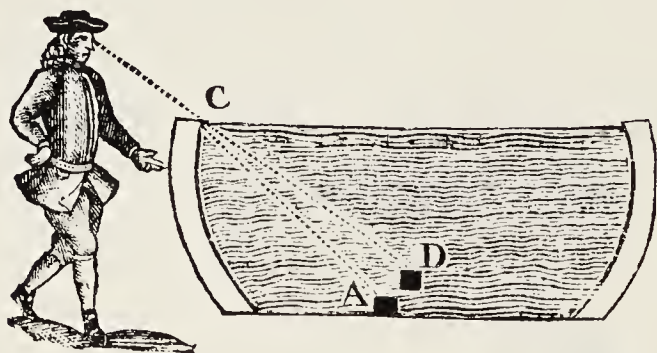
Let us here form a clear Idea of a very common Experiment. Suppose a piece of Gold in this Bason, and your Eye fixed on the side of the Bason, at such a distance, that you cannot see the Piece :



Let

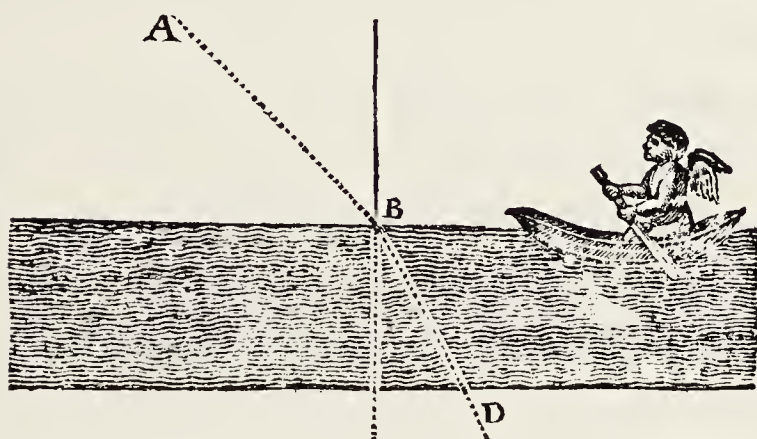
Let Water be poured into it, you did not see the Money at first where it was : but now you see it where it is not ; how happens this ?

The Object A reflects a Ray, which strikes the side of the Basin, and which will never reach your Eye : it also reflects the Ray A B, which passes above your Eye ; but when you receive this Ray A C, it is not your Eye that has changed its Place, but it is the Ray A C ; that has manifestly taken a new Direction at the Edge of the Basin in passing from the Water into the Air, and thereby strikes your Eye from C.



For you always see Objects in a right Line, therefore you see the Object in the right Line C D, and at the Point D, above the Place where it really is.

If this Ray is broke in one manner, when it passes from the Water into the Air, it must break in a contrary manner, when it enters the Water from the Air.



I raise a Perpendicular from this Water ; the Ray, from the luminous Point A is broke at the Point B, and approaches the Perpendicular in the Water by the Line B D. The same Ray D B in its Progression from the Water into the Air, is broke in passing towards A, and removing from the same Perpendicular ; Light therefore is refracted differently, according to the Mediums through which it passes. It is upon this Principle that Nature has disposed the different Humours in our Eyes, in order that the Rays of Light, in their Passage thro' those Humours, may be broke

broke in such a manner, as to reunite after in a Point upon the Retina: to conclude, it is upon the same Principle, Spectacles are made, which occasion still greater Refractions than those of the Eye, and which, thereby uniting a greater number of Rays, are capable of adding about two hundred Times more Force to the Sight; in the same manner as the Invention of the Leaver has augmented the Force of our Arms, which are natural Leavers. We were going to explain the reason discovered by *Newton*, of this Property of Light; but it is necessary to know first in what manner this Refraction acts in our Eyes, and how the Sense of Sight, the most extensive of all the Senses, owes its Existence to Refraction. How well soever we conceive this Matter, it will not be amiss to strengthen the Reader's Ideas of it by a new Enquiry. Those who peruse this little Work, will not be displeased with having no occasion to seek elsewhere for what they may desire to know concerning the Sight.

C H A P. IV.

Of the Form of the Eye, and in what manner Light enters and acts in that Organ.

TO know the Eye of a Man as a Philosopher who considers only Vision, it is necessary to know first, that the first white Cover or Coat, the Defence and Ornament of the Eye, transmits no Rays. The stronger and smoother this White of the Eye is, the more Light it reflects; and when some warm Passion brings unusual Spirits to the Visage, they strain and actuate this Membrane in such a manner that the Eyes seem to flash like Fire.

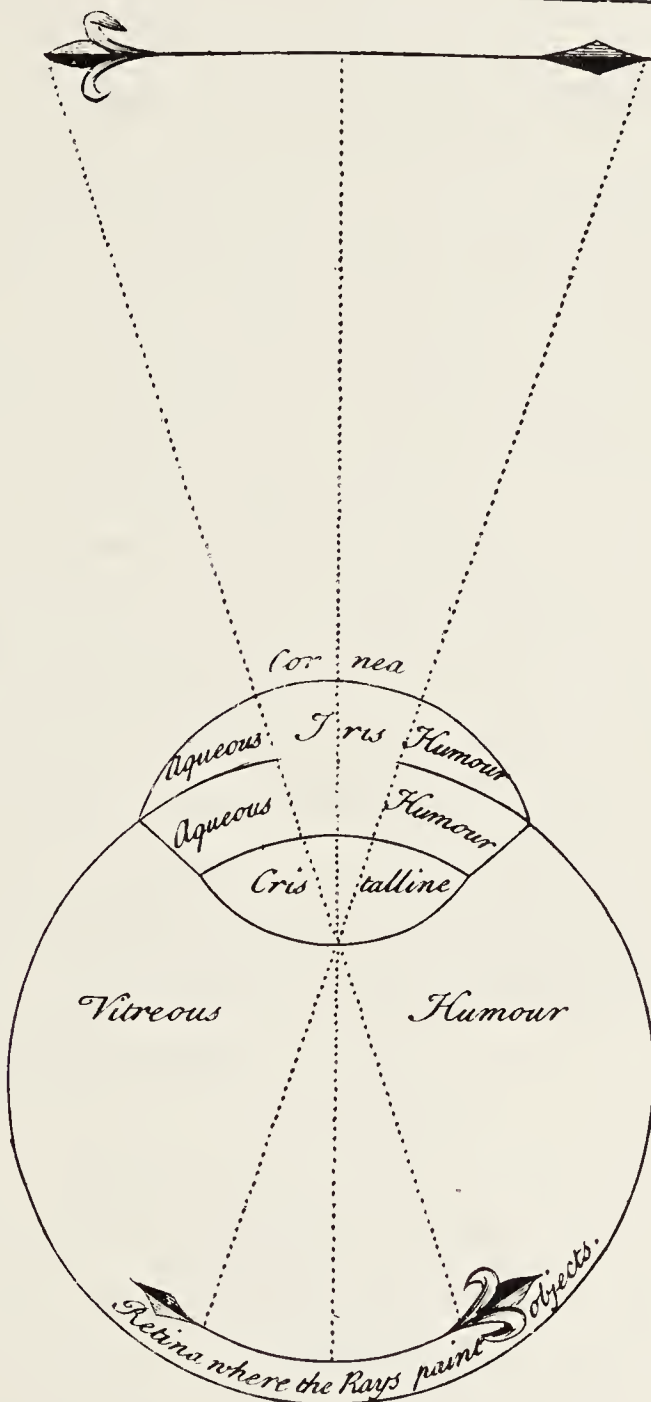
In the midst of this Membrane, the Cornea of the Eye raises itself a little, being thin, hard and transparent, exactly like the Glass of a Watch, when placed upon a Bowl in this manner.



Under

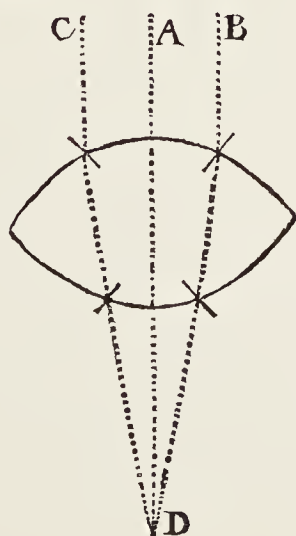
Under this *Cornea*, is the *Iris* another Membrane, which being coloured of itself, diffuses its Colour upon this transparent *Cornea* that covers it. It is from this *Iris*, sometimes blue and sometimes brown, that the Eyes are either blue or black. It is perforated in the middle, which therefore always appears black, and is called the Sight of the Eye. Through this opening the Rays of Light enter; it enlarges itself by an involuntary Motion in dark Places for the reception of more Rays, and contracts again, when too much Light offends it.

The Rays admitted through this Sight are before considerably refracted in passing through the *Cornea* with which it is covered. Imagine this *Cornea* like the Glass of a Watch, that is Convex without, and Concave within: all oblique Rays are broke in passing this Glass; but afterwards its Concavity re-instates what its Convexity has broke. This is what happens in the *Cornea*. The Rays so broke and dispersed, after having passed the *Cornea*, find a transparent Humour into which they enter. This is called the *Aqueous Humour*. The Anatomists do not agree amongst themselves



selves concerning the Form of this little Reservoir. But, whatever its Figure be, Nature seems to have placed this clear and limpid Humour there, to cause Refractions, to transmit the Light clearly, and that the Crystalline Humour which is behind it may advance without difficulty, and change Figure freely, and that the necessary Humidity be preserved, &c.

The Rays having passed this Water, come to a kind of liquid Diamond, in the Form of a Lentil, and set in a fine Membrane, which is itself transparent. This Diamond is the *Crystalline Humour*, that breaks all oblique Rays, and is the principal Organ of Refraction and Sight; in that respect perfectly like a Spectacle-glass of the same Form. Suppose this Figure the Crystalline Humour or Lenticular Glass.

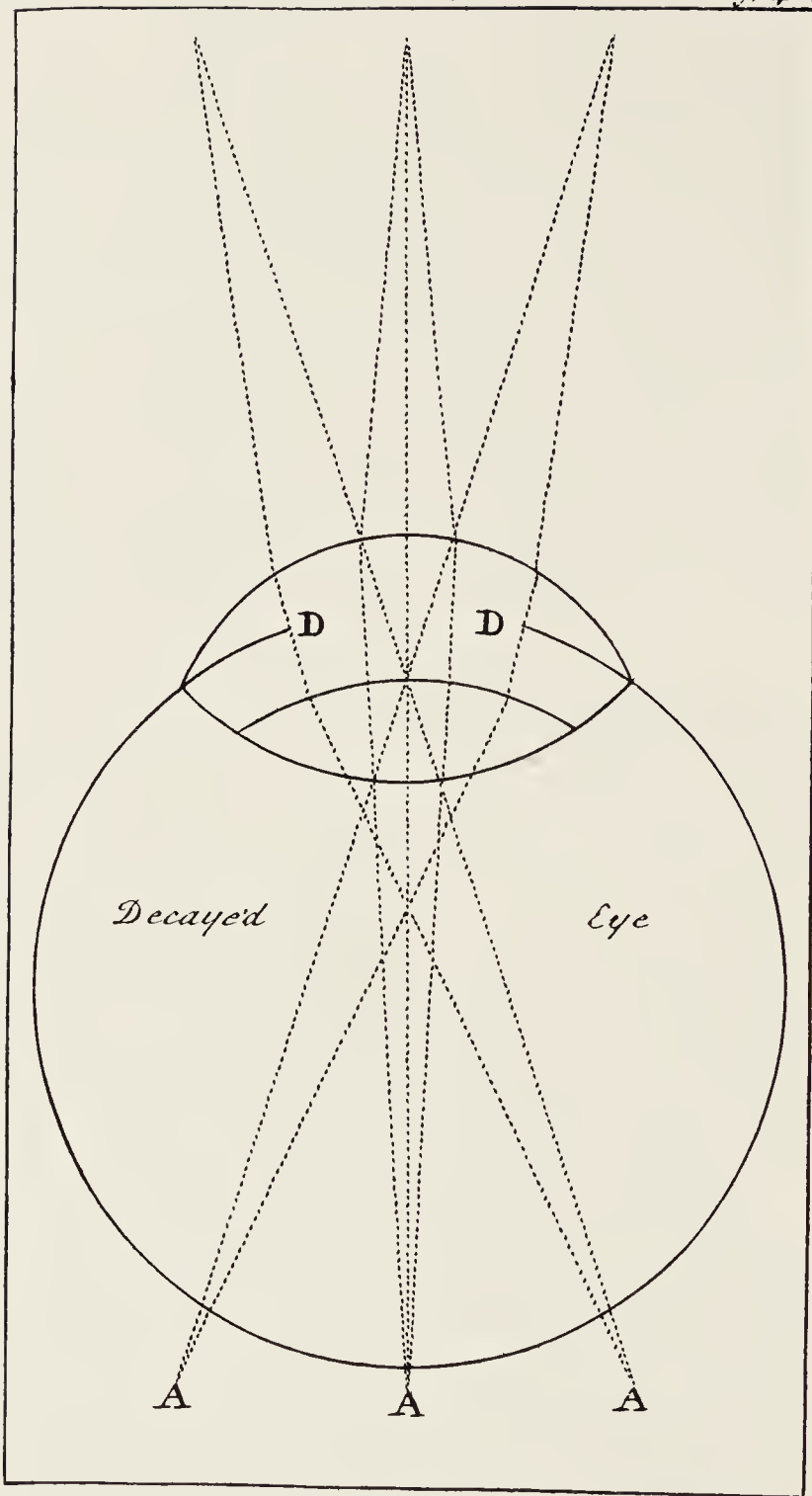


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The perpendicular Ray A penetrates it, without being broke; but the oblique Rays B, C, break in passing this Glass, approaching the perpendicular Rays which are drawn here on the Places where they fall. Afterwards, when they quit the Glass to pass into the Air, they break again removing as you see from the Perpendicular; this new Refraction is exactly what makes them converge in D, the Focus of the Lenticular Glass.

Now the *Retina*, that slight Membrane, that Expansion of the Optick Nerve, which covers the bottom of the Eye, is the Focus of the Crystalline Humour: it is to this *Retina* that the Rays tend; but before they reach it, they again meet a new Medium through which they pass; this new Medium is the Vitreous Humour, less solid than the *Crystalline*, but not so fluid as the *Aqueous*.

In this Vitreous Humour the Rays have time to assemble before their last Union upon the Points of the bottom of the Eye. Imagine then under this Lenticular *Crystalline*, the Vitreous Humour supporting it; that Humour holds the *Crystalline* in its Concavity, and is round towards the *Retina*.



Eye, in which the Cristalline is flat thro age or disease.

The Rays in passing this last Humour finally Converge. Every Groupe of Rays, that issues from a Point of an Object, strikes upon a Point of the *Retina*.

A Figure in which each Part of an Eye is marked with its proper Name, will better explain all this Mechanism, than Lines and A's or B's can do. The Structure of the Eyes being thus understood, the reason why the aid of Glasses is so often necessary, and the Use of Spectacles, may easily be known.

An Eye will often be too flat either thro' ^{Decayed} the Formation of the *Cornea*, or its ^{Eye.} Crystalline Humour, which Age or Disease may have dried up; the Refractions will then be too weak and in less Quantity, nor will the Rays be collected any longer upon the *Retina*. Let us consider this too flat Eye, and call it for Distinction sake the *Decayed Eye*.

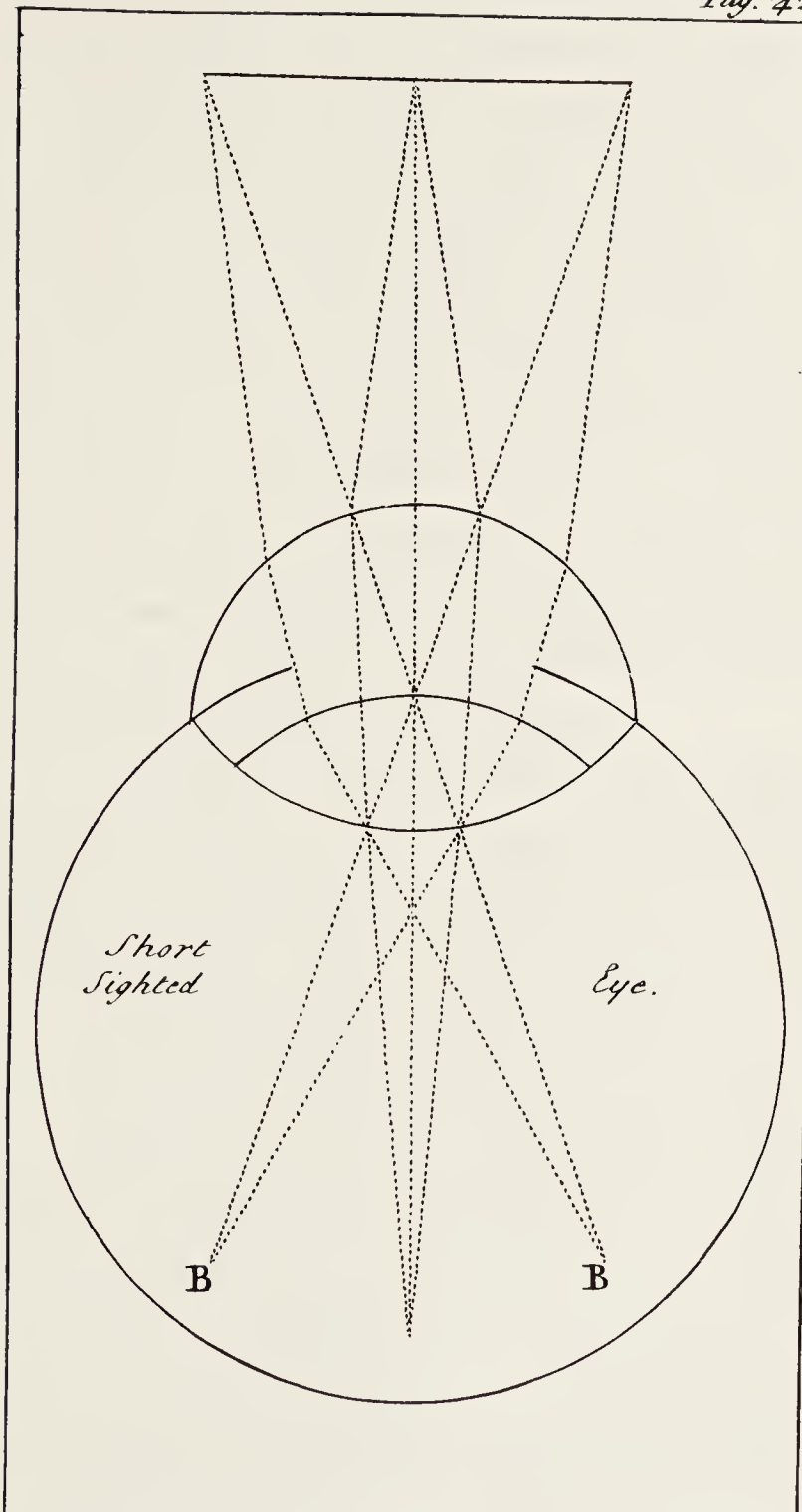
For the greater Facility, let us observe only three Groupes or Cones of Rays falling from the Object on this Eye. They will reunite at the Points A, A, A, beyond the *Retina*, and in Consequence the Objects will be seen confused.

Nature

Nature has supplied an Help against this Inconvenience, by the Power she has given the Muscles of the Eye either to lengthen or make it flat, to make it approach or withdraw from the *Retina*. Thus in this decayed Eye, the *Crystalline Humour* has the Faculty of advancing itself a little to D D: the Space then between it and the bottom of the *Retina* becomes greater, and the Rays are brought to unite upon the *Retina*, instead of going beyond it; but when that Power is lost, human Industry supplies it, and a Lenticular Glass is placed between the Object and the decayed Eye. The Effect of this Glass is to draw the Rays it receives close together, which it conveys to the Eye both more collected and in greater Number: these reach the *Retina* in the Points they ought, and the Sight is then clear and distinct.

Short-sighted Eye.

Observe this other Eye, which has a contrary Defect, it is too round. The Rays unite too soon, as you see at the Point B, they cross each other too fast, they separate in B, and from thence go on to make a Spot upon the *Retina*. This is called *Shortness of Sight*. This Inconvenience decreases in proportion



*Eye, in which the Crystalline is too round,
and occasions Shortness of Sight. —*

portion as Age brings on others, such as Dryness and Weakness: these insensibly render this too round Eye flat, for which reason short-sighted Eyes are said to last the longest. At this time the Person, who was obliged to bring his Book to the Distance of two or three Inches from his Eye, can sometimes read at that of a Foot; but at the same time his Sight soon becomes troubled and confused, and he cannot see distant Objects; such is our Condition, one Defect can scarce ever be repaired but by another.

Now, whilst this Eye is too round, it is necessary to use a Glass, which prevents the Rays of Light from re-uniting too soon. This Glass will have a quite contrary Effect to the former, and instead of being Convex on both sides, must be a little Concave on both sides, to disperse the Rays, which the other collects. They will in Consequence unite farther in the Eye, than they did before, and the Eye will see perfectly well. The Convexity, and Concavity of Glasses are proportioned to the Defects of the Eyes; the same Glasses, that suit the Eyes of one old Man, will be of no Service to another, for there are neither

two

two Diseases, two Men, nor two Things exactly alike in the World.

The Ancients did not know these Spectacles. They knew however Burning-Glasses; the Discovery of one Truth in a Subject, is not always a reason for the Discovery of all the Truths it includes. The Attraction of the Load-stone was known, but its Direction to the Pole remained a Secret. The Demonstration of the Circulation of the Blood was evident, even in the Bleeding practised by all the Greek Physicians, notwithstanding which no-body suspected that the Blood circulated.

It is very likely that the Spectacles and Magnifying-Glasses, which give new Eyes to the Old, were discovered in the time of *Roger Bacon* in the 13th Century; for he is the first that speaks of them.

You have now seen the Effects caused by Refraction in our Eyes, whether the Rays reach them without any intermediate Aid, or pass thro' Crystals: you conceive, that without such Refraction in our Eyes, and such Reflection of Rays from above the Surfaces of Bodies, the Organs of Sight would be of no use to us. The Means employed by Nature in
causing

causing this Refraction, and the Laws she observes, are Myſteries we are going to explain. But firſt we muſt conclude what we have to ſay concerning Sight, and ſatisfy theſe natural Queſtions ? Why do we ſee Objects beyond, and not upon, the Looking-Glaſs ? Why does a Concave Looking-Glaſs render Objects larger than they are ? Why do Telescopes draw Things nigh and magnify them ? By what Artifice does Nature make us ſenſible of Magnitudes, Diſtances and Situations ? And laſtly, why do we ſee Objects as they are, tho' reverſed on our *Retina* ? All theſe Things merit the Curioſity of every Thinking Being ? but we ſhould not have enlarged upon Subjects, which ſo many Illuſtrious Writers have treated of, and ſhould have referred to them, if we had not in view the making known ſome Truths ſufficiently new, and curious to a ſmall number of Readers.

C H A P. V.

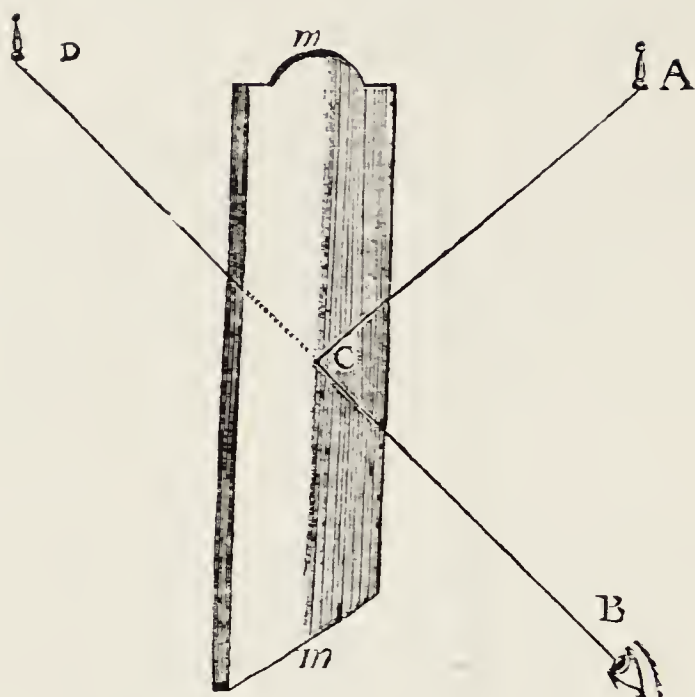
Of Looking-Glasses, and Telescopes: Reasons given by Mathematicians for the Mysteries of Vision; that those Reasons are not altogether sufficient.

THE Rays, which a Power unknown till our Days, causes to reflect to the Eye from above the Surface of a Looking-Glass, without touching that Surface, and from the Pores of that Glass, without touching its solid Parts; these Rays, I say, return to the Eye in the same manner as they arrived at the Glass. If you see your Face in it, the Rays from your Face striking parallel and almost perpendicular upon the Glass, return to it in the same manner as a Ball rebounds from the Floor.

Looking-Glass with a plane Surface.

If in the Glass M, we look at an Object on one side of us as A, the Rays of that Object act in the same manner as a Ball, which should rebound to B, the place of your Eye.

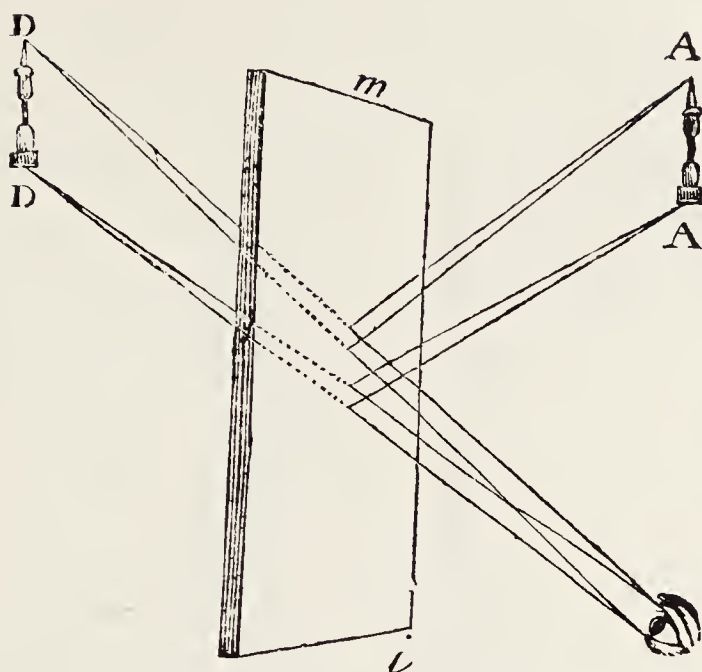
This



Geometry will tell us: that it is because the Angle of Incidence is equal to the Angle of Reflection: because the Eye in B, carries the Object into D; because Objects can act upon you only in right Lines, and because the right Line continued from your Eye B, behind the Glass to D, is as long as the Line A C, and the Line C B added together.

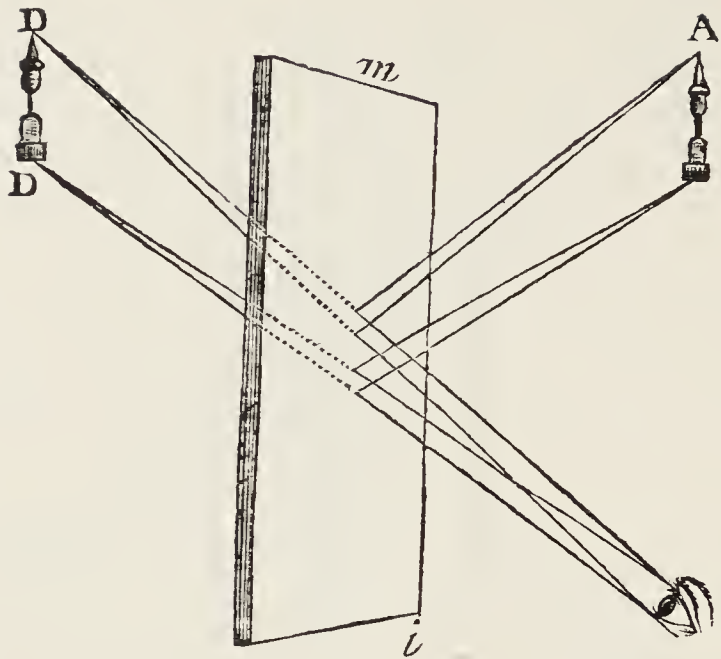
It will tell you also, that you never see Objects but from the Point where the Rays begin to diverge. Suppose the Mirror M I.

The



The Rays from every Point of the Object A, in Cones begin to diverge A the instant they quit the Object; they proceed to the Surface of the Glafs: there each of those Rays falls, difperfes, and is reflected towards the Eye. The Eye carries them back to the Points D D, at the end of the right Lines, where the fame Rays would meet; but in meeting at the Points D D, those Rays act in the fame manner, as at the Points A, A, where they begin to fspread; therefore you fee the Object A A at the Points D D.

These Angles and Lines ferve no doubt to make us understand this Artifice of Nature; but



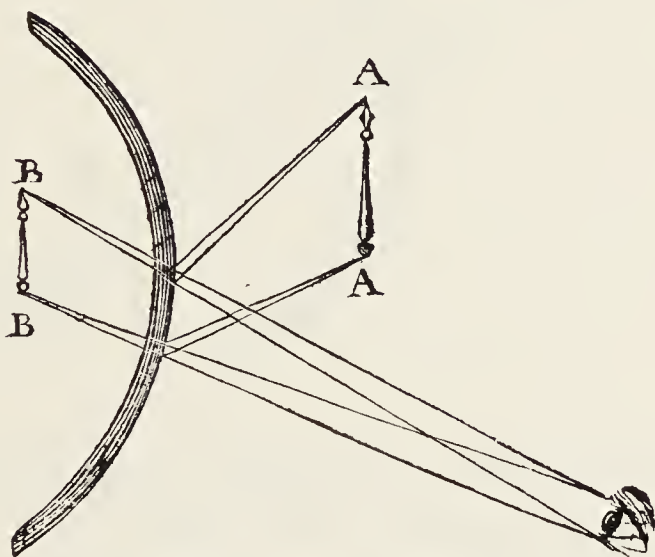
but they are far from informing us of the Physical Efficient Cause, why the Soul without hesitating carries the Object as far beyond the Glas as it is on this side of it. These Lines represent what happens, but do not shew why it happens.

If you would know in what manner a Convex Glas diminishes, and a Concave Glas enlarges Objects, these Lines of Incidence and Reflection will give you the same Reason.

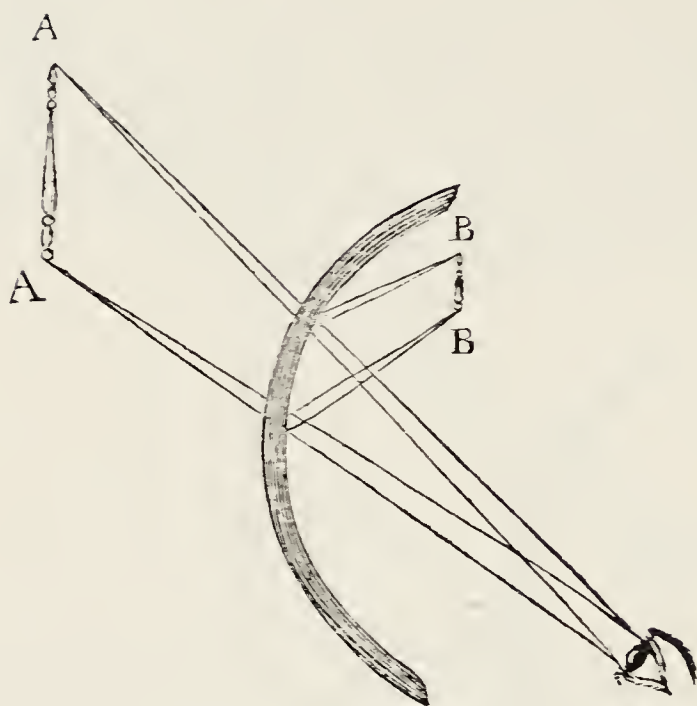
*Convex
Looking-
Glas.*

We are told ; that the Cone of Rays, which diverge from the Point A, and fall on the Convex Glas, makes Angles of Incidence upon it equal to Angles of Reflection,
of

of which Cone the Lines come to the Eye. Now these Angles are less, than if they had fallen on a plain Surface; therefore if they are supposed to pass to B, they will meet or converge there much sooner, and the Object in B B be smaller.



Now the Eye carries the Object to B B in Points, from which the Rays begin to diverge, therefore the Object must appear less, as it does in the above Figure. For the same reason that it appears less, it appears nearer, as the extreme Points of the Rays from B B, are actually nearer the Glass than those of the Rays from A A.

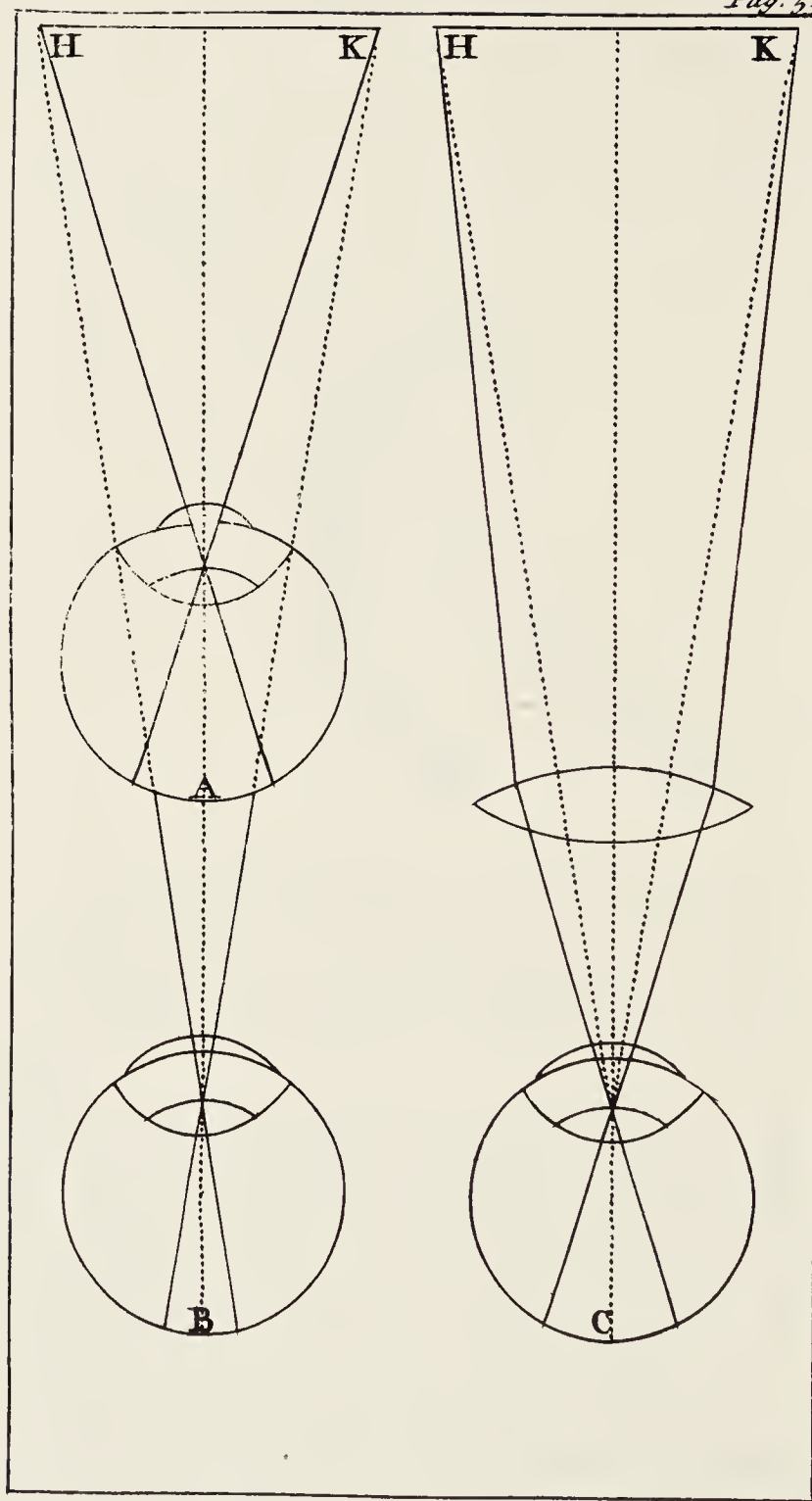


*Concave
Glass.*

By the Rule of Contraries you must see Objects greater and more remote in a Concave Glass, when placed near enough to the Glass.

For the Cones of the Rays from B B, spreading upon the Glass at the Points where those Rays fall, if they were reflected thro' that Glass, they would not unite but in A A, therefore they are seen in A A. Now A A is greater and more remote from the Glass than B B, and therefore we see the Object greater and farther off.

This



This is in general what happens in the Reflection of Rays to our Eyes, and all the Myſteries of Catoptricks are founded on this ſole Principle, that the Angle of Incidence is always equal to the Angle of Reflection.

We are now to know in what manner Glaſſes augment, objects and leſſen Diſtances; and laſtly why Objects, that paint themſelves reverſed in our Eyes, ſhould however be ſeen as they are.

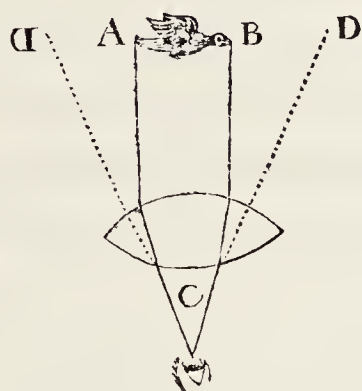
In regard to Magnitudes and Diſtances, *The Geometric Explication of Viſion.* the Mathematicks inform us, that the greater the Angle is, which an Object makes in the Eye, the greater the Object will appear: nothing is more plain. The Line H K at an hundred Paces forms an Angle, as you ſee in the Eye A (Figure 1 ;) at two hundred Paces, it forms another leſs by one half in another Eye at B. Now the Angle formed on the *Retina*, or of which the *Retina* is the Baſe, is as the angle of which the Object is the Baſe. Theſe Angles are oppoſite at their Summits or Vertical Points; therefore, according to the firſt Notions of the Elements of Geometry, they are equal. Hence if the Angle formed in the Eye A, be double the

the Angle formed in the Eye B, the Object will appear as large again to the Eye A, as to the Eye B.

Now, that the Object may be seen as large by the Eye at B, as by the Eye at A, it is necessary to act in such a manner, that the Eye B, may receive as large an Angle as the Eye A, which is as near again to it. The Glasses of a Telescope produce this Effect.

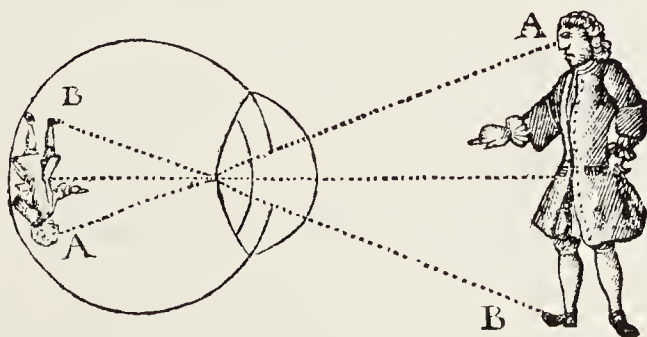
For the greater Facility let us suppose here only one Glass, and abstract from the Effects of many Glasses. The Object H K (Figure 2) transmits its Rays to this Glass, which are united at some distance from it. Let us conceive a Glass so contrived, that those Rays cross one another in such a manner, as to form in the Eye C, as great an Angle as that in the Eye A. The Eye then, you will say, judges by that Angle. It sees the Object of the same Magnitude as the Eye in A. But in A it sees it at the distance of an hundred Paces: therefore in C receiving the same Angle, it will still see it at the same Distance. The whole Effect of multiplied Glasses, different Telescopes, and Microscopes, which magnify Objects, consists there-
fore

fore in bringing Things to the Eye in a greater Angle. The Object A B, is seen by the means of a Glafs in the Angle D C D, which is much greater than the Angle A C B.



You ask the Rules of Opticks again, why Objects, which are painted, reversed upon our *Retina*, are seen in their true Situation.

The Ray from the Head of the Man A, falls upon the lower Point of the *Retina* A, his Feet B are seen by the Rays B B, at the upper Part of the *Retina* B.



Thus

Thus the Man is really painted with his Head downwards and his Feet upwards at the bottom of our Eyes. Why therefore do we not see this Man reversed, but upright and as he is?

To resolve this Question, the comparison of a blind Man is used, who holds in his Hand two Sticks crossed, with which he guesses very rightly of the Position of Objects :



For the Point B which is on the left, being felt by the Right Hand with the help of the Stick, he judges it immediately on the Left; and the Point A, which communicates with his Left Hand by the means of the other Stick, he judges on the Right without mistake.

All the Masters of Opticks tell us therefore, that the lower part of the Eye, immediately transfers its Sensation of the Object to the upper part A, and that the upper part of the *Retina*, as naturally transmits its Sensation to the lower part B, so that the Object is seen in its true Situation.

When we know perfectly well all the Angles and Mathematical Lines, by which the Passage of Light is traced to the bottom of the Eye, we are not to believe however that we know in what manner we attain our Perceptions of the Magnitudes, Distances, and Situations of Things. The Geometrical Proportions of those Angles and Lines are just indeed; but there is no more relation between them and our Sensations, than between the Sound we hear, and the Magnitude, Distance, and Situation of the Thing heard. My Ear is struck by Sound; I know the Notes and nothing more. My Eye is kept by Sight, I see Colours and nothing else. The Proportions of those Angles and Lines cannot only be in any respect the immediate Cause of the Judgment I form of Objects; but in many Cases, those Proportions do not in the
least

least agree with the manner in which I see Objects.

For Instance, we see a Man of the same Size at four and eight Paces from us *. And yet the Image of that Man at four Paces is exactly twice as large in the Eye as at eight. The Angles are different; the Object is however of the same Dimensions; it is evident therefore from this single Example, out of many, that these Angles and Lines are far from being the immediate Cause of the manner in which we see.

Before therefore we pursue the Enquiries we have begun upon Light, and the Mechanick Laws of Nature, it is your Command, that I should here shew in what manner the Ideas of Distances, Magnitudes, Situations, and Objects, are imparted to the Soul. This Enquiry will supply us with some new Truths, which is the only excuse for a Book.

* We judge him to be of the same Size, but do not see him so.

C H A P. VI.

*In what Manner we know Distances,
Magnitudes, Figures, and Situa-
tions.*

LET us begin with Distance. It is plain *Distance* that it cannot of itself be immediately *not known* perceived ; for Distance is no more than a *from the* Line from an Object to us. This Line ter- *Angles and* minates in a Point, we therefore perceive *Lines of* only this Point ; and whether the Object be *Opticks.* a thousand Miles or only a Foot from us, the Point is still the same.

We have not therefore any immediate Means of knowing Distance instantly, as we have by the Touch, of distinguishing whether a Body be hard or soft ; by the Taste, whether it be sweet or bitter ; and by the Ear, whether of two Sounds the one be grave and the other acute. The Idea of Distance therefore must be attained by the Means of some other intermediate Idea ; but I must at least have that intermediate Idea the same time ; for an Idea that I have not, will cer-
tainly

tainly never occasion my having another. I say such a House is a Mile from such a River; but if I don't know where that River is, I certainly don't know where the House is. A Body that easily receives Impression from my Hand I conclude soft; another resists, I immediately perceive its Hardness; it were therefore necessary, that I perceived the Angles formed in my Eyes, in Order to determine immediately the Distances of Objects from them. But nobody ever thinks of these Angles in looking at an Object. Most Men do not so much as know that there are such: It is evident then these Angles cannot be the immediate Cause from which we know Distances.

*Proved by
an Exam-
ple.*

The Person who the first Time of his Life should hear the Report of a Cannon, or the Harmony of a Concert, would not be able to judge whether that Cannon were discharged, or that Concert executed, at the Distance of a League or at that of thirty Paces. Only Experience can accustom him to judge of the Distance between him and the Place from whence those Sounds come. The Vibrations, the Undulations of the Air,
bring

bring Sounds to his Ears, or rather to his Soul, but it apprizes his Soul no more of the Place where the Sounds began, than it instructs him in the Form of the Cannon, or of the Instruments of Musick.

It is exactly the same Thing with Respect to the Rays of Light transmitted by an Object, they do not inform us at all how far that Object is.

They leave us no less in the Dark with
 Regard to Magnitudes, and even Forms or
 Figures.

Magnitudes and Figures not known by those optick Lines.

I see at a great Distance a Kind of little round Tower. I go on, I perceive, and touch a great quadrangular Building. Certainly what I see and touch, is not what I saw before. The little round Object which I had in my Eye, is not this great square Building.

The measurable and tangible Object therefore is one Thing, and the Object of Vision another. I hear in my Chamber the Noise of a Coach : I open my Window and see it;
 I go down and get into it. Now this Coach, which I have heard, this Coach which I have seen, and this Coach I have touched, is
 three

Proved by an Example.

three absolutely different Objects of three of my Senses, which have no immediate Relation to each other.

But farther; it is demonstrated, as I have said before, that there is an Angle in my Eye twice as large, when I see a Man at four Feet from me, as when I see the same Man at eight. However, I always see this Man of the same Size: Whence is it, that my Perception contradicts the Mechanism of my Organs in this Manner? The Object is really as small again in my Eyes, and I see it twice as large as it is. It is in vain to think of explaining this Mystery by the Passage through the Crystalline, or the Form that Humour takes in our Eyes. Whatever Supposition we may make, the Angle in which I see a Man at four Feet from me, is always twice as large as the Angle in which I see him at eight; and Geometry will never solve this Problem.

Nor the Situation of Objects.

These geometrical Lines and Angles are not more really the Cause that we see Objects in their Places, than that we see them of such Magnitudes, and at such Distances.

The Soul does not consider whether such a Part is to paint itself at the Bottom of the Eye, it's not concerned with Lines it does not see. The Eye only turns itself downwards to see what is near the Earth, and upwards to look at what is above it.

All this could only be explained, and made incontestible by some Person born blind, and restored to the Sense of Sight. For if this blind Person, at the Moment he received Sight, had judged of Distances, Magnitudes, and Situations, it had been true that the optick Angles, formed that instant in his *Retina*, had been the immediate Causes of his Thoughts. Dr. *Barclay* accordingly has assured us, after Mr. *Locke*, (and indeed has gone beyond Mr. *Locke* in this Point) that neither Situation, Magnitude, Distance, nor Figure, would be at all discerned by a blind Person, at the Instant his Eyes should receive Light.

But where was the blind Person to be found, on whom the indisputable Decision of this Question depended. In the Year 1729, Mr. *Chiselden*, one of those famous Surgeons, who unite a great Extent of

Proof by an Experiment on a Person born blind, cured by Mr. Chiselden.

Knowledge

Knowledge with Dexterity in Operations, having imagined, that Sight might be given to a Person born blind, by removing the Cataracts, which he conceived to have been formed in his Eyes almost at the Moment of his Birth, he proposed the Operation. The blind Person made Difficulties to consent to it. He could not very well conceive, that the Sense of Sight could contribute much to his Happiness. Without inculcating to him the its use for learning to read and write, he had never desired to see. His Indifference in this Point proves, that *It is impossible to be unhappy by the Privation of the Good of which we have no Idea.* A very important Truth. However that be, the Operation was performed and succeeded. The Youth then about fourteen Years of Age, saw the Light for the first Time. This Experiment confirmed all that *Locke* and *Barclay* had therein rightly foreseen. For a long Time he distinguished neither Magnitude, Distance, Situation, nor even Figure. An Object of an Inch placed before his Eyes, that concealed an House from his Sight, appeared to him as big as the House. Every Thing he saw,
seemed

seemed at first to be upon his Eyes, and to touch them, as the Objects of the Sense of Feeling touch the Skin. He could not distinguish what he had judged round, by the Help of his Hands, from what he had judged square ; nor discern with his Eyes, whether what his Hands had perceived to be above or below, were really above or below. He was so far from knowing Magnitudes, that after having at Length conceived by Sight, that his House was larger than his Chamber, he could not conceive how Sight could give him that Idea. He could not perceive, till after two Months Experience, that Pictures only represented solid Bodies, and when, after so long a Trial of his new Sense, he had thought, that Bodies, and not Surfaces only, were in the painted Tables, he applied his Hand to them, and was amazed that he did not feel those solid Bodies, of which he began to perceive the Representations. He asked which of the Senses deceived him, that of Feeling, or that of Seeing.

This was an indisputable Decision, that the Manner in which we see Objects, is no
immediate

immediate Consequence of the Angles formed in our Eyes ; for the same mathematical Angles were in the Eyes of this Youth, as well as in ours, and were of no Manner of Use to him without the Aid of Experience, and the other Senses.

*In what
Manner
we know
Magni-
tudes and
Distances.*

In what Manner then do we represent Magnitudes and Distances to ourselves? In the same as we imagine the Passions of Men, by the Colours which those Passions paint in their Faces, and the Alteration they make in their Features. There is nobody who does not immediately read Shame or Anger in another's Countenance. This is the Language which Nature speaks to every Eye ; but a Language to be learnt only by Experience. It is Experience only that also teaches us, that when an Object is too remote, we see it confusedly and faintly : From thence we form Ideas, with which the Sensation of Sight is ever after attended. Thus every Man, who, at the Distance of ten Paces, has seen a Horse five Foot high, if he sees, some Minutes after, the same Horse no bigger than a Sheep, his Mind, by an involuntary Judgment, concludes immediately that the Horse is a great Way off.

It

It is certain, that when I see my Horse so small as a smaller Image, a more acute Angle is formed in my Eye ; but that is what attends, not what causes, my Thought.

This Angle is so far from being the immediate Cause that I judge an Horse very far off when he seems very little ; that every Moment I see the same Horse of equal Size at ten, twenty, and thirty Paces from me, tho' the Angle is double, triple, and quadruple at those different Distances.

In like Manner my Brain is affected differently, when I see a Man red with Shame, and when I see him red with Anger ; but those Impressions would suggest nothing to me of what passes in the Soul of that Man, without the Language of Experience, which alone imparts it to me.

I see a great Way off, through a little *Example.* Hole, a Man upon the Top of a House, the Distance and small Number of Rays prevent me from distinguishing at first whether it be a Man or not : The Object seems very small, and I take it for a Statue of two Feet at most : The Object moves, I conclude it a Man, and from that Instant he is thought

to be of the usual Stature ; from whence proceed two Judgments so different ?

When I believe I see a Statue, I imagine it two Feet high, because I see it in such an Angle : No Experience inclines my Thoughts to contradict the Rays impressed upon my *Retina** ; but as soon as I judge it a Man, the Connection implanted in my Brain by Experience between the Idea of a Man and the Idea of an Height from five to six Feet, obliges me, without thinking of it, to imagine, by an instant Judgment, that I see a Man of such a Height.

*We learn
to see as
we learn
to read.*

From all this we must absolutely conclude, that Distances, Magnitudes, and Situations, are not, properly speaking, Things to be seen, that is to say, the proper and immediate Objects of Sight. The proper and immediate Object of Sight is nothing in Nature but coloured Light ; all the rest we only attain to know by Length of Time and Experience. We learn to see, exactly as we learn to speak and read. The Difference is, that the Art of Seeing is the most easy, and that we are all equally Nature's Pupils in learning it.

* Yes, the seeing it confusedly and faintly, tells me its far off, and therefore bigger. See p. 66. l. 17.

The sudden and almost uniform Judgments, which every Mind forms at a certain Age of Distances, Magnitudes, and Situations, makes us think it only necessary to open the Eyes, in order to see Things as they are. But this is a Mistake; the Aid of the other Senses is essential to this Effect. If Men had no other Sense but that of Sight, they would have no Means of knowing Extent, Length, Breadth, and Depth*; and a pure Spirit or Angel could never know it, unless God revealed it to him. It is very difficult to separate in our Understanding the Extension of an Object from the Colours of it. We never see any Thing that is not extended, and from thence are all led into the Belief, that we actually see Extent. We can scarce distinguish in Thought the Yellow, which we see in a Piece of Gold, from the Piece of Gold of which we see the Yellow. Thus when we hear the Word a *Guinea* pronounced, we cannot help annexing the Idea of that Coin to the Sound we hear uttered.

*Extent not
to be known
from the
Sight.*

If all Men spoke the same Language, we should always be ready to believe, that there

* Except relatively, but not really without Feeling.

would

would be a necessary Connection between Words and Ideas. Now in this Point all Men have the same Language, with Respect to Imagination. Nature tells it to all that when you have seen Colours for a certain Time, your Imagination will represent to you, in the same Manner, all the Bodies, in which those Colours seem inherent. That sudden and involuntary Judgment, which you shall form, shall be useful to you during the Course of your Lives; for if, to judge of the Distances, Magnitudes, and Situations of all that surrounds you, it were necessary to wait till you had examined the Angles and Rays of Vision, you would die before you knew, whether the Things you had Occasion to use, were at the Distance of ten Paces from you, or at that of an hundred millions of Leagues, whether they were of the Bigness of a Mite or a Mouse.

We are therefore very much in the wrong when we say our Senses deceive us*. Each of them discharge the Function for which Nature intended them. They assist each other mutually, in conveying to the Soul by the

* We suffer ourselves to be directed by our Senses.

Means of Experience, such a Measure of Knowledge as our Condition admits. We demand of our Senses, what they were not formed to bestow. We are for knowing from our Eyes Solidity, Magnitude, Distance, &c. but the Touch must unite in this with the Sight, and Experience with both. If *Mallebranche* had considered Nature in this View, he had ascribed fewer Errors to our Senses, which are the sole Springs of all our Ideas.

It is Time to resume the Thread of *Newton's* Discoveries, and to return to our physical and mathematical Enquiries.

C H A P. VII.

Of the Cause of the breaking of the Rays of Light in passing from one Medium to another ; that this Cause is a general Law of Nature unknown before Newton ; that the Inflection of Light is also an Effect of the same Cause.

WE have already seen the almost incomprehensible manner, in which the Reflection of Light is performed, and which the known Impulsion cannot cause. That of Refraction, of which we are now going to resume our Examination, is no less surprizing.

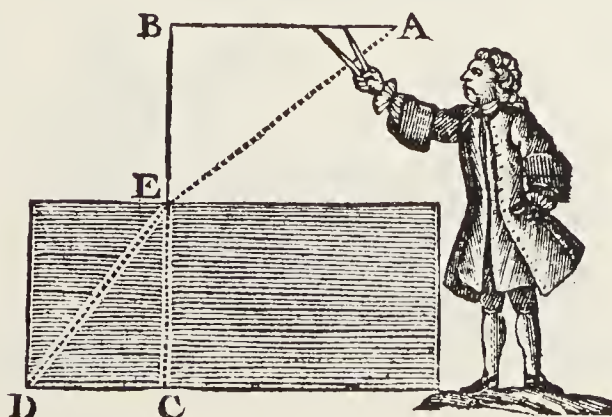
What Refraction is.

Let us begin by establishing in ourselves a clear Idea of the Thing we are to explain. Let us remember well, that when Light falls from a more rare and thin Medium, as the Air, into one more heavy and dense, as the Water, which in appearance should resist it more than the former, that then Light quits its Course or Direction, and breaks in a Line approach-

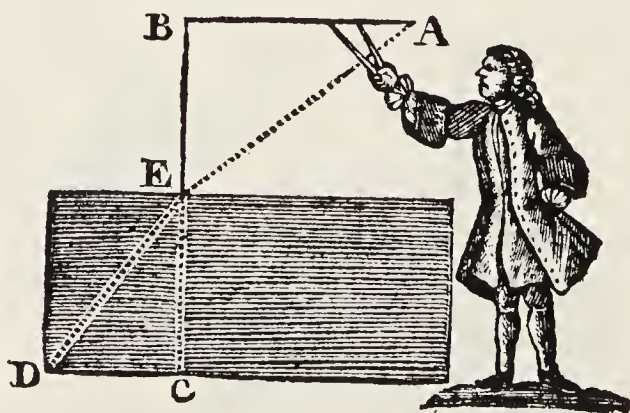
approaching to a perpendicular raised upon the Surface of that Water.

Mr. *Le Clerc*, in his *Physicks*, has said directly the contrary for want of Attention. In the Eighth Chapter of his Fifth Book he says; "The greater the Resistance of Bodies
" is, the more the Light that falls into them
" removes from a Perpendicular. Thus a
" Ray removes from a Perpendicular in passing from the Air into Water." This is not the only Mistake in *Le Clerc*, and a Man who should have the Misfortune to study *Physicks* in the Writings of that Author, would scarce have any but false and confused Ideas.

To have a perfectly clear Idea of this Truth, observe the Ray A, E which falls from the Air into this Crystal.



You know in what manner it is broke. The Ray A E makes an Angle with the Perpendicular B E, in falling upon the Surface of the Crystal. The same Ray refracted in the Crystal makes another Angle with the same Perpendicular, which determines its Refraction. It was necessary to measure this Incidence and breaking of Light. *Snellius* first found the perpetual Proportion, according to which the Rays are broke in different Mediums. The Honour of it was ascribed to *Descartes*. People always ascribe to the Philosopher of greatest Reputation the Discoveries he publishes: he improves by the Labours of the obscure, and augments his own Glory by their Enquiries. The Discovery of *Snellius* was a Master-piece in his Time. That Proportion is very intelligible.



The greater Line A B, which you see, is, the greater also will be the Line C D. The Line A B is called the *Sine* of Incidence. The Line C D is the *Sine* of Refraction. This is not a proper Place to explain in general what a *Sine* is. Those who have studied Geometry know it already. Those who have not, might find some difficulty in the Definition of it. It suffices to understand aright, that these two *Sines*, of whatsoever Extent they be, are always in Proportion to one another according to the Medium.

The Light, which falls obliquely from the Air into the Crystal, is broke there in such a manner, that the *Sine* of Refraction C D is to the *Sine* of Incidence A B, as 2 is to 3 *, which is no more than to say, that the A B is one third greater in the Air, in this Case, than the Line C D is in the Crystal.

In the Water this Proportion is from 3 to 4. Hence it is evident, that the Crystal refracts, or breaks, the Light one twelfth more strongly than Water. Consequently in all Cases, and in all possible Obliquities of In-

* This is true on Supposition that A E and E D were equal, then C D and A B would be Sines of the two Angles to one Radius.

cidence, Crystal will be more refracting than Water by a twelfth. The Question is to know not only the cause of Refraction, but the cause of different Refractions.

*Ingenious,
but false
Idea of
Descartes.*

Descartes, according to his Custom, has invented ingenious and plausible Reasons for this Property of Light; but in this, as well as the rest, setting his Wit in the Place of Reality, he has given us Conjectures instead of Truths. He tells us that Light, in passing from the Air into a new, more dense, and compact Medium, passes more freely in it, and is less retarded in its pretended Tendency to Motion, and *less retarded*, says he, *less interrupted in a dense Medium, as Glass, than in a thinner Medium, as Water.* We have already seen how much he imposes upon himself in asserting, that Light has only a Tendency to Motion. We have seen, that the Rays actually move, because they change their Place before our Eyes in their Refractions. But his Error here is still farther important: He deceives himself in believing, that those Bodies which break the Light most, are always the most solid, in which the Passage of Light is more easy. It

*The most solid Body
does not
refract
most.*

is not true, that all solid Bodies absolutely refract Light more than fluid Bodies ; for tho' in Effect Water does not occasion so strong a Refraction absolutely speaking, as Glass ; however, in regard to its Density, it occasions a stronger. It is certain that Light is broke a twelfth more in Glass than in Water ; but if Refraction were determined in Proportion to Density, it ought much to exceed a twelfth in Glass. Imagine two Men, the one four times stronger than the other. If the stronger carry only a Weight twice as heavy as the weaker, we should say with *Proof*. Truth, that in regard to his Strength, he does not carry so much as the other by a great deal ; for he ought to carry four times as much.

Amber refracts much stronger in Proportion to its Density. Can one say however, that Amber opens a more easy Passage for Light than Crystal ? It is therefore a false Supposition ; *that Light is broken in a Line approaching to a Perpendicular, when it enters a more solid, transparent Body, which resists it the less, because it is more solid.*

Observe

Observe that every Experiment and Calculation destroys almost all the Ideas of *Descartes*, when that great Philosopher founds them only upon Hypotheses. They are shining and delusive Prospects, which diminish in Proportion as we approach them. All the rest of the Philosophers have endeavoured at Solutions of this Problem of Nature; but Experience has also refuted their Conjectures.

Mistake of other great Philosophers upon this Head. *Barrow* taught, after Father *Descalles*, that the Refraction of Light, in approaching to a Perpendicular, was occasioned by the Resistance of the Medium; that the more a Medium resisted the Passage of Light, the stronger that Refraction became.

This Idea was the Reverse of that of *Descartes*; and only proved, that there are different ways to Error. They had only to consult Experiments; they had only to measure the Refractions made in Spirits of Wine, which are much greater than in Water; they had only to consider, that Spirits of Wine undoubtedly do not resist more than Water, and that however they occasion a Refraction as strong again; and they would then have corrected this small Error. And indeed

indeed Father *Deschalles* owns, that he very much suspects his own Doctrine.

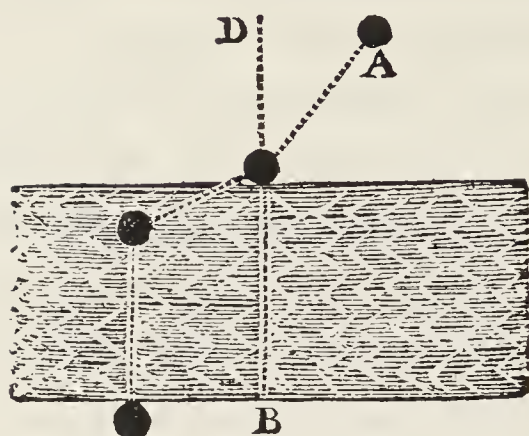
At length *Newton* alone discovered the true Reason enquired after. His Discovery undoubtedly merits the Attention of all Ages. For the Question here does not only regard a particular Property of Light, tho' that were a great Point ; we shall see that this Property extends to all the Bodies in Nature.

*Newton's
great Dis-
covery.*

Consider that the Rays of Light are in Motion, that if they turn aside in changing their Course, it must be an Effect of some Primitive Law, and that, nothing should happen to Light, but what should happen to all other Bodies of the same smallness as Light, *cæteris paribus*.

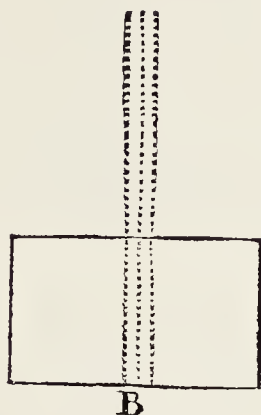
Let a Ball of Lead *A* move obliquely from the Air into the Water, the contrary of what happened to the Ray of Light will happen to the Ball ; for that a subtile Ray enters into the Pores of the Water, and the Ball, whose Superficies is large, encounters the Superficies of the Water which buoys it up.

This



This Ball removes then at first from the Perpendicular DB ; but when it has entirely lost the oblique Motion impressed upon it, it is left to itself, and falls directly in a perpendicular Line, from the Point where it began to sink. Now *Newton* has discovered and proved, that there is a Power in Nature, which makes all Bodies tend towards each other in a strait Line, in direct Proportion to their Quantity. This Power therefore (such as it may be) must act in the Water upon a Ray, and the Quantity of the Ray being incomparably less than that of the Water, the Ray must be sensibly moved towards it.

Observe then this Ray of Light, which falls perpendicularly from the Air upon the Surface of this Crystal. As



As this Line falls perpendicularly, the Power of Attraction, such as it is, acting in a right Line, the Ray does not turn aside from its Course; but arrives more swiftly than it would have done in B; and this is another Truth discovered by *Newton*.

Before him, this Ray of Light was believed to be retarded in its Course by entering into the Water. On the contrary, it enters it with additional Force. But why? Because it falls into it both by its own Motion, and by that which the Attraction of the Water, or the Glafs, impresses upon it. This Ray arrives more swiftly in B, by this acceierative Force, than it would have passed through the Air without it.

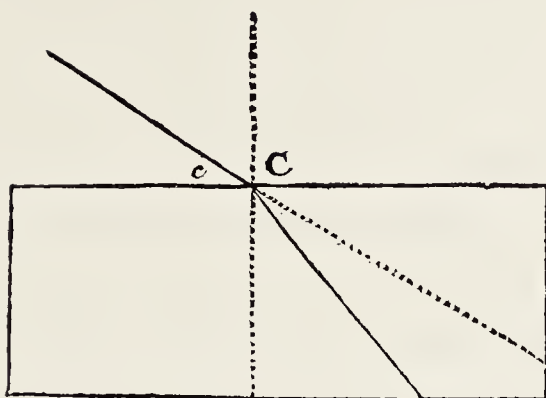
But

But if we consider in the same Basin of Water, or the same piece of Glass, the oblique Ray which falls upon it, what follows? It retains its oblique Motion in a right Line, and acquires a new one in a perpendicular Line *.

That this Attraction, this Tendency, this kind of Gravitation exists, is not to be doubted: for we have seen Light, attracted by Glass, re-enter it without touching any Thing; now this Power necessarily acts in a perpendicular Line, that Line being the shortest way.

As this Power exists, it exists in all the Parts of Matter. The Parts of the Superficies of every Body whatsoever, do exert therefore this Power, before the Ray enters or attains the Center to which it is directed. Thus as soon as this Ray arrives near the Superficies of the Crystal or the Water, it begins to incline a little in this manner towards a Perpendicular.

* Two Forces acting on it the same Time in different Directions, it takes a Course between them.



It begins to break a little in *c*, before it enters : the farther it goes, the more it breaks ; that is, the nearer Bodies are the more they attract each other, and that which is more in Substance determines that which is less towards it. Thus the same happens to this Ray of Light as to every other Body that has two different Directions ; it is engrossed by neither, but holds a Course that participates of both. This Ray therefore neither falls entirely in a perpendicular Line, nor follows its first oblique Direction, in passing thro' the Water or the Glass ; but it follows in a Line, which participates of both, and which descends the faster, in Proportion to the Force with which the Water, or Crystal, attract it. The Water therefore, far from
break-

breaking the Rays of Light by resisting them, as was believed, really breaks them because it does not resist, and on the contrary because it attracts them. We must therefore say, that the Rays are broken in a Line inclining towards a Perpendicular, not when they pass from a more easy into a more resisting Medium, but when they pass *from a less attracting, into a more attracting Medium*. Observe, that this Word *attracting* must never be understood, but as towards the Point to which that known Power, an indisputable Property of Matter, directs itself.

You are sensible, that abundance of People, as much attached to the Philosophy, or rather the Name, of *Descartes*, as they were formerly to the Name of *Aristotle*, have declared against Attraction. Some would not study it, others despised and condemned it, after having scarce examined it; but I beg the Reader to make the three following Reflections.

*The Word
Attraction
should be
examined
before de-
clared a-
gainst.*

1. What are we to understand by Attraction? Nothing but a Force by which one Body approaches another, without any other Force being seen or known to impel.

2. This

2. This Property of Matter is received by the best Philosophers in *England, Germany, Holland*, and even in many Universities of *Italy*, where Laws of a rigorous Nature sometimes bar the Avenues to Truth. The Consent of so many learned Men is no Proof indeed ; it is however a strong Reason for examining at least, whether this Power exists or not.

3. We ought to suppose, that we know no more of the Cause of Impulsion, than we do of that of Attraction. We even have not a greater Idea of the one than the other of these Powers; for no-body can conceive why a Body has Power by them to move another from its Place. Neither, indeed, do we conceive better why the Parts of Matter gravitate towards each other. *Newton* himself did not pretend to know the Reason of this Attraction. He has only proved its Existence: he saw a constant Phænomenon, an universal Property in Matter. If a Man discovers a new Metal in the Earth, would this Metal exist the less, because the first Principles of it were not known. Let the Reader of this little Treatise peruse Mr. *Maupertius's* Metaphysical Discussion upon Attraction, in the
smallest

smallest and perhaps best wrote Philosophical Book in *French*. He will there see thro' the Reserve with which the Author explains himself, what he thinks, and what is to be thought of Attraction, of which the Name has given so much Offence.

We have seen in the second Chapter, that the Rays of Light reflected to us from a Looking-Glass cannot be reflected from its Surface. We have seen experimentally, that the Rays, transmitted by a Glass to a certain Angle, return instead of passing into the Air; that, if there be a Void behind that Glass, the Rays which were transmitted before, return from that Void to us. In this Case there is certainly no Impulsion. Another Power must necessarily be admitted; and at the same time we must inevitably admit, that there is something in Refraction hitherto not understood.

Now what Power is that, which breaks a Ray of Light in a Basin of Water? It is demonstrated, (as we shall shew in the following Chapter) that, what had hitherto been believed a single Ray of Light, is a Groupe of many Rays, which are all differently refracted.

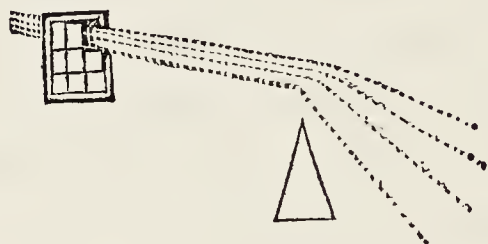
ed. If one of the Rays of Light contained in this Groupe is refracted, for Instance, at four Degrees distance, another will be at three, from a Perpendicular. It is demon-
Proofs of Attraction.
 strated, that the most refrangible, that is to say, those which in being broke on quitting the Glafs, and in taking a new Direction in the Air, go most from the Perpendicular of that Glafs, are also those which are reflected soonest and with most Ease. It is therefore already very probable, that the same Law which occasions the Reflection, occasions also the Refraction of Light.

Lastly, If we find still some new Property of Light, which appears to derive its Origin from the Force of Attraction, ought we not to conclude that so many Effects proceed from the same Cause?

This new Property was discovered by Father *Grimaldi* the Jesuit about the Year 1660, upon which *Newton* has carried his Enquiries so far as to measure the Shadow of an Hair at different Distances. This Property is the Inflection of Light. The Rays not only break in passing the Medium, the Substance of which attracts them; but other Rays, which

*Inflexion
of Light
near Bo-
dies that
attract it.*

which pass in the Air near the Edges of the attracting Body, sensibly approach it, and visibly turn aside from their Course or Direction. Put a Blade of Steel or thin Glass ending in a Point, in a dark Place: let it be set near a little Hole through which the Light passes; and let the Light almost touch the Point of this piece of Steel or Glass.



The Rays will bend in such a manner near it, that the Ray next the Point will be more curve, and the farthest from it less so in proportion. Is it not highly probable, that the same Power, which breaks these Rays, when in this Medium, forces them to incline towards it, and quit their Direction, when they are near it? Thus we see Refraction, Transparence, and Reflection subjected to new Laws; and an Inflexion of Light resulting evidently from Attraction. Thus a new Universe presents itself to the Eyes of those who are willing to see it. We

We shall soon shew, that there is an evident Attraction between the Sun and the Planets, and a mutual Tendency of all Bodies towards each other. But we think proper to observe here, that this Attraction, which causes the Gravitation of the Planets towards the Sun, does not at all act in the same Ratio's, as the Attraction of Corpuscles which touch each other. We must also remember well, that those Ratio's change at the Point of Contact; and not believe, that Light is inflected towards the Crystal and in the Crystal in the same Ratio, for Instance, as Mars is attracted by the Sun. All Bodies, as we shall see, are attracted in the Ratio inverse of the Squares of their Distances; but at the Point of Contact, they are attracted in the Ratio inverse of the Cubes of their Distances, and even considerably more. Thus Attraction is much stronger, and the Force of it dispersed with much greater Velocity; and this Attraction of Bodies, that touch each other, still augments in Proportion to the smallness of the Bodies. Thus the Particles of Light, attracted by the small Substance in Glass, are far from following
the

the Laws of the Planetary System. Two Atoms, and two Planets, as Jupiter and Saturn, are governed by Attraction; but by different Laws of Attraction. This is what we shall explain in our last Chapter but one, and which we thought proper to premise here to remove all Ambiguity.

C H A P. VIII.

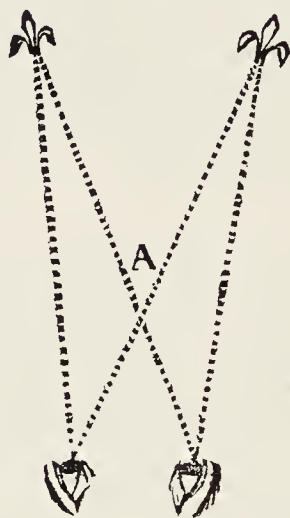
The wonderful Effects of the Refraction of Light. The several Rays of Light have all possible Colours in themselves; what Refrangibility is. New Discoveries.

IF you ask the Philosophers what is the cause of Colours, *Descartes* will tell you, *That the Globules of his Elements are determined to turn round upon themselves with Velocity, besides their Tendency to Motion in a right Line, and that these different Whirlings round are the cause of different Colours.* But, in reality, what are his Elements, his Globules and Whirlings, do they require the Touchstone of Experiment to prove them false? A multitude of Demonstrations annihilate these Chimeras's, of which the following are most simple and sensible.

Dispose a number of Balls against one another: suppose them pushed and turning about with Velocity on all sides, the very Words shew, that it is impossible for these

con-

contiguous Balls to move forward regularly in right Lines. Again in what manner should we see this Point Blue and this Point Green upon a Wall ?



Suppose them marked on this Wall ; they must cross each other at the Point A, before they reach our Eyes. As they cross each other, their pretended Whirling must change at the Point of Intersection. The Whirlings of the Blue and the Green subsist then no longer as before ; in Consequence there would be no longer either the Point Green or the Point Blue. A *Flemish* Jesuit made this Objection to *Descartes*. The latter was sensible of all its Force, but could one have imagined he would answer ; *That those Balls do not actually*

actually turn round, but that *they have a Tendency to turning round*? This *Descartes* says in his Letters. The Act of *transparent*, *quatenus transparent*, is it more intelligible?

You will tell me, without doubt, that there is the same Difficulty in all Systems: that the Rays from the Point Blue and the Point Green necessarily cross each other, whatever Opinion we espouse in respect to Colours; that this Interfection of the Rays must always prevent Vision; in a Word, that it is always incomprehensible, how Rays, which cross each other, should come to our Eyes in their proper Order; but this Scruple will soon be removed, if we consider, that every Part of Matter has incomparably more Pores than Substance. A Ray of the Sun, thirty millions of Leagues in length, has probably not one Foot of solid Matter in its whole Extent. It would therefore be very possible for such a Ray to pass through another in this manner without displacing any thing.

They



They do not only pass in this manner, but over one another like two Staffs. It may further be objected, that the Rays which flow from one Center, do not terminate exactly, and in Mathematical Strictness, at the same Point of the Circumference. That is true : and that Point must always be infinitely small: but two Men never see the same Points of the same Object. This is also true. Of a thousand millions of Persons who should look upon the same Superficies, no two of them would see the same Points.

In the *Plenum* of *Descartes*, it must be confessed, that this Intersection of the Rays is impossible; but every thing is equally impossible in a *Plenum*, and there is no Motion whatsoever that does not suppose and prove a *Vacuum*.

Malle-

Mallebranche in his turn tells us : *It is true* Error of Mallebranche.
Descartes deceived himself. His whirling of Globules is not to be maintained ; but they are not Globules of Light, they are little Whirlings of subtile Matter, capable of Compression, which are the cause of Colours ; and Colours consist like Sounds in the Vibrations of that Pression. And he adds : To me it seems impossible to discover by any Means the exact Proportions of these Vibrations, that is to say, of Colours. It is remarkable, that he talks in this manner in the Academy of Sciences in 1699 ; and that these Proportions (or Ratio's) had already been discovered in 1675 ; not Proportions of little Whirlings which do not exist ; but Proportions of the Refrangibility of the Rays, which forms Colours, as we shall presently shew. What he believed impossible, was already demonstrated, and what is more, demonstrated to the Eyes, acknowledged true by the Senses, which would have highly displeased Father Mallebranche.

Other Philosophers, perceiving the Fallacy of these Suppositions, tell us at least with more Probability : *Colours are produced by the Rays of coloured Bodies more or less reflected.*

White

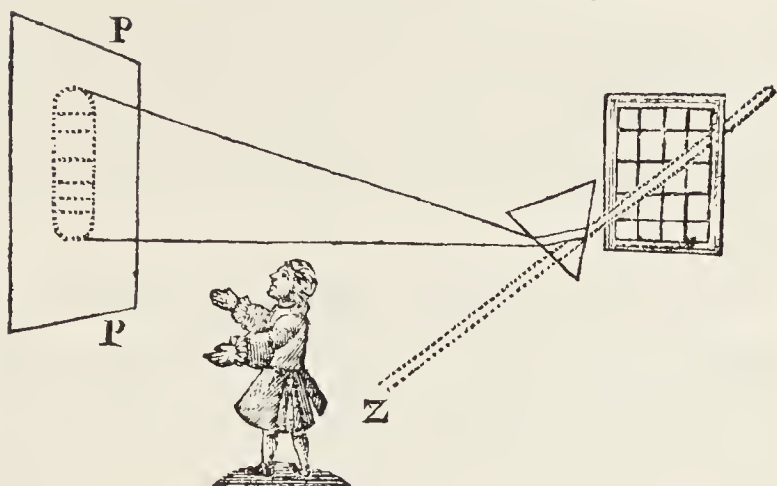
White reflects most, and Black least of them all. The most shining Colours therefore are those which emit most Rays to the Eye. Red, for instance, which pains the Sight a little, ought to consist of more Rays than Green, which gives it most Ease. This Hypothesis appears more rational at first; but is only Conjecture, (and that too very imperfect and erroneous) and a Conjecture is only a new Reason for enquiring, but not for believing.

Newton's
Experi-
ments and
Demon-
stration.

Let us apply to *Newton*. He will tell us; Don't believe me; believe only your Eyes, and the Mathematicks: place yourself in a Room entirely darkened, into which the Light comes only thro' an Hole exceedingly small; the Ray of Light falling upon Paper will give you the Colour White.

Place a Prism of Glass transversally to a Ray of Light; then at the distance of about sixteen or seventeen Feet fix the Sheet of Paper P, opposite to the Prism,

You



You know already that Light is broke in entering the Prism from the Air ; you know that it breaks in a contrary manner in passing from the Prism into the Air. If it was not broke it would fall from the Hole upon the Floor of the Room 'Z. But as this Light in passing from the Prism must remove from the Line Z, it will in Consequence strike the Paper. There then appears the whole Secret of Light and Colours. The Ray, which falls upon the Prism, is not, as was believed, a single Ray, but a Group, consisting of seven principal Groups of Rays, each of which carries in itself a Primitive or Primordial Colour peculiar to itself *. From that Mixture of

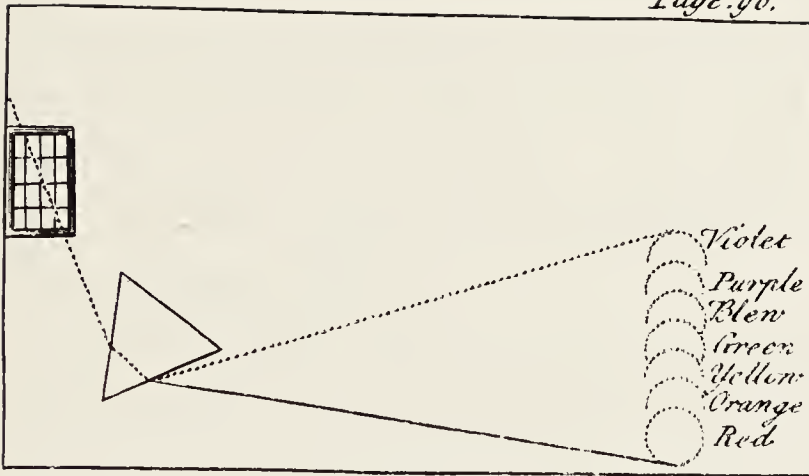
* It's hard to conceive how one Ray can be a Group or Bundle of Rays containing seven other Bundles ; it's easier to conceive Rays of seven different kinds falling mixed on the Prism that are afterwards separated by it.

the seven Rays come all the Colours in Nature ; and the whole seven united, and reflected together from one Object, form Whiteness.

Let us trace this admirable Artifice to the bottom. We have already insinuated, that the Rays of Light are not all refracted or broken equally, of which this is an evident Demonstration to the Eyes *. The seven Rays of Light having quitted the Body of the Ray, which is anatomized at passing from the Prism, place themselves each in its Order, upon the white Paper, each Ray occupying an Oval. The Ray which has least Force, Rapidity, and Matter to keep its Direction, removes most in the Air from the Perpendicular of the Prism. That which is the strongest, most dense, and most vigorous, removes least from it. Observe these seven Rays, which are broke one above another.

Each of them paints upon the Paper the primitive Colour peculiar to itself. The first Ray, which removes least from the Perpendicular of the Prism, is the Colour of Fire ;

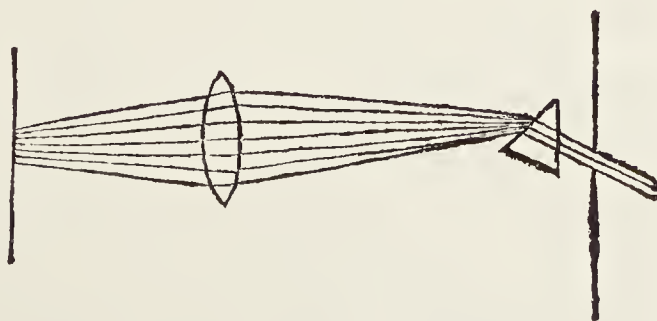
* There can be no Demonstration to the Eye, not so much for that the Sense is deceitful, as for that it's doubtful whence that Appearance flows.



the second orange; the third yellow; the fourth green; the fifth blue; the sixth indigo; and the last, which removes most from the Perpendicular, and rises above all the rest, is the violet.

A single Group of Light, which at first *Anatomy of Light.* composed only Whiteness, is therefore one consisting of seven Groups of Rays, which have each their peculiar Colour. The assemblage of seven Primordial Rays therefore is what composes white.

If this be still doubted, take a Lenticular Spectacle-Glass, which collects all the Rays at its Focus: place this Glass upon the Hole at which the Light enters, and you will never see any thing at the Focus but a round Spot of white. Place the same Glass at the Point, where it can collect all the seven Rays that pass thro' the Prism.



It unites, as you see, those seven Rays in its Focus. The Colour of those seven Rays is white; which demonstrates that the Colour of all the Rays united is Whiteness. Consequently the Body which reflects no Light will be black.

*Colours in
the primitive
Rays.*

For when by the help of the Prism we have separated some of these primitive Rays, tho' we make them fall upon a Looking-Glass, a Burning-Glass, or another Prism, they will never change their Colour nor separate into other Rays. To contain such a Colour is their Essence, nothing can alter them more; and as a super-abundant Proof, if we take Silk-Threads of different Colours, and lay one of them, a blue one for Instance at the red Ray, the blue Silk will become red. Put the same to the yellow Ray it becomes yellow; and so on with the rest. In fine neither Refraction, Reflection, nor any other Means conceivable can change this primitive Ray, being as unalterable, or rather more so, than Gold proved in the Crucible.

This Property of Light, this Inequality in the Refraction of its Rays, is what *Newton* calls Refrangibility. At first its Existence

was

was opposed, and continued to be denied a long time, because Mr. *Mariote* had erred in making *Newton's* Experiments in *France*.

People were better pleased to say, that *New-*
ton had boasted of having seen what he had
 not seen, than to think *Mariote* had not ta-
 ken proper Methods for seeing the same, and
 had not been happy enough in the Choice of
 his Prisms. Even afterwards, when these
 Experiments had been well made, and Truth
 had shewn itself to our Eyes, Prejudice still
 subsisted to such a Degree, that in several
 Journals and Books published since the Year
 1730, the same Experiments are confident-
 ly denied, tho' made by all *Europe* every Day.
 In the same manner, after the Discovery of
 the Circulation of the Blood, These were
 maintained against that Truth, and the Per-
 sons who explained that new Discovery,
 nick-named *Circulators*, by way of Ridicule.

At length, there are some who still hold
 out when obliged to yield to Evidence :
 they have seen the Fact, but they cavil at
 the Expression: they have declared War a-
 gainst the Term Refrangibility, as well as
 against those of Attraction and Gravitation.

But,

*Vain Ob-
 jections a-
 gainst these
 Discove-
 ries.*

But, in the Name of Nonsense, what signifies the Term, provided it implies a Truth? When *Christopher Columbus* discovered the Island *Hispaniola*, had he not a Right to call it by whatever Name he thought fit? And have not Inventors an equal Right to name what they create or discover? People have cried out and wrote against Words, which *Newton* has used with the wisest Precaution to prevent Errors.

*Criticisms
still more
absurd.*

He calls these Rays, red, yellow, &c. *rubrifick, flavifick* Rays, that is to say, exciting the Sensation of red, yellow, &c. His Intent in this was to stop the Mouths of those, who should have the Ignorance, or Injustice, to impute to him, that he believed with *Aristotle*, that Colours are in the things themselves, in the yellow and red Rays, and not in our Mind. He had reason to apprehend this Accusation. I have met with Persons, and those too of some Merit, who have assured me, that *Newton* was a Peripatetick, that he thought the Rays themselves actually coloured, as Fire was formerly believed hot; but the same Criticks assured me also, that *Newton* was an Atheist. It is true, they

they had not read his Works, but they had heard them spoken of by others, who had wrote against his Experiments, without having seen them.

The gentlest Treatment those who wrote first against *Newton*, gave his System, was to say it was an Hypothesis; but what is an Hypothesis? A Supposition. And can Facts so often demonstrated be justly called a Supposition? Is it thro' Self-Love, that People will absolutely have the Honour of writing against a great Man? Ought they not rather to be better pleased with being his Disciples than Opponents? Is it because they are born in *France*, that they are ashamed of receiving Truth at the Hands of an *Englishman*? Such a Thought would ill become a Philosopher. Whoever thinks right, has no regard here to *French* or *English*; he that instructs us is our fellow Countryman.

C H A P. IX.

The Cause of Refrangibility; from which it appears that there are indivisible Bodies in Nature.

THE Refrangibility, which we have now seen, being united to Refraction, must have its Source in the same Principle. The same Cause must preside in setting all these Springs in Motion: this is the Order of Nature. All Vegetables are nourished by the same Laws; all Animals have the same Principles of Life. Whatever happens to Bodies in Motion, the Laws of Motion are immutable. We have already seen, that the Reflection, Refraction, and Inflection of Light, are the Effects of a Power, which is not Impulsion (at least known Impulsion :) this same Power shews itself in Refrangibility; the Rays, which disperse themselves to different Distances, inform us, that the Medium, in which they pass, acts unequally upon them. A Group of Rays is attracted into the Glass; but that Group is composed of Rays unequal
in

in their Substance. Those unequal Quantities therefore obey unequally the Power by which the Medium acts upon them. The more solid and compact a Ray of Light is, the more it must resist that Power, the less it must turn aside from its Course or Direction, and the less it must be refrangible. These Experiments confirm it in all Mediums and Cases. The red Ray is always that, which turns aside least from its Direction; and the violet, that which always turns aside most. So the red Ray has always more Substance, is harder, and more shining, and tires the Sight more. The violet, which of all the coloured Rays eases the Sight most, is the most refrangible, and consequently is composed of the finest, and least gravitating Parts. We must not believe here, that Light having Weight, and that one Ray weighs more than another, are meer Conjectures, formed at a venture.

*Difference
between
the Rays
of Light.*

Experiments made by the most learned and judicious Persons, inform us, that many Bodies acquire Weight, after having imbibed Light for a considerable Length of Time. The Particles of Fire, which penetrate their Substance,

*Light has
Weight.*

Substance, augment it. But should these Experiments be called in question; Fire is Matter; therefore it has Weight, and Light is nothing but Fire.

It is evident, that a white Ray * weighs all the Rays that compose it. Now suppose for a Moment, that all the Rays of a Group equally remove from one another, it is then evident, that the red Ray being seven Times less refrangible than the violet Ray, it ought to have seven Times more Substance, and seven Times more Weight, than the violet Ray. Thus the red Ray weighing as seven; the orange, we suppose here, as six; the yellow, as five; the green, as four; the blue, as three; the purple-indigo, as two; and the violet, as one: the total Amount of all these Weights being twenty-eight, and the white Ray including them all, the white Ray according to this Calculation, is demonstrated to weigh twenty-eight times as much as the violet Ray †.

* By the white Ray is meant a Bundle of the seven different Rays.

† If the violet Ray be also a Bundle of as many Rays, it's the fourth Part of the other.

We have already seen how prodigiously small the Rays of Light must be, which, containing in them all Colours from the Sun, penetrate a Pore of a Diamond. Abundance of Rays enter that Pore, and unite near the interior Part of one of its Surfaces. Of this great number of Rays, that occupy so small a Space, there is not any, that do not contain seven primordial Rays. Each of those Rays is itself a Group of Rays tinged with its Colour. The red Ray is an Assemblage of a very great Number of red Rays. The violet is an Assemblage of violet Rays. If therefore this Group of violet Rays weighs eight and twenty times less than one of white Rays *, what must a single one of them weigh?

Let us consider one of these single Rays, that differs from one of another Colour; for Instance, the smallest of the red Rays differs in every thing from the smallest of the violet: The solid Parts of which it is composed, must be so many Atoms perfectly hard. And indeed, if Bodies were not composed of

Atoms of which Light is composed.

* Not the Group but one Ray in it, for the Rays in the one are as many as in the other.

*Atoms are
the Princi-
ples of Bo-
dies.*

solid, hard, indivisible Parts, that is to say, of real Atoms, how could the Species of Bodies continue eternally the same? How could so invariable a Difference be preserved? Must not the Parts, that constitute their Essence, be sufficiently hard, solid, and firm, to be always what they are? For how in the Texture of a single Grain of Corn, would so many Grains of Corn be included, and nothing else, if the Configuration of its small Parts were not always the same, and always solid and indivisible: which implies nothing else but always undivided? In the Egg of a Fly there are Flies *ad infinitum*; but if those small Parts, which contain so many Flies, were not perfectly hard, they would certainly be broke in pieces against each other, thro' the rapid Motion in which every thing in Nature is. They would be broke so much the more, because the smaller Bodies are, the more Surface they have in Proportion. However this Inconvenience does not happen: the Egg of a Fly always produces the Flies it contained; every Seed, from that of Gold to that of Mustard, remains eternally the same. It is therefore to be believed, that all the

Seeds

Seeds of things are composed of Atoms always undivided, of which the Substances of every Thing consist; but it is not sufficient to point out this great Truth, to which the Observation of the Rays of Light has led us; we must demonstrate it, and prove in the strictest Manner, that Atoms physically indivisible necessarily exist *; which is what we proceed to shew in the following Chapter.

* He means not Atoms that have no Parts, but that the Parts are not separable, as pag. 111. line 12.

C H A P. X.

Proofs that there are indivisible Atoms, and that the simple Particles of Light are Atoms of that kind. Discoveries continued.

WE have already seen how extremely porous all Bodies are. Water itself, which is but nineteen times less heavy than Gold, passes however thro' its Pores, tho' the most solid of Metals. There is no Body, which has not incomparably more Pores than Matter: but let us suppose a Cube, if you please, which has as much apparent Matter as it has Pores: by this Supposition then it will actually have only half the Matter it appears to have *; but each Part of this Body being in the same Case, and losing in like manner the half of itself, this Cube then, by this second Operation, will be only the fourth Part of itself; in Consequence it will have only the fourth Part of the Matter it seems to have. Dividing in this manner each Part of each Part, the eighth Part of the

*Proof of
the Existence of Atoms.*

* If the Matter be actually one half and the Pores the other half, the Matter hath no Pores, and there is an End of it.

Matter

Matter will remain. This Progression continued *ad infinitum*, and the Division carried on thro' all Degrees of Infinite, the End of the encreasing of the Pores will be Infinity, and the End of the Diminution of Matter will be nothing. Therefore if Matter could be physically divided *ad infinitum*, it would be found, that there would be nothing but Pores and no Matter. Matter then, such as it is, is not in reality physically divisible *ad infinitum*: Therefore it is evident, that there are indivisible Atoms, that is to say, Atoms which will never be divided, as long as the present Constitution of the World subsists.

Let us consider this Demonstration in a still more palpable manner. I am come by my Division to the two last Pores: there either is a Body between them, or there is not, if there is not, there was then no Matter; if there is, that Body is then without Pores. I say it is without Pores; because I am come to the last Pores, this Particle of Matter is therefore actually indivisible.

Moreover, this Proposition ought not to appear contradictory to Geometrical Demonstration, which proves a Line divisible to Infinity.

These

The Divisibility of Matter does not prevent the Existence of Atoms.

These two Propositions, which seem to destroy each other, agree very well together. Geometry has for its Object the Ideas of the Mind. A Geometrical Line is a Line in Idea, always divisible in Idea, as a numerical Unity is always reducible into as many Unites as I think fit to conceive. I can divide the Unity of a Foot into an hundred thousand millions of millions of other Unites; but then I can always consider the same Foot as a single * Unity.

Points without Lines, Lines without Surfaces, Surfaces without Solids, the Infinite 1, the Infinite 2, the Infinite 3, are in reality the Objects of certain Geometrical Propositions: but it is no less certain that Nature cannot produce Surfaces, Lines, or Points, without Solids. It is no less indisputable, that a Line in Geometry is divisible to Infinity; it is also certain, that there are

* Mr. *de Malefieu*, in the Duke of *Burgundy's* Geometry, has not sufficiently considered this Truth, p. 117. He finds Contradiction where there is none. He asks as a Question not to be solved, whether a Foot of Matter be one Substance, or many? It is certainly one Substance, when considered as a Cubick Foot. But it is seventeen hundred and twenty-eight Substances, when divided into Inches.

indivisible

indivisible Bodies in Nature, that is to say, undivided Bodies, Bodies which will remain such, as long as the present Constitution of Things subsists.

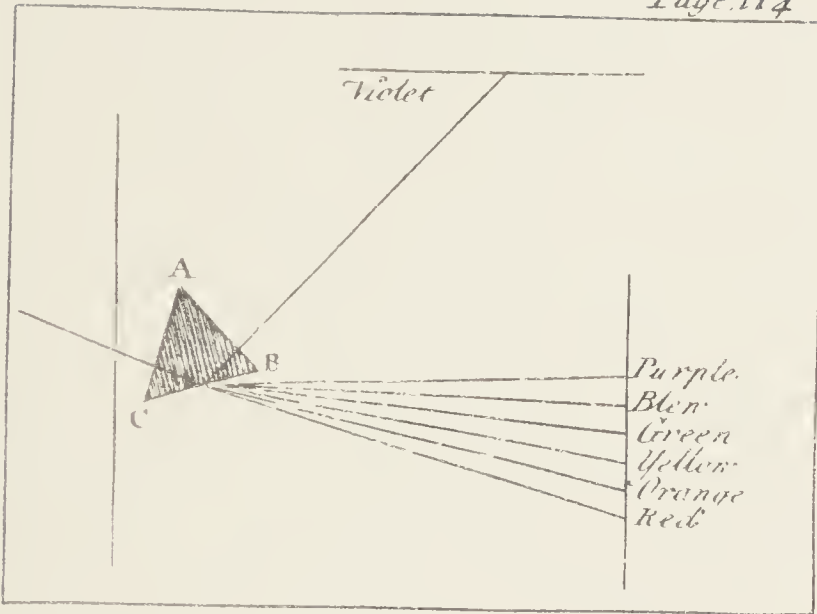
Let us hold therefore as certain, that there are Atoms. Each constituent Part of a simple coloured Ray, may be considered as an Atom; each of these Atoms is of Weight; it is the different Attraction, which causes the different Refraction. Let us conceive, that the most refrangible of these Atoms are also the most reflexible, and that as they are refracted in Proportion to their Attraction towards the most actuating Medium, it follows, that they are reflected in Proportion to the same Attraction. It is easy to know at this time, that the violet Ray, for Instance, which is the most refrangible, is always the first reflected on quitting the Prism which has received all the Rays. *Newton* made this Experiment by the help of four Prisms, with a Sagacity and Industry worthy of the Discoverer of so many Truths,

I shall here give the most simple of his Experiments.

*Important
Experiments.*

The Prism has thrown the seven Colours upon the Paper: turn the Prism upon itself in the manner A, B, C, and you will presently have the Angle, according to which all Light will be reflected from the inside to the outside of the Prism, instead of being thrown upon the Paper: as soon as you begin to approach that Angle, you see on a sudden the violet Ray quit the Paper, and rise to the Ceiling. After the violet, the purple does the same, after the purple the blue; and so on, till the red quits its place upon the Paper last, and is reflected on the Ceiling in its turn. Every Ray therefore is the more reflexible in proportion as it is more refrangible: in Consequence the same Cause produces Reflection and Refraction.

Now the solid Part of the Glass occasions neither this Refraction, nor this Reflection: once more then these Properties have their Rise in some other Cause than the Impulsion, known to us upon the Earth. There is nothing to be said against these Experiments; we must submit to them however tenacious we are against Evidence.



Matter might be taken even from *Newton's* Experiments to form some Difficulties against the Laws he establishes. One might tell *Objection.* him, for Instance: you have proved that no known Impulsion of Body can produce either the Refraction or Reflection of Light, because it is refracted in Pores, and reflected in Void: you have told us, that there is a Power in Nature which makes all Bodies tend towards each other; and till you shew us, as you have promised, the Laws by which that Power acts, we conceive, that it must act in Effect upon all Matter, and that the smallest Bodies imaginable must be determined in the same manner by this Power, as the greatest Bodies possible: you have told us, that one of the Laws of this Power is to act upon all Bodies according to their Quantity or Substance; and we confess that to be very probable; but do not your own Experiments contradict this System? Water has much more Solidity or Substance than Spirits of Wine, or Spirits of Turpentine; it however attracts the Rays of Light less; those Rays are not so much refracted in Water as in Spirits of Wine; this Power of Gravitation and Attraction there-

therefore does not act, as you tell us, according to Quantity or Substance.

*Answer.
Why Fluids of less Weight attract Light more.*

This Objection, far from making the Truth of the new Discoveries doubtful, really confirms it. To answer it clearly let us consider, that all Bodies tend towards the Center of the Earth; that they all fall in the Air with a Force proportioned to their Mass or Substance; but if besides this Force another be applied to them, they will move with greater Velocity than they have from their own Weight. This is the Case of the Rays of Light when they enter Bodies already full of fiery Particles, which are nothing but Light itself retained in their Pores.

These Atoms of Fire, which actually reside in certain sulphurous and transparent Bodies, encrease the Refraction of Light towards a perpendicular Line, as a new Force applied to it: it happens in this Case, as in that of a Torch just put out and still smoaking; it will light again at a certain distance from another lighted Torch.

It is entirely as natural for the Rays of Light to enter with Ease into the sulphurous Spirit of Turpentine, as for the Flame to
catch

catch the smoaking extinguished Torch; now a new Cause added to Refraction necessarily augments it.

Besides which Re-action is always equal to Action: Sulphurous Bodies are those on which Fire, that is nothing but Light, acts with greatest Force; those Bodies therefore must also act upon, break and refract Light more than any other.

Let us here observe, that this Attraction *Attraction does not extend to all the Effects of Light.* inherent in Matter, does not extend universally, and produce all Effects. The Mystery of Light reflected from the midst of Pores, and from above Surfaces without touching them, has Depths which the Laws of Attraction cannot fathom: only Quacks boast of Universal Medicines; and he would be a Quack in Philosophy, who should refer every thing without Proof to the same Cause: the same Force of Mind, which enabled *Newton* to discover the Power of Attraction, made him confess that that Power was far from being the sole Agent of Nature.

It is true, that the most refrangible Ray being the most reflexible, is an evident Proof, that the same Power operates the Reflection,
Refrac-

Refraction, and Acceleration of the Rays in the Glass, &c. but however, the Force of Attraction seems to have nothing in common with other Phænomena. There are especially Vibrations of Rays, alternative Dartings of Light, backwards and forwards over Bodies, which could not be explained by Gravitation; but these new Difficulties *Newton* himself did make. He has not only discovered the Mysteries, which Gravitation reveals, but others, which it does not reveal. These alternative Dartings of the Reflection of Light, are one of the Secrets of Nature, which, it is astonishing, human Eyes have ever been able to perceive.

We shall speak of this Singularity in its Place in the thirteenth Chapter; let us continue our view of the Effects of Refrangibility. The Rainbow is one, and the most considerable of its Effects, which we proceed to explain in the following Chapter.

C H A P. XI.

Of the Rainbow; that Phænomenon a necessary Effect of the Laws of Refrangibility.

THE Rainbow, or Iris, is a necessary Effect of the Properties of Light, of which we have just been speaking. There is nothing in the Writings of the *Greeks, Romans, or Arabians*, that gives us reason to believe, they knew the cause of this Phænomenon. *Lucretius* says nothing of it, and by all the Absurdities, which he vents in the Name of *Epicurus* upon Light and Vision, it appears, that his Age, so polite in other Respects, was profoundly ignorant in Point of Physicks. They knew, that to see what we call the Rainbow, or Iris, a thick Cloud is necessary, dissolving in Rain before the Rays of the Sun; and that our Eyes should be between that Star and the Cloud, *Mille trahit varios adverso sole Colores*, but this was all they knew; no-body imagined either why a Cloud exhibited Colours, how the Nature and Order of those

those Colours are determined, or wherefore we always see that Phænomenon under the Form of a Semi-circle.

Albertus, surnamed *Magnus the Great*, because he lived in an Age wherein Men were very little, imagined that the Colours of the Rainbow proceeded from a Dew between us and the Cloud, and that those Colours received upon the Cloud, were transmitted by it to us. You will observe besides, that this *Albertus Magnus* believed, with all the Schools, that Light was an Accident.

*See 4r.
A. 7. p. 21.
Antonio de
Dominis
was the
first, who
explained
the Rain-
bow.*

At length the celebrated *Antonio de Dominis*, Archbishop of *Spalatro* in *Dalmatia*, expelled from his Bishoprick by the Inquisition, about the Year 1590, wrote his little Treatise, *De Radiis Lucis & de Iride*, which was not printed at *Venice* till twenty Years after. He was the first who shewed, that the Rays of the Sun, reflected even from the inner Part of Drops of Rain, formed those Colours, that appeared in the Bow, which seemed an inexplicable Miracle; he rendered the Miracle Natural, or rather he explained it by new Prodigies of Nature.

His

His Discovery was so much the more singular, as in other Respects he had very false Notions of the manner in which Vision is performed. He assures us in his Book, that the Images of Objects are in the Ball of the Eye, and that there is no Refraction in it : a Notion singular enough for a good Philosopher ! He had discovered Refractions, unknown before, in the Drops of the Rainbow, and denied those operated in the Humours of the Eye, of which himself began the Demonstration ; but let us leave his Errors to examine the Truth he discovered.

He saw with a Sagacity very uncommon in those Days, that every Row or Circle of Drops of Rain, that form the Rainbow, must transmit the Rays of Light in different Angles, he also saw, that the difference of those Angles must occasion that of the Colours : he found means to measure the Magnitude of those Angles : he took a very transparent Crystal Ball which he filled with Water, and hung up at a certain Height exposed to the Rays of the Sun.

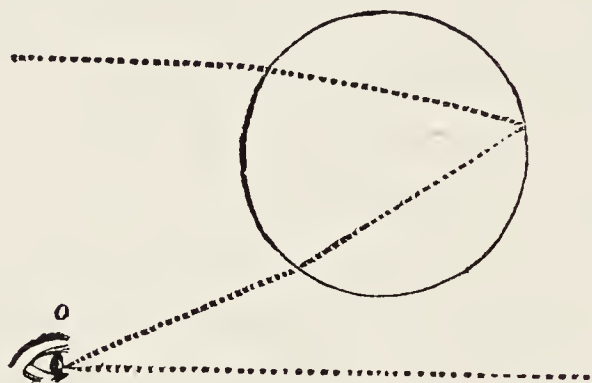
Descartes, who followed *Antonio d' Domini*, and rectified and surpassed him in some

His Experiment.

Imitated by Descartes.

things,

things, and who perhaps ought to have quoted him, made also the same Experiment. When this Ball is suspended at such an Height, that the Ray of Light, which falls from the Sun upon the Ball, makes an Angle with the Ray, that falls from the Ball to the Eye, of forty two Degrees two or three Minutes, the Ball always exhibits a red Colour.



When that Ball is suspended a little lower, and those Angles are smaller, the other Colours of the Rainbow appear successively in such a manner, that the greatest Angle in this Case forms the red, and the smallest of forty Degrees seventeen Minutes forms the violet. This is the Foundation of the Knowledge of the Rainbow; but at the same time it is only the Foundation of it.

Refran-

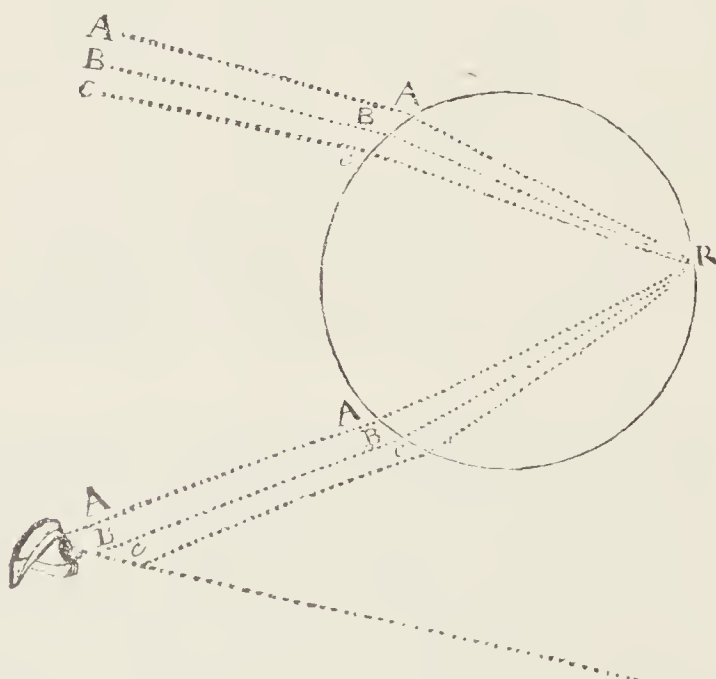
Refrangibility alone explains a Phænomenon so common, so little known, and of which few Beginners have a clear Idea: let us endeavour to render the thing obvious to all the World. Let us suspend a Ball of Crystal full of Water, exposed to the Sun: let us place ourselves between the Sun and it; wherefore does this Ball transmit Colours to me, and wherefore particular Colours? Great quantities of Light, millions of Groups of Rays, fall from the Sun upon this Ball: in each of those Groups there are primitive Rays, homogeneous Rays, many red, many yellow, many green, &c. all which break at their Incidence into the Ball, each differently and according to its Species, and the Place in which it enters.

Refrangibility the sole Cause of the Rainbow.

You already know that the red Rays are the least refrangible; the red Rays of a certain determinate Group will therefore unite at a certain determinate Point at the bottom of the Ball, whilst the blue and purple Rays of the same Group will do the same elsewhere. These red Rays will also quit the Ball at one place, and the green, blue, and purple at another. This is not enough. We must

must examine the Points, where those red Rays fall in entering the Ball, and in quitting it to come to the Eye.

To make this as clear as possible, let us conceive this Ball, as it really is, an Assēblage of an infinite Number of plane Superficies; for the Circle being composed of Right-points infinitely small, the Ball is only an Infinity of such Superficies.



The red Rays A, B, C, fall parallel from the Sun upon those three small Superficies. Is it not true that each of them breaks according to its Degree of Incidence? Is it not
mani-

manifest that the red Ray A, falls more obliquely upon its little Superficies, than the red Ray B doth? Thus both come to the Point R, by different Ways or Directions.

The red Ray C, falling upon its little Superficies still less obliquely than the two former, is much less broke, and arrives also at the Point R, with very little Incurvation.

I have now three red Rays, that is to say, *That Phænomenon explained.* three Groups of red Rays, which terminate at the same Point R.

At this Point R, each of them makes an Angle of Reflection equal to its Angle of Incidence, each is broke at emerging from the Ball in a Line removing from the Perpendicular of the new little Superficies it comes to, in the same manner as each is broke at its Incidence in Lines, approaching each other, to their Perpendiculars; all therefore return parallel, and enter the Eye according to the opening of the Angle peculiar to the red Rays.

If there be a sufficient quantity of these homogeneous red Rays to move the optick Nerve, we must indisputably have the sensation of red.

These

These Rays A, B, C, are termed the visible and operative Rays of the Drop of Rain; for each Drop has its visible Rays.

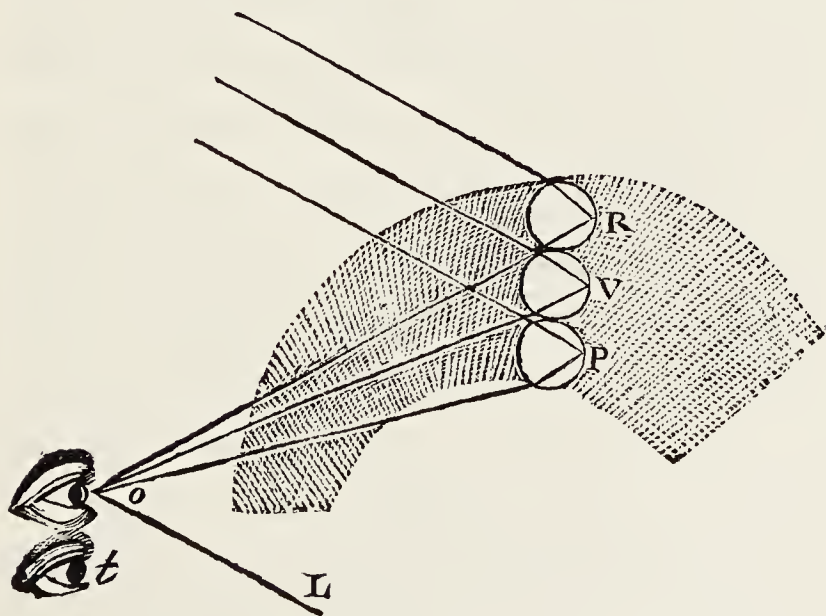
There are thousands of other red Rays, which falling upon other little Superficies of the Ball, higher and lower, or which falling on the same Superficies at another Obliquity, do not terminate in R; these are lost to you, but will be seen by other Eyes placed higher or lower.

Abundance of orange, green, blue and violet Rays have fallen indeed with the visible red ones upon the Superficies A, B, C; but you cannot receive them. You know the reason, which is their being all more refrangible than the red Rays: it is because in entering all at the same Point, each of them takes a different Path in the Ball; as they are all more broken, they come below the Point R, and break also more than the red ones in quitting the Ball. The same Power, which in the inside of the Ball made them approach in a Line more remote from the Perpendicular of each Superficies, disperses them therefore more at their return into the Air: they all return therefore above the Eye; but lower
the

the Ball, and the Angle becomes less. Let this Angle be of forty Degrees and about seventeen Minutes, and you will see no Colour but the violet.

There is no-body who upon this Principle may not easily conceive the Doctrine of the Rainbow; imagine several Rows or Circles of Drops of Rain; every Drop has the same Effect as this Ball.

Cast your Eye upon the Bow R, V, P, and to avoid Confusion, consider only three Rows of Rain-drops, three coloured Circles.



It is visible that the Angle P, o, L, is less than

than the Angle V, o, L, and that the Angle R, o, L, is the greatest of the three. The greatest Angle of the three is therefore that of the red primordial Rays: that in the middle is that of the primitive green; and the least P, o, L, is that of the primitive purple. We therefore must see the Rainbow red on its external, green on its middle, and purple and violet on its internal Circles. Observe only, that the last Circle, the violet, is always tinged with the whitish Colour of the Cloud in which it loses itself.

It is easy to conceive then, that we see the Drops only in the operative or visible Rays, which come to the Eye after one Reflection and two Refractions in determinate Angles. If we change the place of the Eye, and instead of being in o, bring it to t, we see the same Rays no longer: the Circle which before was red is now become orange or green, and so on with the rest: at every Motion of the Head you see a new Iris.

This first Rainbow being well understood, we shall easily comprehend the second, which is generally seen encircling the first, and which is called the false Rainbow, or *faint Bow*,
be-

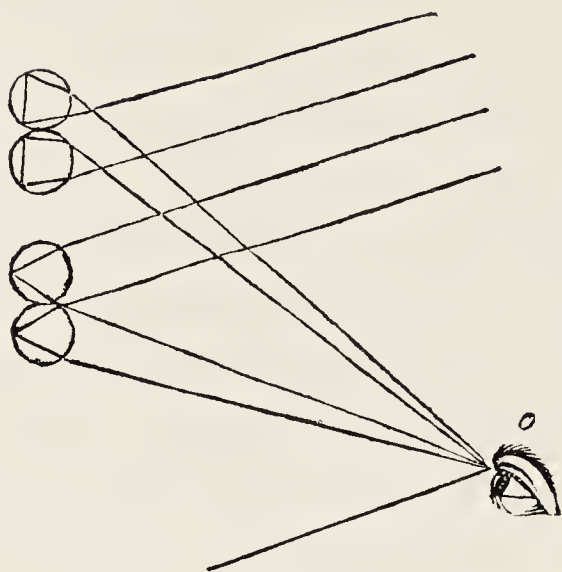
because its Colours are not so lively, and are reversed in their order to those of the other.

For the Appearance of two Rainbows, it suffices that the Cloud which forms them be sufficiently thick and extended. That Bow which appears above the first and surrounds it, is formed in like manner by the Rays, which the Sun darts into the Rain-drops, and which are broken and reflected in them in such a manner, that each Row of Drops transmits also primitive Rays to the Eye; this Drop a red, and that a violet Ray.

*Two Rain-
bows.*

But every thing in this great Bow is the reverse of what passes in the smaller; how comes that? It is because your Eye, that receives the sensible or operative Rays of the smaller Bow, which fall from the Sun into the upper Part of the Drops, receives on the contrary the Rays of the greater Bow from the lower part of the Drops.

You perceive, that the Drops of Water of the smaller Bow receive the Rays of the Sun upon the upper part of each Drop; the Drops of the greater Bow on the contrary receive the Rays, that reach them, on their lower part. Nothing in my Opinion will be
more

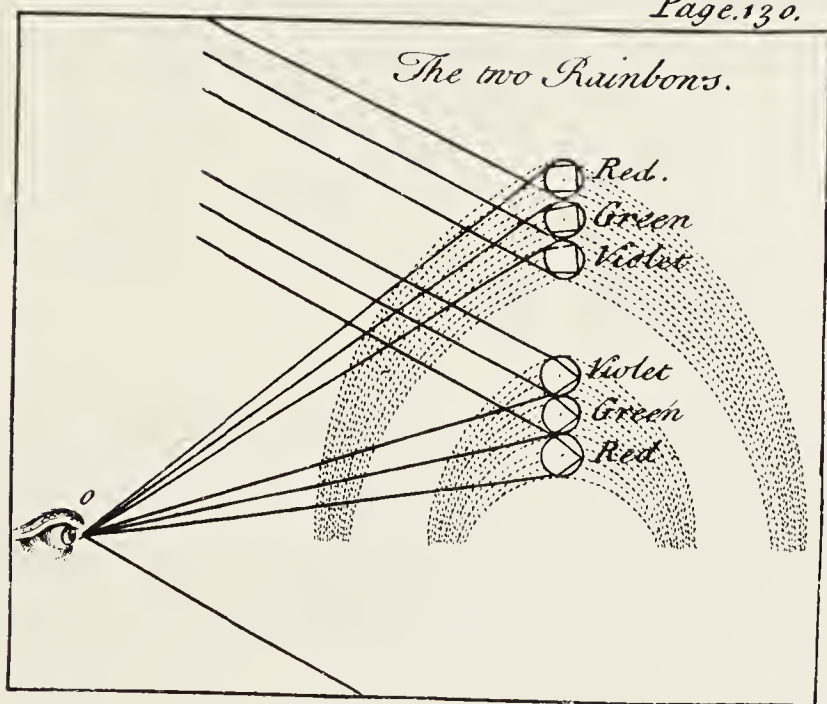


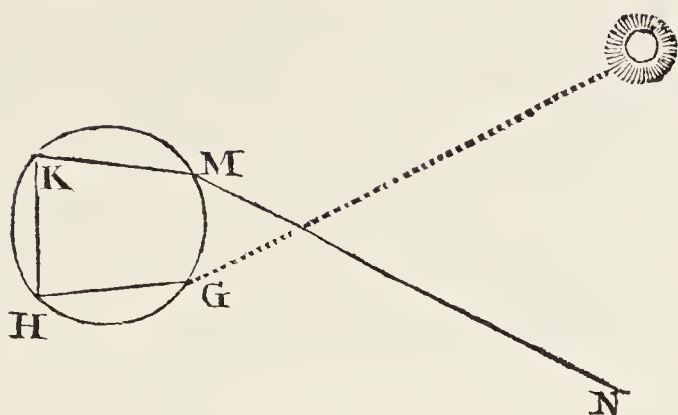
more easy to conceive, than the manner in which the Rays are twice reflected in the Drops of the great Rainbow, and how those Rays twice refracted and twice reflected exhibit an Iris reversed in the order of its Colours, and fainter than the former. You have just seen that the Rays enter thus into the little lower Part of the Drops of Water of this exteriour Iris.

A number of Rays fall on the Superficies of the Drop in G, a part of those Rays are refracted there within, and another scattered without; thus the Eye has already lost part of those Rays. The Part refracted comes to

H,

The two Rainbows.





H, one half of this Part is dispersed in the Air on quitting the Drop, and is again lost to the Eye. The little that remains in the Drop is transmitted to K, there a Part of it escapes again: this is a third Diminution. What has remained of it in K is transferred to M, and on this Emergence to M, a Part of it is again dissipated: fourth Diminution; and what remains comes to the Eye at last in the Line M, N. Thus therefore we see in this Drop as many Refractions as in the Drops of the smaller Bow; but there are, as we have shewn, two Reflections instead of one in this greater Bow. Twice the Light therefore is lost in the greater Bow, in which the Light is twice reflected, whilst less by one half is lost in the smaller Bow, where the

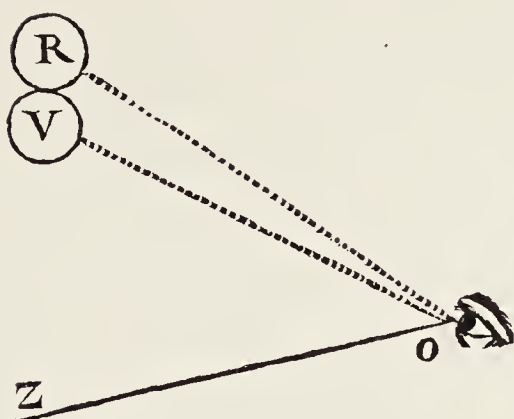
Drops

Drops are once reflected. It is therefore demonstrated, that the exterior Rainbow must always be fainter by one half in its Colour than the smaller within it. It is also demonstrated by the double Reflection of the Rays, that they must come to the Eye in a manner opposite to that of the first Bow, for your Eye is placed in O.

In this place O, it receives the least refrangible Rays of the first exterior Circle of the smaller Bow, and must receive the most refrangible of the first Circle of the second greater Bow; these most refrangible Rays are the violet. Thus then we have here the two Rainbows in their natural Order, giving them only three Colours to avoid Confusion.

This Phenomenon always seen in a Semi-circular Figure.

It only remains for us to know wherefore those Colours are always perceived in a circular Figure. Consider this Line O, Z, which passes thro' your Eye. Conceive the two Balls R, V, to move always at equal Distances from your Eye; they will describe the Bases of Cones, of which the Points will always be in your Eye.



Conceive that the Ray of the Drop of Water R, coming to your Eye o, turns round this Line o, Z, as round an Axis, making always an Angle with your Eye of forty-two Degrees two Minutes; it is plain this Drop will describe a Circle, which will appear red. Suppose the other Drop V, to turn in the same manner, making always another Angle of forty Degrees seventeen Minutes, it will form violet Circle; all the Drops therefore in this Plan will form a violet Circle, as those in the Plan of the Drop R, will a red one. We see therefore this Iris as a Circle, but not as an entire Circle; because the Earth cuts it, we see only an Arch, the Section of a Circle.

Neither *Antonio de Dominis* nor *Descartes* could penetrate any farther into most of these

Truths:

Truths: they could not discern wherefore these different Angles exhibited different Colours; but it was a great deal to have discovered the Art. The Perfection of Arts are seldom owing to the first Inventors. Not being able therefore to guess that Colours depended on the Refrangibility of Rays, that each Ray contained a primitive Colour in itself, that the different Attraction of those Rays was the cause of their different Refrangibility, and occasioned those Removals which formed the different Angles, *Descartes* abandoned himself to his Spirit of Invention to explain the Colours of the Rainbow. In order to this he employed the imaginary *whirling round of Globules* and his *Tendency to whirling round*; Proofs of Genius, but Proofs of Error. Thus to explain the *Systole* and *Diastole* of the Heart, he imagined a Motion and Conformation of that Organ, of which all Anatomists have admitted the Falsity. *Descartes* would have been the greatest Philosopher of the World, if he had invented less.

C H A P. XII.

*New Discoveries touching the Cause of Colours, which confirm the preceding Doctrine, Demonstration that Colours are occasioned by the Density and Thickness of the Parts of which Bodies are composed *.*

IT results then, from what has hitherto been said, that all Colours proceed from the Mixture of the seven primitive ones, of which the Rainbow and the Prism give us a distinct View.

The Bodies that are most proper to reflect the red Rays, and whose Parts either absorb or transmit the other Rays, will be red; and in like manner of the rest. The Meaning of this is not, that the red Rays are actually reflected by the Parts of these Bodies; but that there is a Power, a Force hitherto unknown, which reflects these Rays from about the Surfaces of Bodies, and the Cavity of their Pores.

Colours then are in the Rays of the Sun,

* Or as in pag. 137, line 2, the Thickness of the Parts that compose the Surfaces only, and pag. 138, line 15, and pag. 140, line 13.

*A more
minute In-
quiry con-
cerning
the Forma-
tion of Co-
lours.*

and return to us from the Surfaces and Pores of Bodies, and from the Vacuum. Let us now enquire in what the apparent Power of Bodies to reflect these Colours consists, what occasions Scarlet to appear red, why the Meadows are green, and why a clear Heaven is blue: For to say that this proceeds from the Difference of the Form of their Parts, is to advance an indeterminate Notion, that makes us never the wiser.

*Great
Truths
drawn
from a
common
Experi-
ment.*

A childish Diversion, that seems to have nothing in it but what is contemptible, gave Sir *Isaac Newton* the first Idea of these recent Truths which we are now to explain. Every Thing to a Philosopher may be a Subject of Meditation, and nothing is despicable in his Eyes. He perceived, that in those Bubbles of Soap and Water that are blown up by Children, the Colours changed every Moment, passing downwards successively from the Top of the Bubble, in proportion as the Thickness of it diminished, till at last the Weight of the Water and Soap, which still fall to the Bottom, breaks the Equilibre of that light Sphere, and causes it to vanish. He presumed from hence, that Colours might

might probably depend on the Thickness of the Parts that composed the Surfaces of Bodies ; and to assure himself of it, he had recourse to the following Experiments *.

Let two Glasses touch one another in a single Point. They need not be both convex ; it is sufficient that the first is so, and that it be placed upon the other in this manner.



Let Water be put between these two Glasses, to render more sensible the Experiment which is made at the same Time in the Air. When the Glasses are pressed a little against each other, a small, transparent, black Spot appears at the Point of their Contact. From this Point, surrounded with a little Water, coloured Circles form themselves, in the same Order and Manner as in the Bubble of diluted Soap. In a Word, by measuring the Diameter of these Circles, and the Convexity of the Glass, Sir *Isaac Newton* determined the different Thickness of the

* There seems to be a difference between the Parts of Gold or Scarlet Cloth, and Bubbles of Water that are hollow and transparent.

Portions of Water which gave these different Colours. In particular, to reflect white Rays, he found that the Thickness requisite, was about the 250,000th Part of an Inch, that is, about four such Parts of an Inch as the Division of it into a Million would produce. The azure Blue, and the Colours bordering upon a Violet, depend on a Thickness yet much less. Thus the purest Vapours which arise from the Earth, and which colour the Air without clouding it, being of a very thin Surface, produce that celestial Blue which charms our Sight.

Colours depend on the Thickness of the Parts of Bodies, notwithstanding that these Parts reflect not the Light themselves.

This Discovery, that Colours are attached to the Thickness of Surfaces, has been supported by other Experiments, no less curious than what we have now mentioned.

The same Body that was green, when it was somewhat thick, has become blue, when it has been rendered thin enough to reflect nothing but blue Rays, and to transmit all the others. These Truths, of so delicate a Research, and which seem to withdraw themselves from human Sight, deserve well to be closely pursued: This Part of Philosophy is by a Microscope, with which the Mind discovers Magnitudes infinitely small *. All

* But not the Atoms in the Rays of Light,

All Bodies are transparent; we have only to reduce them to a proper Tenuity, and then the Rays of Light, finding but a thin Plate, but a Leaf to pass thro', make their Passage accordingly. Thus when a Leaf of Gold is placed against a single Hole in a dark Room, it reflects from its Surface the yellow Rays, which cannot pass thro' its Substance, and transmits green Rays into the Room; so that Gold then produces a green Colour. This is a farther Confirmation of what was before advanced, that Colours depend on the Difference of Densities.

A yet stronger Proof of the same thing, is in the Experiment of the two Glasses, which are made to touch in a convex Point: The Water here is not the only Element that produces different Colours according to its different Densities; the Air produces the same Effect, only the coloured Circles that it makes between the two Glasses, have a larger Diameter than those of the Water.

There is a secret Proportion therefore, established by Nature, between the Force of the constituent Parts of all Bodies, and the primitive Rays which colour those Bodies: The
thinnest

*All Bodies
are trans-
parent.*

*A Proof
that Co-
lours de-
pend on
Thickneses.*

thinnest Bodies give the most feeble Colours, and to reflect a Black, the same Thickness, or rather the same Tenuity, the same Thinness is requisite, as that which constitutes the very Top of a Bubble of diluted Soap, in which a little black Spot is perceived ; or even the same as is in the Point of Contact between the convex and the flat Glass, which Contact produces also a black Spot.

*And that
neverthe-
less, the
solid Parts
do not re-
flect the
Light.*

But once more ; It must not be imagined that Bodies reflect the Light by their solid Parts, because we have shewn that Colours depend on the Density of these Parts : There is a Power attached to that Density, a Power that acts near the Surface ; yet it is not in the least the solid Surface, that repels, that reflects. This Truth shall be more sensibly demonstrated in the following Chapter, than it has hitherto been. It seems to me, that the Reader should by this Time be arrived at a Point, where nothing ought to surprise him for the future : But what he has just been seeing will lead him farther than he may imagine ; so many Singularities being, if we may use the Expression, but the Frontiers of a new World.

C H A P. XIII.

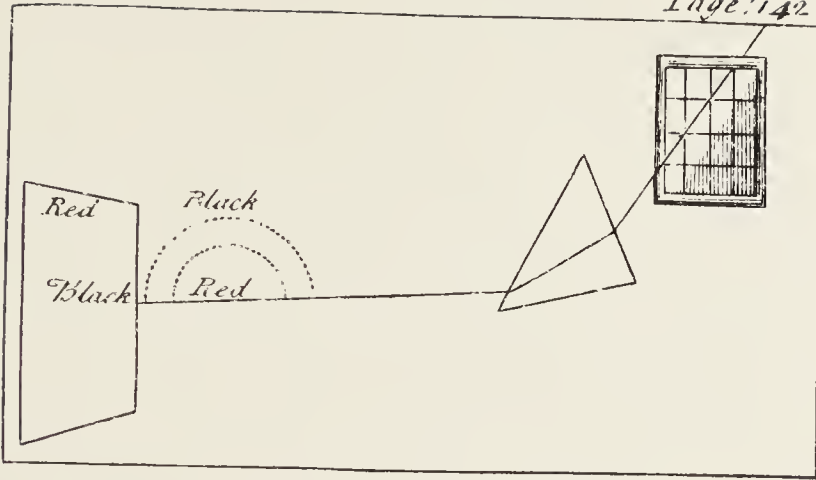
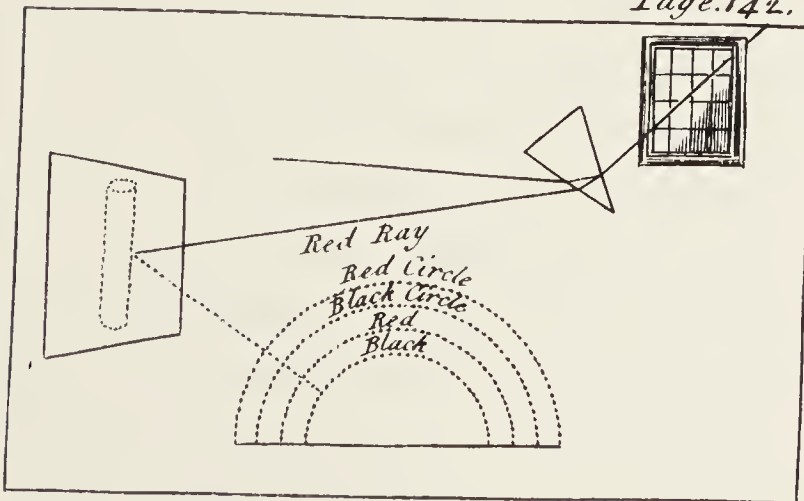
Consequences of these Discoveries. The mutual Action of Bodies upon Light.

THE Reflection of Light, its Inflection, its Refraction, its Refrangibility being known, the Origin of Colours being discovered, and even the necessary Thickness of Bodies to occasion certain Colours being determined ; it remains that we should examine two more Properties of Light, not less new, nor less surprising than the rest. The first of these Properties is that Power itself which acts near the Surfaces of Bodies, and which is a mutual Action of the Light upon Bodies, and of Bodies upon the Light. The second is a Resemblance which is found between Colours and the Notes in Musick, between the Objects of the Sight and those of the Hearing. We proceed to render an Account of these two miraculous Qualities : and with this Account we shall finish our Introduction to Sir *Isaac Newton's Opticks*.

You

You have seen that two Glasses, touching one another in a Point, produce Circles or Rings of different Colours, as red, blue, green, white, &c. Make the Trial of these Glasses in your dark Room, where you made the Experiment of the Prism expos'd to the Light that comes in on it through a Hole. You remember, that in this Experiment of the Prism you saw the Decomposition of Light, and the Anatomy of its Rays: You placed a Sheet of white Paper over against the Prism, which Paper received the seven primitive Colours, every one in its proper Order. Now expose your two Glasses to one of the coloured Rays, which you please, as reflected from the Paper; you shall always see that coloured Circles will form themselves between these Glasses, but that these Circles will then be of the Colour of the Rays which are reflected to you from the Paper. Hold up your Glasses, for Instance, to the Light of the red Rays, and you shall have red Circles only between them: But, what is very surprizing, between every one of these red Circles there will be a Circle quite black. To clear up this Matter, and
the

*A very
singular
Experiment.*



the Singularities that are attached to it, yet more perfectly, take your Glassess from the Paper, and present them to the Prism itself, in such a manner as that one of the Rays which escape from the Prism, a red one for Example, may fall upon the Glassess; still red Circles only will form themselves between the black ones: then put the Sheet of Paper behind your Glassess, and every black Ring will produce a red one on the Paper, and every one that is red when reflected towards you, will produce a black one on the Paper.

It results from this Experiment, that the Air or the Water which is between your Glassess, reflects the Light in one Place, and in another lets it pass, or transmits it. I confess, I cannot here sufficiently admire that Depth of Penetration, that Sagacity more than Human, with which Sir *Isaac* has pursued these imperceptible Truths; he was satisfied of these wonderful Propositions, even by Measure and Calculation.

At the Point of Contact of the two Glassess, you see no Reflection of any Light: immediately after this Contact, the first and thinnest Body of Water or Air, that touches the black
Point,

Point, produces a Reflection: the Water or Air of a second Degree of Density, that is, twice as thick as the first, reflects nothing: that of the third, which has thrice the Density of the first, reflects: that of the fourth Degree, like the second, does not reflect: that which has five Times the first Thickness, transmits: that which has six, transmits nothing. So that the black Circles follow in this Progression, 0, 2, 4, 6, 8, and the coloured and luminous ones in this, 1, 3, 5, 7, 9.

Consequences of these Experiments.

What passes in this Experiment, happens in like manner in other Bodies, which all reflect one Part of the Light, and receive another Part of it into their Substances. This Property then is fully demonstrable to the Mind, and even to the Sight, that it is not the solid Surface which reflects the Light. For, in short, if solid Surfaces did really reflect; 1st, The Point of Contact, in the two Glasses would have this Quality, and not be obscure, as we see it. 2^{dly}, Every solid Part, which gave you only one sort of Rays, ought also to have given you every Species of them. 3^{dly}, The solid Parts would not transmit the
Light

Light in one Part, and reflect it in another ; for being all solid, they would all reflect. 4thly, If Light was reflected by solid Parts, it would be impossible to see one's self in a Looking-glass, as we have before said ; because the Glass being rugged and uneven, could not send back the Light in a regular manner *. It is indubitable then, that there is a Power acting about Bodies, without touching them, and that this Power acts between these Bodies and the Light. In a Word, far from striking on the Bodies themselves, and rebounding back to us, we have reason to believe that the greatest Part of the Rays of Light which impinge against solid Parts, remain there, are there lost, are there extinguished.

This Power, which acts about Surfaces, acts from one Surface to another. It is chiefly from the last Surface, on the farther side of a transparent Body, that the Rays rebound : We have proved this before.

* And yet it does, because smoother than other Surfaces, though many Rays are lost by some Degrees of Ruggedness ; but if there be no Contact, no matter whether rugged or smooth, the Power of reflecting might reside with the one as well as the other.

*The mutual
Action of
Bodies up-
on Light.*

We must admit a Power then, which acts upon the Rays of Light from above one of these Surfaces to the other, a Power which transmits and reflects the Rays alternately. This Play between Light and Bodies was not merely suspected by Sir *Isaac Newton*; he has computed many thousands of these alternative Vibrations, these transmitted and reflected Throws. But, this Action of Bodies upon Light, and of Light upon Bodies, leaves us yet many Uncertainties in the manner of explaining it.

*Conjec-
tures of Sir
Isaac
Newton.*

He who discovered this Mystery, was not able, in the Course of his long Life, to make Experiments enough to assign the certain Cause of these Effects. But even tho' by his Discoveries he had taught us only new Properties of Matter, would not this alone have been a sufficient Service rendered to Philosophy? He conjectured that Light flows from the Sun, and other luminous Bodies, by Starts, by Vibrations; that the first of these Vibrations operates a Reflection, the second a Transmission, and so on to Infinity. He had also prepared Experiments, which might conduce to shew us wherein this Sport of Nature

Nature agrees with the Grand Principle of Attraction: but he had not Time to finish his Researches. He conjectured moreover, that there is in Nature a very elastic and thin Matter, which becomes by so much the more thin, as it is farther distant from opaque Bodies; that the Starts or Throws of Light excite Vibrations in this elastic Matter: And it must be confessed, that this Hypothesis accounts for almost all the Mysteries concerning Light, and above all for the Attraction and Gravitation of Bodies. But an Hypothesis, even tho' it gives a Reason for almost every thing, ought not to be admitted. It is not sufficient that a System be possible to make it be believed; it ought to be proved. If the Vortices of *Descartes* could support themselves against all the Difficulties with which they are embarrassed, it would nevertheless be necessary to reject them, because they are merely possible: therefore we will not lay any real Strefs upon the Conjectures even of Sir *Isaac Newton* himself.

But we must not rely on Conjectures.

If I speak of them, it is rather to publish the History of his Thoughts, than to draw the least Conclusion from his Ideas, which

I look upon as the Dreams of a great Man. He did not at all build upon them himself: He was contented with Facts, without daring to determine any thing concerning their Causes. Let us pass to the other Discovery, the Agreement which exists between the Rays of Light and the Notes in Musick.

C H A P. XIV.

*Of the Resemblance between the seven
Primitive Colours and the seven
Notes in Musick.*

IT was you know perceived, a very long Time before *Descartes*, that a Prism exposed to the Sun exhibits the Colours of the Rainbow. Colours had often been seen to paint themselves upon Linnen, or upon white Paper, in an Order which is always the same. The Curious soon proceeded, from Experiment to Experiment, even to measure the Space that is occupied by every one of these Colours. At last it was found, that these Spaces are the same with regard to one another, as those of the Lengths of a Cord, that expresses the seven Notes in Musick. I had often heard it said, that *Newton* had taken from *Kircher* this Discovery of the Analogy between Light and Sound. *Kir-* A very remarkable Thing in *Kircher*.
cher indeed, in his *Ars Magna Lucis & Umbræ*, and in others of his Works, denominates Sound the Ape of Light. Some Persons

sons have inferred from hence, that *Kircher* was acquainted with the Particulars in which they agree: but it is proper, to prevent a Mistake, to lay before the Reader what he says, in his 146th and following Pages.

“ Those, says he, who have a loud and
 “ strong Voice, partake of the Nature of an
 “ Ass: they are indiscreet and petulant, as
 “ Asses are known to be; and this Voice
 “ holds a resemblance with the black Co-
 “ lour. Those whose Voice is grave at the
 “ first, and afterwards sharp, partake of the
 “ Ox: they are, like that Animal, dull and
 “ cholerick, and their Voice answers to a
 “ sky-blue.”

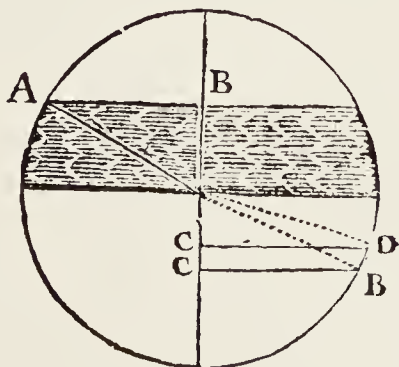
He takes care to strengthen these fine Discoveries by the Testimony of *Aristotle*. This is all that Father *Kircher* teaches us, who was otherwise one of the greatest Mathematicians, and most Learned Men of his Age; and it was thus, in a manner, that all those who were merely Scholars reason'd at that Time. Let us proceed now to the Reasoning of Sir *Isaac*.

*Manner of
 knowing
 the Pro-
 portions of
 the seven
 primitive
 Colours of
 Light.*

There are, you well know, seven principal Rays in every Ray of Light, which have all their Refrangibility: every one of these Rays
 hath

hath its Sine, and every one of these Sines its Proportions with the common Sine of Incidence; observe what passeth in these seven primitive Rays, which part by dividing in the Air.

It is not our Business here to consider, that even in the Glass all these Rays are scattered, and that every one of them there hath a different Sine: We must regard the Assemblage of Rays in the Glass as a single Ray, which has only the common Sine A, B. But in emerging from the Glass, every one of these Rays visibly separating from the rest, each hath its different Sine; that of red (the least refrangible Ray) is described by the Sine C, B; that of violet (the most refrangible of all) by the Line C, B, D.



These Proportions being settled, let us see
what

what is this Agreement, no less exact than singular, between Colours and Musick. Let the Sine of Incidence of the white Collection of Rays be to the Sine of Emergence of the red Ray, as this Line A, B, is to the Line B, C.

The Sine given in the Glafs

A B

The Sine given in the Air

B C

Let the same Sine of Incidence A, B, be to the Sine of Refraction of the violet Ray, as the Line A, B, is to the Line C, D.

A B

 C D.

You perceive that the Point B is the Limit of the least Refrangibility, and D the Limit
 of

A I C H G F E B D.

Then the Length from A to C makes the red ; the Length from A to H, the orange ; that from A to G, the yellow ; that from A to F, the green ; that from A to E, the blue ; that from A to B, the purple ; that from A to D, the violet. Now the Spaces here given are such, that every Ray may be refracted, a small matter more or less, in every one of these Spaces, but can never go beyond the Space prescribed it: the violet Ray will play between B and D, the red Ray between C and I, and so of the rest ; the whole in such Proportion, that if you divide the Length from I to D into 360 Parts, every Ray shall have to itself the Dimensions that are exhibited in the large Scheme hereunto annexed.

These

The Analogy between the Notes in Musick and the seven Colours.

These Proportions are precisely the same as those of the Notes in Musick. The Length of the Cord, which, being stretched, shall sound *Re*, is to the Cord which shall give the Octave of *Re*, as the Line A, I, which gives the red in I, is to the Line A, D, which gives the violet in D: so that the Spaces which mark the Colours, in this Figure, mark also the Notes in Musick.

The greatest Refrangibility of the violet answers to *Re*; the greatest Refrangibility of the purple, to *Mi*; that of the blue, to *Fa*; that of the green, to *Sol*; that of the yellow, to *La*; that of the orange, to *Si*; that of the red, to *Ut*; and, in a Word, the least Refrangibility of the red agrees with *Re*, which is the highest Octave. And one may form a compleat Idea of all these Proprieties, by casting his Eyes on the Table which I have drawn up, and which he will find over against the Observations in the preceding Page.

There is another Resemblance between Sounds and Colours, which is, that the most distant Rays, the violet and the red, strike our Eyes at the same Time, and that the most distant Sounds, the gravest and the sharpest,

sharpest, come also to our Ears with equal Velocity. I do not mean by this, that we see and hear Things at the same Distance in the same Time ; for Light makes an Impression on us, at least six hundred thousand times sooner than Sound ; but the Sense is, that blue Rays, for Example, come not from the Sun to our Eyes sooner than red Rays, in like manner as the Sound of the Note *Si* does not reach our Ears sooner than that of the Note *Re*.

This Analogy between Light and Sound gives room for a Suspicion, that all Things in Nature have secret Relations, which perhaps may be discovered hereafter. It is already certain, that there is an Agreement between *Feeling* and *Sight*, since Colours depend upon the Configuration of Parts *. It is even maintained, that there have been Persons who were born blind, that could by their Feeling distinguish the Difference between white, black, and some other Colours.

An ingenious Philosopher has attempted to push this Relation between Seeing and Hearing farther, perhaps, than it may seem

* Or as before on the Thickness of their Surfaces.

*Idea of an
Ocular
Harpsicord.*

permitted for Men to proceed. He has contrived an ocular Harpsicord, which is to exhibit a Succession of harmonic Colours, as our Harpsicords do of Sounds : He has work'd at it with his own Hands, and pretends that in Time he shall be able to play Tunes to the Eyes. Doubtless we cannot but thank a Man, who takes such Pains to introduce new Sciences, and new Pleasures among us : There have been Countries, where he would have received a publick Recompence. It is certainly to be wished, that this Invention may not be, like so many others, a very ingenious, but unprofitable Effort. This rapid Passage of a great many Colours before the Eyes, it is to be feared, will be more likely to astonish, dazzle, and fatigue the Sight. Our Eyes, perhaps, may have need of Repose, in order to enjoy the Agreeableness of Colours. It is not enough to propose a Pleasure to us ; Nature must have made us capable of receiving that Pleasure. In a Word, it is Experience alone that must justify this Invention. Mean while, methinks every equitable Judge cannot but praise the Efforts of such a Genius, as endeavours to

enlarge the Carrier of Arts, and that of Nature.

We will not extend this Introduction concerning Light any farther; perhaps we have already said too much of it in a Treatise of Simple Elements: but the greatest Part of these Truths are new to most Readers. Before we go on to the other Part of this Philosophy, let us remember, that the Theory of Light hath something in common with the Theory of the Universe, on which we are now to enter. This Theory is, that there is a kind of Attraction observed between Light and Bodies, as well as among all the Orbs of our Universe, which we are next to consider. These Attractions are discovered by different Effects; but, in brief, Attraction is always a Tendency of Bodies to one another, without any apparent Impulsion.

All this Theory of Light has Relation to the Theory of the Universe.

Among so many Properties of Matter, such as those Fits of Transmiffion and Reflection of Light, that Repulfion which Light meets with in the Void, in the Pores of Bodies, and about their Surface; among all these Properties, I say, we ought chiefly to fix our Attention to that Power by which the Rays
are

are reflected and broken, to that Force by which Bodies act upon Light, and Light upon Bodies, without ever touching each other.

Matter has more Properties than has been imagined.

These Discoveries may serve, at least, to render us extremely circumspect in our Decisions concerning the Nature and Essence of Things.

Without the Sense of Feeling, we could have no Idea of the Extension of Bodies; without our Eyes, we could not think of such a Thing as Light; if we had never moved ourselves, we could never have believed the Mobility of Matter *: the small Number of Senses which God has given us, can discover to us but a few of the Properties of Matter. Our Reason supplies the want of other Senses, and teaches us that Matter has yet other Attributes, as Attraction and Gravitation. In all Probability it has many more belonging to its Nature, of which Philosophy, perhaps, may hereafter give some Ideas to Mankind.

* Some think actual Motion might be known, by seeing Bodies change their Distance from one another when we are at rest.

C H A P. XV.

*Introductory Ideas concerning Gravity and the Laws of Attraction: That the Opinion of a subtil Matter, Vortices, and a Plenitude, ought to be rejected *.*

AN intelligent Reader, who shall have considered with Attention these wonderful Properties of Light, convinced by Experience that they are not produced by any known Impulse, will doubtless be impatient to know more of this new Power which we have spoken of under the Name of *Attraction*, and which must needs act more sensibly upon all other Bodies than upon that of Light. That we may not any more be frightened with Terms, let us examine simply the Facts.

I shall make use indifferently of the Words *Attraction* and *Gravitation*, in speaking of Bodies, whether they sensibly tend towards one another, or turn in immense Orbs round one common Centre, or fall upon the Surface of

* But not that subtil *Æther* which Sir *Isaac* makes the Cause of Attraction, Refraction, Animal Motion, &c. which pervades the Universe.

the Earth, or unite to compose solid Bodies, or, lastly, globify themselves in Drops to form Liquids. Let us enter upon our Subject.

All known Bodies gravitate; and the Notion of specifick Levity has been a long Time counted among the acknowledg'd Errors of *Aristotle* and his Followers.

Since the Invention of the famous pneumatic Engine, or Air-Pump, we have been in a much fairer Way to know the Gravity of Bodies; for when they fall in the Air, the Particles of that Element sensibly retard the downward Motion of those Bodies which have large Surfaces and little Substance; but in that Machine deprived of Air, Bodies being abandon'd to that Force, whatever it be, which precipitates them without Obstacle, do fall according to their whole Weight.

The pneumatic Engine, invented by *Otto-guerick*, was soon after brought to Perfection by *Mr. Boyle*; it was furnished with Glass Recipients much longer than at first, and these were entirely deprived of Air. In one of these long Recipients, composed of four Tubes, the whole together being eight Foot high, were suspended at the Top, by a Spring,

Pieces

An Experiment which demonstrates a Vacuum, and the Effects of Gravitation.

Pieces of Gold, Bits of Lead, Scraps of Paper, and Feathers; the Question was, to know what would be the Consequence, when the Spring was let fly. The philosophical Gentlemen foresaw, that the whole would come to the Bottom at the same Time: But much the greatest Number were confident, that the most solid Bodies would fall with far greater Velocity than the Rest. The Multitude, which is almost always in the wrong, was astonish'd at the Event; for in every Experiment that was made, the Gold, the Lead, the Paper, and the Feathers, descended equally swift, and came to the Bottom of the Recipient in one and the same Instant,

Those who still held for the *Plenitude* of *Descartes*, and for the pretended Effects of the subtile Matter, could not give any good Reason for this Fact; for Facts were the Rocks on which they split. If there was an absolute Plenitude, tho' we allowed there might notwithstanding be such a Thing as Motion, (which is absolutely impossible) at least this pretended subtile Matter must exactly fill all the Recipient; it must be there in as great Quantity as Water, or Mercury, that
might

might have been put there ; it must resist the Pieces of Paper, according to their Surfaces, and let the Gold and the Lead descend much sooner : But this Descent is performed in the same Instant ; therefore there is nothing in the Recipient that resists ; therefore the pretended subtile Matter cannot produce any sensible Effect in this Recipient ; therefore there is some other Power which causes Gravity.

It would be in vain to say, that there may possibly remain a subtile Matter in the Recipient, because it is penetrated by the Light : There is a great deal of Difference in the two Cases. The Light, which is in this Glass Vessel, does not fill, at the most, the hundred thousandth Part of it ; but according to the *Cartesians*, we are to imagine that their subtile Matter fills it much more completely than if I supposed it full of Gold ; for there is a great deal of Vacuum in Gold, but they admit none in subtile Matter.

*Boaies gra-
vitate in
proportion
to the
Quantity
of their
Matter.*

Now by this Experiment, the Piece of Gold, which weighs an hundred thousand Times as much as the Paper, descends with

* Yea, the Needle in it would turn to its Point..

† Sure there is Light at each Part where a Mite is visible.

the

the same Velocity as the Paper ; therefore the Power, which makes it descend, acts an hundred thousand Times more forcibly upon the Gold, than upon the Paper ; in like manner as a hundred Times more Strength is requisite in my Arm to move an hundred Pounds, than to move one Pound. That Power then, which is the Cause of Gravitation, acts in direct Proportion to the Quantity of Matter in Bodies. In Effect, it acts so according to the Quantity of Matter in Bodies, and not according to their Surfaces, that a Pound of Gold reduced into Dust, will weigh precisely as much as the same Quantity beat out into Leaves. The Figure of Bodies makes no Alteration in their Gravity ; the Power of Gravitation then operates upon the internal Nature of Bodies, and not in proportion to their Superficies.

This Power does not reside in the pretended subtile Matter, of which we shall speak in the next Chapter : That Matter must be a Fluid ; and every Fluid acts upon Solids in proportion to their Superficies. Thus the Vessel presenting a smaller Surface at her Prow, cuts through the Sea which would resist her Sides.

Whence the Power of Gravitation proceeds.

Sides. Now if the Superficies of a Body be the Square of its Diameter, the Solidity of this Body is the Cube of the same Diameter : But the same Power cannot act at one Time in proportion to the Cube and the Square ; therefore the Gravity of Bodies is not the Effect of this Fluid. Besides, it is impossible that this pretended subtile Matter should, on the one Side, have so much Force as to precipitate a Body from the Height of 54000 Feet in a Minute (for such is the Descent of Bodies) and that, on the other, it should be so weak, as not to hinder the lightest Wooden Pendulum to proceed from Vibration to Vibration in the pneumatic Engine, which is supposed to be compleatly filled with this imaginary Matter.

I shall make no Scruple then to affirm, that if any Impulse should ever be discovered, which is truly the Cause of the Tendency of Bodies towards a Center, the Cause, in a Word, of Gravitation and Attraction, that Impulse will be altogether of a different Nature from any Thing we are acquainted with *.

* Every Body must tend to the Center of the Earth, if there be a Vacuum or little Resistance there.

There is one primary Truth then, that was pointed out elfewhere, and has been proved in this Chapter, that there is a Power, which occasions all Bodies to gravitate, in exact Proportion to the Quantity of their Matter.

If it be actually enquired, why one Body is more ponderous than another, the fingle and only Reason of it will eafily be found: It will be concluded, that this Body muſt have more Solidity, more Matter under the ſame Extent: Thus Gold is heavier than Wood, becauſe there is in Gold much more Matter, and much leſs Vacuity, than in Wood.

Deſcartes and his Followers maintain, that one Body is heavier than another without containing more Matter. Not content with this Idea, they ſupport it by another altogether as falſe: They admit a grand Vortex, Tourbillon or Whirlpool, of ſubtile Matter, encompaſſing our Globe; and it is this grand Vortex, ſay they, that in its Circulation drives all Bodies towards the Center of the Earth, and impreſſes on them that Quality which we call Gravity.

Why one Body weighs more than another.

The System of Deſcartes cannot account for it.

It is true, they have not given any Proof
of

of this Assertion *. There is not the least Experiment, not the least Analogy in Things of which we have any Knowledge, whereon to establish even a slight Presumption in favour of this Whirlpool of subtile Matter ; so that for this very Reason alone, that this System is a mere Hypothesis, it ought to be rejected: Nevertheless, it was on no other Account that it obtained Credit. This Vortex was conceived without Difficulty ; an indefinite Explanation of Things was given, by pronouncing the Words *subtile Matter* ; and when the Philosophers were sensible of the Contradictions and Absurdities that cleav'd to this philosophical Romance, they dream'd rather of correcting than abandoning it.

Huygens and many others have made in it a thousand Corrections, of which they themselves confess the Insufficiency: But what shall we put in the Place of these Tourbillons, and this subtile Matter ? It was this too common Way of Reasoning, more than any Thing, that confirm'd Men in the Error they had embraced. But we ought to abandon what is manifestly false and insupportable,

* This is a great Condescension.

as well when we have nothing to substitute in its Room, as when we have the Demonstrations of *Euclid* to put in its Place. An Error is neither more nor less an Error, whether the Loss of it be or be not, supplied by Verities. Ought I to admit the horrid Notion of a Vacuum in a Pump, because I am not yet able to judge, by what Mechanism the Water rises in that Pump*?

Before we proceed any farther then, let us take upon us to prove that the Vortices of subtile Matter have no Existence; that the Idea of Plenitude is not less chimerical; that therefore the whole System, founded on these Imaginations, is no more than an ingenious Romance, without the Appearance of Truth. We will enquire first, what is meant by these Vortices; and afterwards examine, whether or no a Plenitude be possible.

* *Descartes* does not require us to believe a Vacuum in a Pump, he explains it by a Plenum; for the Sucker being drawn upwards, presses the Matter above it, which Pressure is continued to the Surface of the Water at the Bottom of the Pump, which presses the Water up the same Instant, all being full.

C H A P. XVI.

That the Vortices and Plenitude of Descartes are impossible, and consequently that there is some other Cause of Gravity.

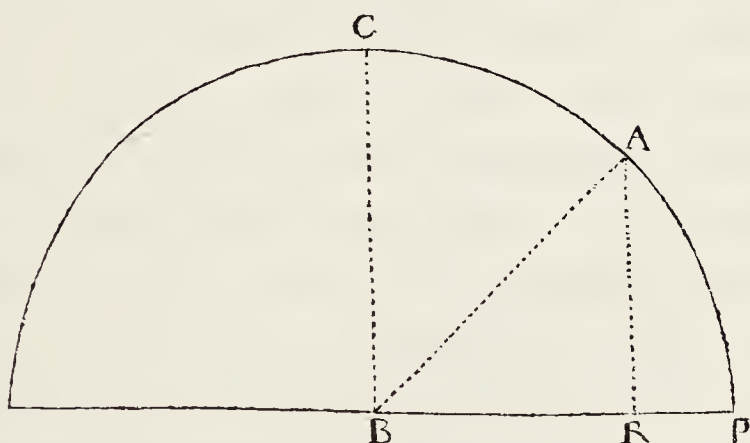
DESCARTES supposes an immense Heap of imperceptible Particles, which carries the Earth round, with a rapid Motion from West to East, and which from Pole to Pole moves parallel with the Equator. This Vortex of Matter, which extends beyond the Moon, and drags her also along with it in its Course, is enclosed in another Vortex yet much more extensive, which touches another yet larger, without being confounded with it; and so on.

*Proof of
the impos-
sibility of
the Vor-
tices.*

If this were so, 1st, the Vortex which is supposed to move round the Earth from West to East, would drive the Bodies that are upon the Earth from West to East also*: Now all Bodies, in falling, describe a Line, which, being prolonged, would pass very near thro' the Centre of the Earth: therefore this Vortex has no Existence. 2^{dly},

* Not if the Earth move along with it as it does with our Atmosphere which moves but very little faster.

2dly, If the Circles of this pretended Vortex moved and acted parallel to the Equator, all Bodies must fall perpendicularly, every one under that Circle of the subtle Matter to which it answers: a Body in A, near the Pole P, must, according to *Descartes*, fall in R *.



Whereas it falls, within a Trifle, according to the Line A, B, which makes a Difference of about 1400 French Leagues; for we may compute near that Number from the Point R, to the Equator of the Earth B; therefore this Vortex hath no Existence.

3dly, If this Vortex of Matter around the Earth, and those other pretended Vortices around Jupiter, Saturn, &c. existed; all these

* This is an Argument of some Weight, except we suppose that Bodies tend to the Center, where there is less Resistance, as the Winds do,

immense Vortices of subtile Matter, rowling so rapidly in different Directions, could never suffer any one Ray of Light, darted from a Star, to come to us in a right Line. Now it has been proved that these Rays arrive in a very short Time, considering the immense Way they come: **Therefore** there are no Vortices.

4thly, If these Vortices carried round the Planets from West to East, the Comets, which traverse these Spaces, in all Directions, from East to West, and from North to South, could not traverse them at all. And tho' it should be supposed, that the Comets have never actually pass'd from North to South, and from East to West, yet nothing would be gain'd by this Evasion; for it is known, that when a Comet is seen in the Region of Mars, of Jupiter, of Saturn, it moves incomparably swifter than Mars, than Jupiter, or than Saturn; therefore it cannot be carried round by the same Bed of fluid Matter which is supposed to carry round those Planets*; and therefore no Vortices.

5thly, These Vortices must be either equally dense, equally compact with the Pla-

* Except there be a suspended Force.

nets, or they must be more dense, or, finally, they must be less dense. In the first Case, the pretended Matter, which encompasses the Moon and the Earth, being supposed equally dense with the same Bulk of Earth, we should experience the same Resistance, in lifting, for Instance, a Cubic Foot of Marble, as we should in lifting a Column of Marble as high as from the Earth to the Moon, whose Basis was only a Foot square. In the second Case, the fluid Matter being heavier than the Earth, our Globe would swim upon this Fluid, as a Vessel swims upon the Water, and could not be plunged, as is pretended, into the subtile Matter. In the third Case, the Fluid being less dense, less weighty than the Earth, this Fluid could never sustain it, for the same reason as Water cannot sustain Iron, nor any thing that weighs more than itself*: Therefore no Vortices.

6thly, If these imaginary Fluids had any Existence, all the Order of the Celestial Orbs would be inverted: The Sun, which turns upon its own Axis, would soon lose its Mo-

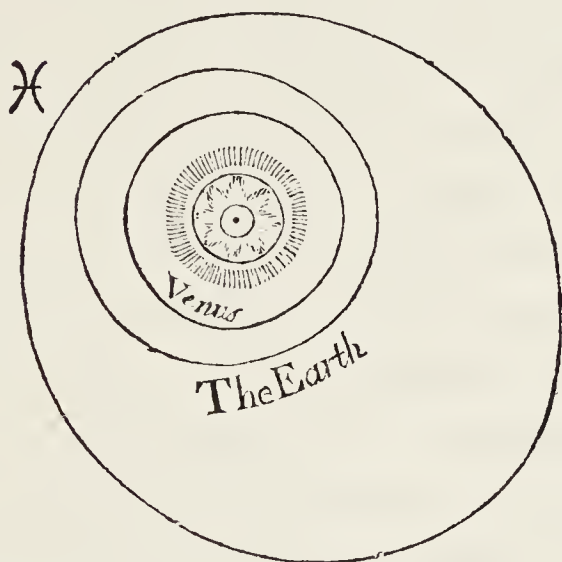
* If there be a Plenum no Body is more dense than another, only it contains more of Homogeneous Matter.

tion from the Obstruction of this Fluid; and not one of the Planets would keep the Course it now holds, would have the Motion it now has, or would long have any Motion at all.

7thly, The Planets carried round in these Vortices could move circularly only, because the Vortices, at equal Distances from the Center, must be equally dense; but the Planets move in Eclipses, and there cannot be carried round in any such Vortices; therefore no such Vortices exist.

8thly, The Earth has her Orbit, which she passes thro', between the Orbit of Venus and that of Mars: All these Orbits are elliptical, and have the Sun for their Center: Now when Mars, Venus, and the Earth, are nearest one to another, the Matter of this pretended Torrent, which carries round the Earth, must be much more compressed than at other Times: This subtile Matter should then precipitate its Course, as a River that is straitened in its Banks, or flows under the Arches of a Bridge; and, consequently, should then force the Earth on with much greater Rapidity, than when it is in any other Position: But, on the contrary, it is just
then

then that the Motion of the Earth is more retarded than at other Times*.



When Mars appears in the Sign Pisces, that Planet, the Earth, and Venus, are nearly in the Proximity here represented; and then the Sun seems to be retarded for some Minutes, that is, the Earth is retarded: It is demonstrably impossible then, that there should be Torrents of Matter which carry round the Planets: Therefore the Vortices have no Existence.

9thly, Among the more abstracted Demonstrations, which destroy the Being of these Vortices, we will chuse the following.

* This would hold good if the Planets were fixed as the Pillars of a Bridge.

By one of *Kepler's* Fundamental Laws*, every Planet describes equal Areas in equal Times: By another Law not less certain, every Planet makes its Revolution round the Sun in such a Manner, that if, for Example, its middle Distance from the Sun was 10, by taking the Cube of that Number, which makes 1000, the Time of the Revolution of that Planet round the Sun, will be found proportionable to the Square Root of the Number 1000. Now if there were Torrents of Matter which carried round the Planets, these Torrents could not follow these Laws; for the Swiftneſſes of the Torrents must be proportional to their Distance from the Sun, and, at the same Time, to the Square Roots of those Distances; which is incompatible.

To ſum up the whole; every one ſees what muſt happen to two Fluids, circulating in oppoſition the one to the other: They would neceſſarily be confounded together, and form a Chaos, inſtead of maintaining an Order in Nature. This alone, would at once have expoſed the Cartefian System to the utmoſt

* The Period of each Part of the Vortex is as the Cube of its Distance.

Ridicule, if the Love of Novelty, and an habitual Difuse of free and impartial Examinations, had not prevailed.

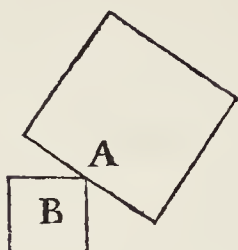
We are now to prove that the Plenitude, *Proof a-*
in which these Vortices are supposed to move, *gainst a*
is as impossible as the Vortices themselves. *Plenitude.*

1st, A single Ray of Light, which does not weigh any thing near the hundred thousandth Part of a Grain *, must difcompose the Order of the whole Universe, if it was to open its way to us thro' an immense Space, every part of which would not only resist of itself, but the whole Line of Matter which presses on it.

2dly, Two hard Bodies, A and B, (we have already proved that there must be hard Bodies,) touch one another at one Surface, and are supposed to be encompassed with a Fluid, which presses them on all sides: Now, when they are separated, † it is clear that the pretended subtile Matter must arrive sooner at the Point A, where they divide, than at the Point B.

* If his Atoms have any Weight, a Line of them to the Stars, or a Ray, will have considerable Weight.

† Two polished Surfaces will not part, by which he proves a Plenum.



There is a Moment then, wherein there must be a Void at B ; therefore even in the System of the subtile Matter there is a Void.

3dly, If there was no such Thing as Vacuity and Space, there could be no Motion, even in the System of *Descartes* himself. He supposes that God created the Universe full, consisting of small Cubes * : Let there then be a given Number of Cubes, representing the Universe, without their having the least Interval between them : It is evident, that one of them must move out of the Place it occupies ; for if every one continues in its Place, there can be no Motion, because Motion consists in changing of Place, in moving from one Point of Space to another. Now who does not perceive, that one of these Cubes cannot quit its Place, without leaving a Vacuum at the Instant it goes out of it ;

* See rather *Descartes* himself.

since it is clear that this Cube, in turning itself round, must present its Angle to the Cube it touches, before that Angle can be beat in Pieces ? At that Time then there is Space between these two Cubes ; therefore, even in the System of *Descartes* himself, these cannot be Motion without a Vacuum.

4thly, If all was full, as *Descartes* would have it, we ourselves should feel an infinite Resistance in walking, whereas we perceive no other than that of the Fluids in which we are : That of Water, for Example, resists 860 Times, and that of Mercury 14,000 Times, more than that of Air. Now the Resistances of Fluids are in proportion to the Squares of Velocities: Thus if a Man, in a Third of Time, makes his way thro' a Foot of Mercury, which resists him 14,000 Times more than Air ; if this Man, in the next Third, move twice as far, the Mercury in this Third, will resist in proportion to the Square of 2 multiplied by 14,000 ; a Resistance 56,000 Times more powerful than that of Air: If all were full, it would be absolutely impossible to walk a step, to breathe, &c. *

* Resistance is not according to the Quantity of Matter, but to the yielding of the Particles, or parting more or less easily.

5thly, The *Cartesians* have endeavour'd to elude the Force of this Demonstration, but they had no other way of doing it, than by advancing a manifest Error. They pretend, that this infinite Torrent of subtile Matter penetrating all the Pores of Bodies, cannot hinder their Motion. They did not reflect, that every Body, which moves in a Fluid, feels a Resistance in proportion to the Extent of Surface it opposes to this Fluid: Now the more Pores there are in a Body, the larger is its Surface: So that the pretended subtile Matter, by clogging up all the Inside of a Body, must oppose the Motion of that Body much more forcibly, than by touching only its outward Superficies. This is capable of the most undeniable Demonstration.

6thly, All Bodies in a Plenitude would be equally weighty: It is impossible to conceive that a Body bears upon me, and presses me, but by its Quantity of Matter; a Pound of Gold Dust weighs as much on my Hand, as a Lump of Gold of a Pound. In vain the *Cartesians* answer, that the subtile Matter penetrating the *Interstitia* of Bodies, has no Weight, and that we ought to esteem nothing

thing weighty but what is not subtile Matter. This Opinion, in *Descartes*, is no less than a direct Contradiction; for, according to him, it is the pretended subtile Matter alone that causes the Gravity of Bodies, by forcing them towards the Earth *: This subtile Matter itself then gravitates upon these Bodies; and if it doth so, there can be no Reason why one Body should be more weighty than another, since all being equally full, all must be equally in Quantity of Matter, whether Solids or Fluids: A Plenitude then, is a Chimæra; there is a Vacuum therefore, and nothing can be done in Nature without a Vacuum; therefore Gravity is not the Effect of a pretended Vortex, in an imaginary Plenitude.

* But it does not thence follow, that that subtile Matter gravitates; for tho' Matter descending in one Tube forces it up in another, it does not therefore go up itself.

C H A P. XVII.

*What is meant by Vacuity and Space,
without which there could be neither
Gravity nor Motion.*

*Objections
against a
Void.*

THOSE who cannot conceive a *Void*, object, that this Void must be nothing, that nothing cannot have Properties, and therefore, that there can be no Operation in the Void.

Answer.

We answer, It is not true that a Vacuum is nothing ; it is the Place of Bodies ; it is Space ; it hath Properties ; it is extended in Length, Breadth, and Depth ; it is penetrable, inseparable, &c. I cannot, indeed, form in my Head an Image of extended Space, as I can of extended Body ; but I can demonstrate to myself that this Space exists. I cannot represent to myself, in Geometry, an Infinity of Circles passing between a Circle and a Tangent ; but I can nevertheless demonstrate to myself that the Thing is true in Geometry, which is sufficient to my Purpose. I cannot conceive what it is within

me that thinks, yet I am convinced that something thinks within me. In like manner I demonstrate to myself the Impossibility of a Plenitude, and the Necessity of a Void, without having any Image of a Void : For I can have no Image but of that which is corporeal, and Space is not corporeal. It is one thing to represent an Idea to one's self, another thing to conceive a Truth : I have a full Conception of Space; and the *Epicurean* Philosophers, who were wrong in every thing else, conceived it very well.

There was no other Way to answer this Argument, than by saying that Matter is infinite. This is what many antient Philosophers have affirmed, and what *Descartes* after them has revived.

But on what Foundation do they imagine that Matter is infinite? Only on another Supposition, which they are pleased to make. They say, Extension and Matter are the same Thing : We cannot conceive any Limits to Extension ; therefore we must admit that Matter is infinite. *Matter is not infinite.*

This proves how easily Men bewilder themselves, when they reason only on Suppositions.

It

It is false that Extension and Matter are the same Thing : All Matter is extended ; but all Extension is not Matter. *Descartes*, by advancing that there could be no Extension but of Matter, advanced a very unphilosophical Notion ; for we know nothing at all of what Matter is ; we know only some few of its Properties ; and no Man can deny, but Millions of other extended Substances may exist, different from that which we call Matter : Now where must these Substances have their Being, if not in Space ?

Besides this Error, *Descartes* contradicts himself again ; for he admits a God. Now where is this God ? He is not in a mathematical Point ; he is immense : What is his Immensity, is it not immense Space ?

With regard to the pretended Infinity of Matter, that Idea hath as little Foundation as the Vortices. We have seen the absolute Necessity of a Void in the Order of Things, and that therefore Matter, as it fills not all Space, is not infinite. But what are we to understand by an infinite Matter ? For the Term *Indefinite*, used by *Descartes*, either must be explained by this, or it signifies nothing

*Discussion
of this
Truth.*

at all. Do they mean, that Matter is essentially infinite in its own Nature? If so, then Matter is God. Do they mean, that God has created it infinite? Whence do they know that? Do they mean, that Extension and Matter are the same Thing? The Falsity of that Argument has been sufficiently proved.

The Existence of infinite Matter, is, at the Bottom, a Contradiction in Terms. But, it will be said, you admit an Immensity, and Infinity of Space; why do you not admit the same concerning Matter? Here lies the Difference: Space exists of Necessity, because God necessarily exists; it is immense; it is, like Duration, a Mode, an infinite Attribute of a necessary, infinite Being. But Matter is nothing of all this: It does not necessarily exist; and if such a Substance were infinite, it would be either an essential Attribute of God, or God himself: But it is neither the one nor the other; therefore cannot be infinite.

I shall conclude this Chapter with a Remark, which to me seems worthy of the utmost Attention. *Descartes* admitted a God,

A singular Remark.

* If Space be an Attribute it must be in a Subject; not in God, for he is in Space, *Page 182. Line 12.*

the Creator and Cause of all Things, but he denied the Possibility of a Void : *Epicurus* denied that there was a God, the Creator and Cause of all, but admitted a Void. Now it was *Descartes* who, according to his Principles, ought to have denied a divine Creator, and it was *Epicurus* who should have admitted him. We will prove it evidently.

For if a Void was impossible*, if Matter was infinite, if Extension and Matter were the same Thing, it would follow that Matter must be necessary : Now if Matter was necessary, it must exist of itself by an absolute Necessity, inherent in its primitive Nature, antecedent to all Things: Matter would then be God ; therefore he, who maintains the Impossibility of a Void *, ought not, if he reasons consequentially, to admit any other God than Matter.

On the contrary, if there be a Void, then Matter is not a necessary self-existent Being, consequently, it was created ; consequently, there is a God. It was the Part of *Epicurus* therefore to believe a God, and of *Descartes*

* This is not for Void being in the Pores of Bodies.

to deny one *. Wherefore then, on the contrary, is *Descartes* continually speaking of a God, the Creator and Preserver of all Things, and why does *Epicurus* reject such a Being ? for this very Reason, that Men, in their Sentiments, as in their Conduct, seldom follow their own Principles ; that their Systems, as well as their Lives, are Contradictions.

We learn from all that has been said, that *Conclusion* Matter is finite, that there is a Void, that is to say, *Space* †, and even incomparably more Space than Matter in our World ; for the Quantity of Pores is much more than that of Solids. We conclude that a Plenitude is impossible ; that the Vortices of subtile Matter are equally so ; that *Descartes's* Cause of Gravity and Motion is a Chimera.

We have been taught, by the Experiment in the pneumatic Machine, that there must be a Power which occasions the Descent of Bodies towards the Centre of the Earth, that is, which gives them their Gravity ; and that this Power must act in proportion to the Quantity of Matter of which Bodies consist :

* He thought it no Reason to disbelieve a God, because he could not comprehend his Works.

† Where Matter is there is Space, tho' occupied.

We are now to enquire, what are the Effects of this Power ; for if we can make any Discovery of its Effects, the Existence of it will be evident. Let us not begin with assigning Causes, and forming to ourselves Hypotheses ; that is the sure Way to wander from the Mark : Let us pursue, Step by Step, that which really passes in the System of Nature *. We are Voyagers, arrived at the Mouth of a River, and must labour up the Stream, before we guess at the Situation of the Source.

* The Experiment seen must not be explained by your Principle, because I can give no other.

C H A P. XVIII.

Gravitation demonstrated from the Discoveries of Galileo and Newton: That the Moon revolves in her Orbit by the Force of this Gravitation.

GALILEO, the Restorer of Reason in *Italy*, discovered this important Proposition, That heavy Bodies, which descend to the Earth (allowing for the small Resistance of the Air) have a Motion accelerated in a certain Proportion, of which I shall now endeavour to give a concise and clear Idea.

Laws of the Gravitation of Bodies found by Galileo.

A Body abandoned to itself from the Top of the Tower, descends, in the first second, a Space which is found equal to 15 *Paris* Feet, according to the Discovery of *Huygens*, the great Mathematician. It was thought before *Galileo*, that this Body in two seconds, would have passed thro' only twice the same Space, and that thus it would fall 150 Feet in ten seconds, and nine hundred Feet in a Minute. This was the general Opinion, and a very probable Opinion it was to a Person who

who did not examine things closely. Nevertheless, it is certain that in a Minute this Body would fall 54,000 Feet, and 216,000 Feet in two Minutes.

Let us see how this Progress, which at first astonishes the Imagination, is performed necessarily, and with Simplicity. A Body is precipitated with its own proper Weight: That Power, whatever it be, which animates it to descend fifteen Feet in the first second, acts equally at every Instant; for nothing having changed it, it must of necessity continue the same: Thus at the next second, the Body will have the Force which it has acquired in every Instant of the first, and the Force which it experiences every current Instant. Now by the Force which animated it in the first second, it descended 15 Feet; it hath still that Force then, when it descends the next second. It hath beside that the Force of 15 other Feet, which it acquired by descending this first second, and that makes 30. It must still have also in the second second (nothing being changed) the Power of falling 15 Feet which makes 45. By the same Reason, this
Body

Body will descend 75 Feet at the third second; and so proportionately in the rest.

Hence it follows, 1st, That in equal Times infinitely small, a moving Body acquires Degrees of Velocity infinitely small, which accelerate its Motion towards the Center of the Earth, provided it meets no Resistance.

2dly, That the Degrees of Velocity which it acquires, are in proportion to the Degrees of Time it employs in descending.

3dly, That the Spaces it passes through, are as the Squares of these Times, or of these Degrees of Velocity.

4thly, That the Progression of Spaces passed through by this moving Body, are as the unequal Numbers 1, 3, 5, 7. This necessary Knowledge of a Phenomenon, that happens on every Side of us every Moment, shall be render'd sensible, even to those who may at first be a little embarrass'd with all these Proportions: They need only cast their Eyes, with a little Attention, on the Table annex'd, which every Reader may enlarge at his Pleasure.

Times in which the Body falls.	Spaces which it passes through in every Time.	Spaces passed over, which are as the Spaces of the Times.	Unequal Numbers, which mark the Progref- sion of Mo- tion, and the Spaces passed over.
1st Se- cond, one Ve- locity.	The Body descends 15 Feet.	The Square of 1 is 1. The Body falls 15 Feet.	Once fif- teen.
2d Se- cond, two Veloci- ties.	The Bo- dy de- scends 45 Feet.	The Squares of two Seconds or two Ve- locities, is four. Four times fifteen are 60. The Body then has descended 60 Feet, that is 15 in the first second, and 45 in the second.	Three Times fif- teen. Thus the Progref- sion is from one to three in this se- cond.
3d Se- cond, three Ve- locities.	The Bo- dy de- scends 75 Feet.	The Square of 3 se- conds is 9: Nine Times 15 makes 135. The Body then has descended 135 Feet in 3 Se- conds.	Five Times fifteen. Thus the Progref- sion is visible according to the unequal Numbers 1, 3, 5, &c.

It is manifest at first Thought, that in every Instant infinitely small, the movable Body receives an accelerated Motion; since it appears, both by the Proposition and the Experiment, that this Motion augments continually. A slight Inspection of this little Table will demonstrate, that at the End of a Minute the Body will have descended 54,000 Feet, for 54,0000 make the Square of 60 Seconds, multiplied by 15. Now 15 multiplied by the Square of 60, which is 3,600, the Product is 54,000.

These Experiments gave Birth to a new Conjecture, in reality well founded, but which nevertheless required a particular Demonstration. For, observing that a Body, of a Weight almost equal, descended 60 Times as fast at the End of 60 Minutes as it did during the first Minute, it was presumed that the Weight itself must vary, in some certain Proportion to its Distance from the Center of the Earth. Several great Men, who sought a new Road to the Knowledge of Nature, and among others the famous Lord *Bacon*, Chancellor of *England*, began also to suspect that there was a Gravitation, an Attraction of Bodies

dies to the Center of the Earth, and of the Earth to Bodies. He proposed, in his excellent Book, *Novum Scientiarum Organum*, the making of Experiments with Pendulums upon the Tops of the highest Towers, and at the Bottom of the deepest Wells: For, said he, if the same Pendulums vibrate more rapidly at the Bottom of a Well than on the Top of a Tower, we must conclude that Gravity, which is the Principle of these Vibrations, will be much more powerful at the Centre of the Earth, to which the Well is nearest. He attempted also to make Experiments of the Descent of Bodies from different Elevations, and to observe if they descended less than fifteen Feet the first second: But there never appeared any Variation in these Experiments, the Elevations and Profundities where they made them being of too little Consequence.

In this Uncertainty they continued, and the Idea of a Power acting from the Center of the Earth remained a random Conjecture.

Descartes was acquainted with these Particulars, and even speaks of them in treating of Gravity: But Experiments, which alone could clear up this grand Question, were still wanting.

wanting. The System of the Vortices hurried away this vast and sublime Genius: It was his Pleasure, in creating his Universe, to give the Direction of every thing to his subtile Matter, which he made the Dispenser of all Motion and all Gravity. By little and little *Europe* adopted his System, for want of a better.

At last in 1672, Mr. *Richer*, in a Voyage *Experiment made by some Academicians, which conduced to this Discovery.* to *Cayenna*, near the Line, undertaken by Order of *Lewis XIV.* under the Protection of *Colbert*, the Father of all the Arts; *Richer*, I say, among many Observations, found that the Pendulum of his Clock no longer made its Vibrations so frequently as in the Latitude of *Paris*, and that it was absolutely necessary to shorten it by a Line, that is, eleventh Part of our Inch, and about a Quarter more *.

Natural Philosophy and Geometry were not then, by far, so much cultivated as at present. Who could have believed, that from this Remark, so trifling in Appearance, that from the Difference of the eleventh of our

* A Foot in Measure at *Paris* being more than an *English* Foot, so is their Digit or 12th Part of it more than our Inch, in proportion as 144 to 135.

Inch, or thereabouts, could have sprung the greatest of physical Truths? It was found, at first, that Gravity must needs be less under the Equator, than in the Latitude of *France* *, since Gravity alone occasions the Vibration of a Pendulum †.

In Consequence of this it was discovered, that, whereas the Gravity of Bodies is by so much the less powerful, as these Bodies are farther removed from the Center of the Earth, the Region of the Equator must absolutely be much more elevated than that of *France*; and so must be farther removed from the Center; and therefore, that the Earth could not be a Sphere. Many Philosophers, on occasion of these Discoveries, did what Men usually do, in Points concerning which it is requisite to change their Opinion; they opposed the new-discovered Truth. Many Doctors of the Church, even till the fifteenth Century, had

*The Earth
higher in
Proportion
at the E-
quator than
at the
Poles.*

* Some think the Vibrations at the Equator are fewer than near the Pole, because of the denser Medium there, by the Multitude of Vapours at the Equator from the Sun's Heat: for in the same Latitude the number of Vibrations change as the Medium in which

† Perhaps not the Number of them, but the Medium that resists less or more.

believ'd the Earth to be flat, longer from East to West than from North to South, and covered with the Sky, as a Vault, in the Form of a Tent. Their Opinion appear'd to them by so much the more certain, as they believed it founded upon the Bible. But a very little Time before the Discovery of *America*, a Bishop of *Avila* treated the Opinion of the Earth's globular Form as an Impiety, and an Absurdity. At last Reason, and the Voyage of *Christopher Columbus*, restored to the Earth its ancient spherical Form, which the *Egyptians* and *Chaldeans* had given it. People then pass'd from one Extreme to another; they believed the Earth a perfect Sphere, and that the Stars made their Revolution in a true Circle.

Nevertheless, from the Moment that they began to be certain of the Earth's diurnal Rotation upon its own Axis, they ought to have judg'd from that alone, that a Form entirely spherical could not belong to it. They need only have considered, that such a Rotation once in twenty four Hours must elevate the Waters of the Sea; that these Waters, being more elevated than the rest of
the

the Globe, would fall back upon the Land in the Region of the Equator, and overflow it: But the Waters have no such Fall; therefore the solid Earth must be as much elevated as the Waters. This Reasoning, so very simple, so natural, escaped the greatest Genius's of that Time; a certain Proof of the Strength of Prejudice, that it did not permit even this slight Examination. They still contested *Richer's* Experiment: They pretended, that the Vibrations of our Pendulums were less frequent towards the Equator, for no other Reason but because the Heat lengthened Metal: They perceived, that the Heat of the most scorching Summer, would lengthen an Iron Rod above thirty Feet long, about the eleventh Part of our Inch; but the Question here was concerning a greater Alteration, perhaps even twice as great, in a Rod of little more than three Feet in Length.

Some Years after, Mess. *Deshayes*, *Varin*, *Feuillée*, and *Couplet*, repeated the same Experiment of the Pendulum near the Equator: They found it necessary continually to shorten it, the nearer they came to the Line, tho' the Heats were often less under the Line itself,

self, than at fifteen or twenty Degrees distance. This Experiment has been lately confirmed, by the Academicians who are at present in *Peru*; and they have just now informed us, that about *Quito*, in a Time when it freezed, they were obliged to shorten the Pendulum for Seconds about two Lines, or the sixth Part of a Digit.

While they were thus discovering of new Truths, under the Line, Mr. *Picart*, in Conformity to the same Orders, gave to the World in 1669 a Measure of the Earth, by tracing over a small Part of the Meridian of *France*. He did not indeed give so exact a Measure of the Earth, as he might have done, if he had measured the Degrees in *France* both towards the Pole and towards the Equator : But this Difference was too insignificant to be taken notice of, among the Things that will now fall under our Consideration.

These Discoveries were necessary to found the Theory of Sir *Isaac Newton*. We think ourselves obliged here to insert a certain curious Anecdote, concerning these Discoveries and this Theory, which will not be unprofitable in the History of human Minds, and

and which will serve to discover the great Necessity of Exactitude in the Sciences, and with what Sincerity Sir *Isaac* proceeded in his Search after Truth.

*Anecdote
concerning
these Dis-
coveries.*

He had laid the Foundation of his admirable System of Gravitation ever since the Year 1666; but there was wanting, to reconcile this System with Truth in all its Parts, and above all to draw those Conclusions from the Motion of the Moon which we are by and by to consider; there was wanting, I say, a Demonstration that the Degrees of Latitude were every one about 25 common *French* Leagues, that is, near 70 *English* Miles.

In the Year 1636, *Norwood*, an *English* Mathematician, had done that, in pure Curiosity, which the Benevolence of the *French* Minister caused *Picart* to undertake afterwards, in 1669: He had made the same Experiments concerning the Degrees of Latitude between *London* and *York*, in the North of *England*, as *Picart* made to the North of *Paris*, in a less Extent of Ground.

The Degrees of *Norwood* were found, within a Trifle, to consist of 70 *English* Miles,

or

or 25 *French* Leagues : This was precisely the Measure that Sir *Isaac Newton* had guess'd at by his Theory, and which alone could justify it.

But what will appear surprizing is, that in 1666, and even many Years after, Sir *Isaac Newton* knew nothing of *Norwood's* Measures, taken above 30 Years before the Misfortunes which had afflicted *England*, had been as fatal to the Sciences as to the State : *Norwood's* Discovery was buried in Oblivion ; every one kept to the erroneous Measure of the Pilots, who, in their random Computation, reckon'd only 60 Miles for a Degree of Latitude. And our Philosopher being retir'd into the Country during the Plague in 1666, was not in the Way of getting any Information concerning *Norwood's* Measures, and therefore stuck to the false Computation of 60 Miles.

It was by this erroneous Measure that he proceeded to enquire, as we have already said, whether the same Power that occasions the Gravitation of Bodies towards the Center of the Earth, was what held the Moon in her Orbit. He found himself far enough from those Conclusions, which he could have drawn
with

with a more exact Measure of the Earth, and for that Time abandon'd his Research.

He resumed it some Years after, upon the Measures of *Picart*, and still farther confirm'd himself in it in 1683, by the more exact Measures of *Cassini*, *Lattise*, *Chazelles*, and *Varin*, who, encouraged by *Colbert*, traversed a much larger Tract than *Picart*.

These Academicians examined the Meridian even as far as *Auvergne*; but *Colbert* being dead, *Louvois*, who succeeded him in the Jurisdiction of the Academy, but not in his Taste for the Sciences, interrupted a little this laborious Undertaking.

It was not till about that Time, that *Newton* became acquainted with the Operations of *Norwood*: He saw with Astonishment, that these Measures were the same with those of *Picart* and *Cassini*, with only this Difference, that *Norwood's* Degree exceeded that of *Picart* 240 Fathoms, but surpassed that of *Cassini* only eight. *Newton* attributed this small Excess of 8 Fathom in a Degree to the Figure of the Earth, which he believed to be that of a Spheroid, depress'd or flatten'd towards the Poles; and he judg'd that

that *Norwood*, by drawing his Meridian in Regions more Northerly than those of *France*, necessarily found his Degrees longer than those of *Cassini*, because he supposed that part measured by *Norwood* to have a longer Curve. However that be, here follows the sublime Theory which he drew from these Measures, and from the Discoveries of the great *Galileo*.

The Gravity of Bodies upon our Globe, is in reciprocal proportion of the Squares of their Distances from the Center of the Earth: Theory drawn from these Discoveries. Thus, the more these Distances are increased, the more is Gravity diminished.

The Power which is the cause of Gravity, depends not upon Whirlpools of subtile Matter, the Existence of which is demonstrably false.

That Power, whatsoever it be, acts upon all Bodies, not according to their Surfaces, but in proportion to the Quantity of their Matter. If it acts at one Distance, it must act at all Distances: If it act in reciprocal Proportion of the Squares of these Distances, it must always act according to the same Proportion upon all known Bodies, when they

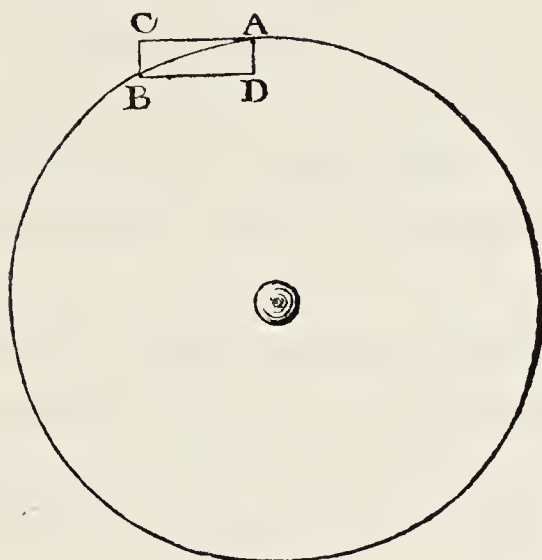
they are not at the Point of Contact, that is, let them be as near together as possible, without being joined.

If, according to this Proportion, the Power of Attraction, upon the Surface of our Globe, causes a Descent of 54,000 *Paris* Feet in 60 Seconds; a Body that shall be distant from the Center of the Earth about 60 of its Semi-diameters, by the same Rule will fall only fifteen *Paris* Feet in the same Time.

The same Power which occasions the Gravitation of Bodies towards the Earth, directs the Moon in its Course round the Earth.

The Moon, in her mean Motion, is distant about 60 Semi-diameters of our Terrestrial Globe from the Center of that Globe. Now by the Measures taken in *France*, we know how many Feet the Moon's Orbit contains; we know that in her mean Motion, she describes 187,961 *Paris* Feet in a Minute.

The Moon, in her mean Motion, is advanced from A to B: She has obeyed then, both the projectile Force, which directs her in the Tangent A, C, and the Power which would make her descend according to the Line A, D, equal with B, C. Take away the Force which directs her from A to C, and



and there will remain a Force which may be estimated by the Line C, B. This Line C, B, is equal to the Line A, D: But it is demonstrable that the Curve A, B, being 187,961 Feet, the Line A, D, or C, B, will be only fifteen: Therefore whether the Moon falls into B, or into C, it is here the same Thing; she will have descended 15 Feet in a Minute from C to B; therefore she will have descended 15 Feet in a Minute also from A to D. But in descending this Space in a Minute, she will have travelled 3600 Times as far as a moveable Body upon the Earth would have travelled in the same Time: Now 3600 is just the Square of her Distance;

Distance; therefore the Gravitation which acts here upon all Bodies, acts also between the Earth and the Moon precisely in the same Ratio of the Square of their Distances.

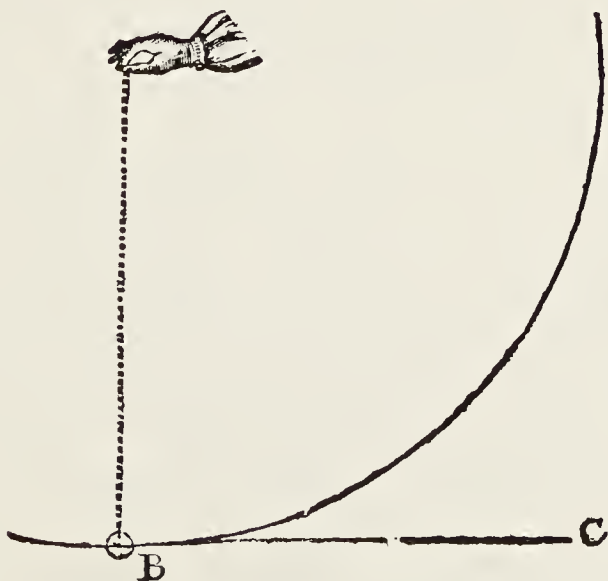
But if this Power which animates Bodies, directs the Moon in her Orbit, it must direct the Earth in its Orbit also; and the Effect which it produces upon the Planet of the Moon, it must produce also upon the Planet of the Earth: For this Power is every where the same; all the other Planets must be subject to it, and even the Sun also must experience its Law: And if there be no Motion of the Planets with Regard one to another, which is not the necessary Effect of this Power, it must then be confessed, that all Nature demonstrates it: This is what we proceed to observe, in a more ample Manner.

C H A P. XIX.

That Gravitation and Attraction direct all the Planets in their Courses.

ALMOST all the Theory of Gravity, according to *Descartes*, is founded upon this Law of Nature, that every Body which moves in a Curve Line, endeavours to move away from its Center in a right Line, which would touch the Curve in a Point. Such is the Sling, which escaping from the Hand at the Point B, would follow the Line B, C.

How we ought to understand the Theory of Gravity according to Descartes.



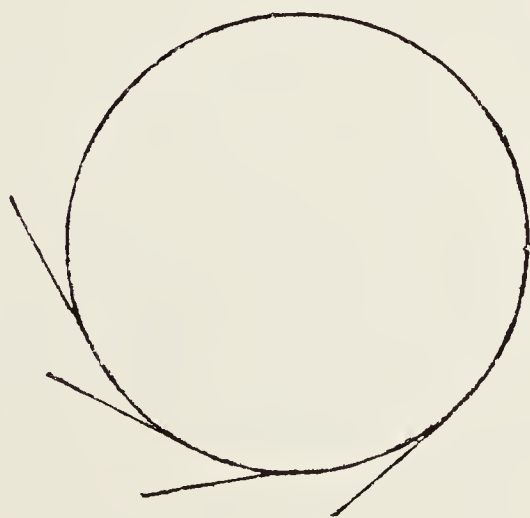
All Bodies, in turning with the Earth, endeavour thus to remove from the Center; but the subtile Matter, say they, making a much greater Effort, repels all other Bodies.

It is easy to perceive, that it could not be in the subtile Matter to make this greater Effort, and to remove itself from the Center of the pretended Vortex rather than other Bodies: On the contrary, it would be its Nature, (supposing it to exist) to make towards the Center of its Motion, and let the other Bodies, which are more compact and solid, move to the Circumference *. This is in Effect what happens upon a Table which is made to turn round, when in a Tube fixed thereon we put several Powers and Liquors, of Weights specifically different: All the most solid and weighty Bodies remove from the Center, and all the lightest approach it. Such is the Law of Nature; and when *Descartes* made his pretended subtile Matter to circulate the Circumference of his Vortex, he began by violating that Law of Centrifugal Forces, which he laid down as his first

* *Descartes* supposed these Particles of subtile Matter to be most hard and solid.

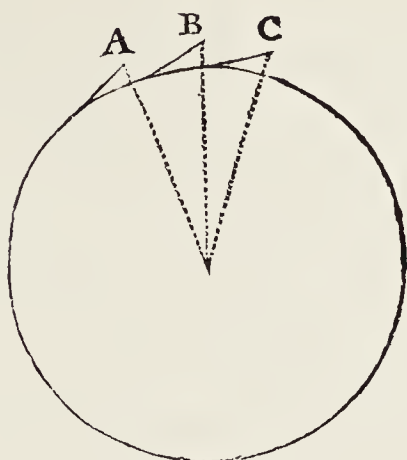
Principle. It was to little purpose his imagining that God had created Dice * turning against one another ; that the Rubbings of these Dice, which made his subtile Matter, dispersing on all sides, acquired thereby a swifter Motion ; that the Center of a Vortex incrustated itself, &c. These Imaginations were far from rectifying his Error.

Without losing more Time to combat these imaginary Beings, let us follow the mechanical Laws which operate in Nature. A Body which moves circularly, at every Point of the Curve which it describes, takes a Direction that would remove it out of the Circle, by making it follow a right Line, in this Manner.



* He does not call them Dice but Particles of various Figures. So

So far its true. But care must be taken that this Body do not thus remove from the Center, but by this other grand Principle : That every Body, being of itself indifferent with regard to Rest and Motion, and having that *Vis inertiae*, that Sluggishness which is an Attribute of Matter, follows necessarily the Line in which it is moved. Now every Body which turns round a Center, follows every Moment a right Line infinitely short, which would become a right Line infinitely long, if it met with no Obstacle. The Result of this Principle therefore, reduced to its just Value, is no more than this: That every Body which moves in a right Line, would always move in a right Line, if no Power acted upon it ; there is another Power wanting then, to make it describe a Curve: This other Power, therefore, by which it describes a Curve, would make it fall every Moment to the Center, in Case the projectile Motion in a right Line was to cease. In a Word, this Body would move, from Moment to Moment, to A, to B, to C, if freed from the latter Power.

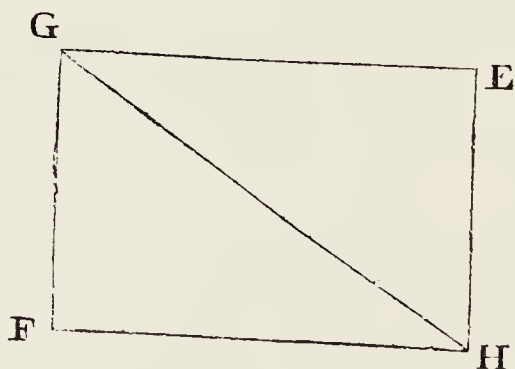


It would also, from Moment to Moment, fall from A, from B, from C, to the Center, if the other Power was wanting. The reason is, that its Motion is composed of two sorts of Motions, of a projectile Motion in a right Line, and also of an imprinted Motion in a right Line, by the Centripetal Force, a Force by which it would fall to the Center. Thus even from the Inclination of the Body to describe these Tangents A, B, C, it is demonstrable that there is a Power which draws it from these Tangents, even at the Instant that it begins them. It is absolutely necessary then, to consider every Body that moves in a Curve, as being moved by two Powers; one of which is, that which would make it describe Tangents, and

What is meant by the Centrifugal and Centripetal Forces.

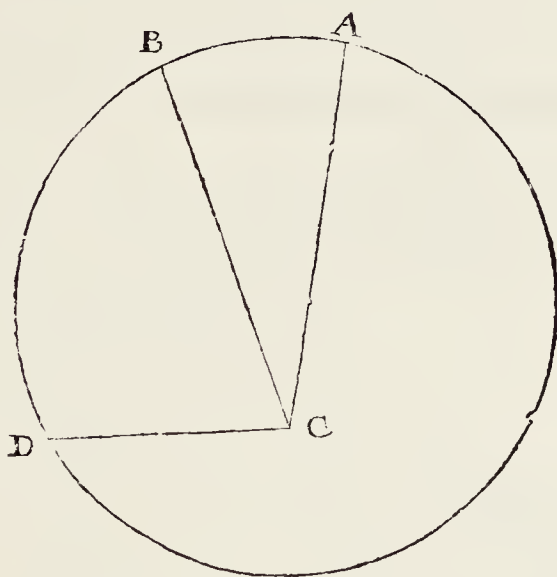
and which is called the Centrifugal Power, or rather the Power of resting, of Inactivity, by which a Body always follows a right Line, if it meets with no Obstruction ; the other is the Power which draws the Body towards the Center, which is called the Centripetal, and is the true Power.

It is thus that a Body, moved according to the horizontal Line G, E, and according to the Perpendicular Line G, F, obeys these Powers every Moment, by passing along the Diagonal G, H.



From the Establishment of this Centripetal Force, there results at first Sight of this Demonstration: That every Body which moves in a Circle, or in an Ellipsis, or in any Curve whatsoever, moves round a Center to which it tends.

It follows moreover; that this Body, what Portions of the Curve soever it may pass over, will always describe equal Areas in equal Times, both in its largest and smallest Arches. If, for Instance, a Body in one Minute describes the Space A, C, B, containing an hundred Miles of Area, it will in two Minutes describe the Space B, C, D, containing two hundred Miles.



This Law inviolably observed by all the Planets, and utterly unknown to Antiquity, was discovered about 150 Years ago by *Kepler*, who has merited the Name of *Legislator* in Astronomy, notwithstanding his Philosophical Errors. He could not, however, come
at

at the Reason of this Rule, to which all the Celestial Bodies are subject. The extreme Sagacity of *Kepler* discovered the Effect, of which the Genius of *Newton* has found out the Cause.

I shall now give the Substance of *Newton's* Demonstration, which will easily be comprehended by every attentive Reader: For Men have a natural Geometry in their Minds, which makes them lay hold of Proportions, when they are not too complicated. The Demonstration shall be found more at large in the Notes.



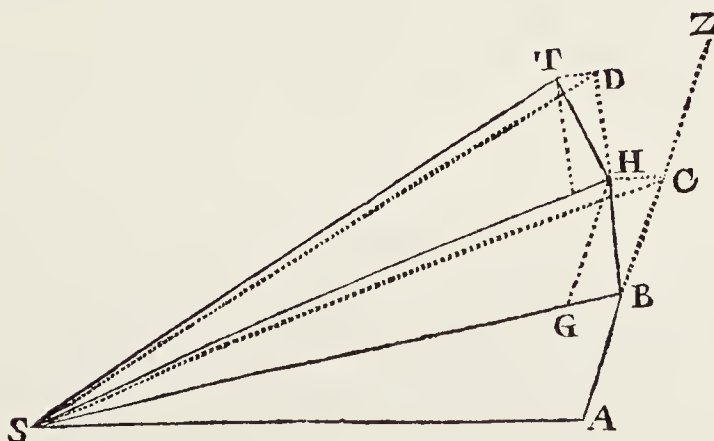
Let the Body A be moved to the Point B, in a very short Space of Time. At the End of an equal Space of Time, a Motion equally continued (for there is here no Acceleration) would bring it to the Point C: But in B it finds a Power which draws it in the Line B, H, S.

B, H, S. It does not follow then, either the Road B, H, S, or the Road A, B, C: Draw this Parallelogram C, D, B, H; and then the Body being moved by the two Powers passes along the Diagonal B, D. Now this Line B, D, and this B, A, being supposed infinitely short, make a Curve, &c. Therefore this Body necessarily moves in a Curve.

It

DEMONSTRATION.

That every moveable Body, drawn by a Centripetal Force, describes in a Curve Line, equal Areas in equal Times (1).



(1) All Bodies move in a uniform Motion, when there is no accelerating Force: Therefore the Body A, moved in a right Line in the first Space of time from A to B, will pass

This Demonstration proves that the Sun, and not the Earth, is the Center of the Universe.

It must surround equal Spaces in equal Times; for the Space of the Triangle S, B, A , is equal to the Space of the Triangle S, B, H : These Triangles are equal; therefore these Areas are equal; therefore every Body which surrounds equal Areas in equal Times, in a Curve, makes its Revolution round the Center of the Forces towards which it tends; therefore the Planets tend towards the Sun, turn round the Sun, and not the Sun round the Earth. For by taking the
Earth

pass in the same Time from C to Z . These Spaces being conceived equal, the Centripetal Force in the second Time gives a certain Motion, and the Body, instead of going to C , goes to H . Now what Direction has it had different from that of B to C ? Draw the four Lines, $C, H; G, B; C, B; G, H$; and you perceive the Body has followed the Diagonal of this Parallelogram B, H .

Now the two Sides of Parallelogram $B, C; B, G$; are in the same Plan as the Triangle A, B, S ; therefore the Forces are directed towards G, S , and towards the right Line A, B, C, Z .

The Triangles, $S, H, B; S, B, C$; are equal, because they are upon the same Basis S, B , and between the Parallels, $H, C; G, B$; but $S, B, A; S, C, B$; are equal, having the same Base, and the same Height; therefore $S, B, A; S, H, B$; are equal also.

The same may be said concerning the Triangles $S, T, H; S, D, H$; therefore all these Triangles are equal. Lessen the Height to Infinity, the Body; in every Space of Time infinitely small, will describe the Curve, whose Lines all tend to the Point S ; therefore in all these Instances, the Areas of these Triangles are proportional to the Times.

Earth for the Center, their Areas are found unequal in proportion to the Times; and in taking the Sun for the Center, these Areas are always found proportional to the Times; if you except only the small Irregularities, caused by the Gravitation of the Planets themselves.

The

DEMONSTRATION.

That every Body, describing in a Curve equal Triangles round a Point, is moved round that Point by a Centripetal Force (2).



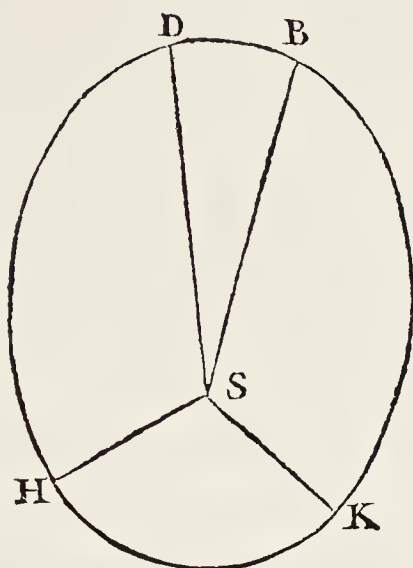
(2) Let this Curve be divided into equal Parts infinitely small, A, B; B, H; H, F; described in equal Times; let the Power be supposed to act at the same Points B, H, F; prolong A, B, to C, and B, H, to T; the Triangle S, A, B, will be equal to the Triangle S, B, H; for A, B, is equal to B, C; therefore S, B, H, is equal to S, B, C; therefore the Force in B, G, is parallel to that in C, H; but this Line B, G, parallel to C, H, is the Line B, G, S, tending

The better yet to understand what is meant by the Areas proportional to the Times, and to discover by Inspection the Advantage you may draw from this Knowledge, consider the Earth as carried in its Ellipsis round the Sun, S, its Center. When it goes from B to D, it encompasses as large a Space, as when it passes round the great Arch H, K: The Sector H, K, regains in Breadth what the Sector B, S, D, hath in Length. To make the Area of these Sectors equal in equal Times, the Body must pass much swifter from H to K, than from B to D. Thus the Earth, and every Planet, moves swifter in its Perihelion, which is the nearest Curve to the Sun, S, than in its Aphelion, which is the farthest Curve from the same Center S.

We

ing to the Center. The Body in H, is directed by the Centripetal Force along a parallel Line to F, T; in the same manner as in the Point B, it was directed by the same Force in a parallel Line to C, H: Therefore the Line parallel to F, T, will tend also towards S; therefore all Lines thus drawn, will tend to the Point S.

Conceive now to S, Triangles like those above; the smaller those Triangles above shall be, the more the Triangles to S, will approach to a physical Point, which Point S, will be the Center of the Forces.



We know then what is the Center of a Planet, and what Figure it describes in its Orbit, by the Areas that it furrounds: We know that every Planet, when it is farther from the Center of its Motion, gravitates less towards that Center. Thus the Earth being nearer the Sun by a thirtieth Part, that is by a million of Leagues, during our Winter than during our Summer, is more attracted also in Winter, and passes swifter then by reason of its Curve: Thus we have eight Days and a half more Summer than Winter, and the Sun appears in the Northern Signs eight Days and a half more than in the Southern. Therefore since every Planet follows,

It is for the preceding Reasons that we have more Summer than Winter.

lows, with regard to the Sun, its Center, that Law of Gravitation which the Moon experiences with regard to the Earth, and to which all Bodies are subject in falling upon the Earth, it is demonstrable that this Gravitation, this Attraction, acts upon all Bodies that are known to us.

But another powerful Demonstration of this Truth, is the Law that all the Planets follows respectively, in their Courses, and in Distances : This is what it is now incumbent on us to examine.

C H A P. XX.

Demonstration of the Laws of Gravitation, drawn from the Rules of Kepler: That one of these Laws of Kepler demonstrates the Motion of the Earth.

KEPLER found out another admirable Kepler's
Grand
Rule. Rule, of which I proceed to give an Example before I define it, in order to render the Thing more sensible and easy.

Jupiter has 4 Satellites, which make their Revolutions round him: The nearest is distant 2 Diameters and five sixths, from Jupiter's Body, which it furrounds in 42 Hours: The most remote makes its Revolution in 402 Hours, I would know how far distant this last Satellite is from the Center of Jupiter. To accomplish this, I lay down the following Rule: As the Square of 42 Hours, the Revolution of the first Satellite, is to the Square of 402 Hours, the Revolution of the last; so is the Cube of 2 Diameters and $\frac{5}{6}$ to a fourth Term. This fourth Term being found,

found, I extract its Cube Root, which Cube Root is found to be $12 \frac{1}{2}$: Thus I learn that the fourth Satellite is distant from the Center of Jupiter 12 and $\frac{1}{2}$ of his Diameters.

I make use of the same Rule for all the Planets which revolve round the Sun, I say; Venus revolves in 224 Days, and the Earth in 365: The Earth is 30 millions of Leagues from the Sun, how many Leagues then must Venus be? I answer; as the Square of the Earth's Year is to the Square of the Year of Venus, so the Cube of the Earth's mean Distance is to a fourth Term, whose Cubic Root will be about 21,700,000 Leagues, which make the mean Distance of Venus from the Sun. I say the same with regard to the Earth and Saturn, &c.

This Law then is, that the Square of a Revolution of any one Planet, is always to the Square of the Revolutions of the other Planets, as the Cube of its Distance is to the Cubes of the Distances of the others, from the common Center.

*Reasons
unworthy
of a Philo-
sopher, gi-
ven by
Kepler for
this admi-
rable Rule.*

Kepler, who found this Proportion, was very far from finding the Reason of it. Being less a good Philosopher than an admirable Astronomer,

stronomer, he says (in his 4th Book of his Epitome) that the Sun hath a Soul; not an intelligent Soul, *Animum*; but a vegetant, active Soul, *Animam*: That in turning round upon his own Axis, he draws the Planets to himself; but that the Planets do not fall on the Sun, because they also revolve upon their Axis. In making this Revolution, says he, they present to the Sun sometimes a friendly, and sometimes a hostile side; the friendly side is drawn, and the hostile side is repell'd; which produces the annual Courses of the Planets in the Ellipses.

It must be confessed, for the Humiliation of Philosophy, that it was from this Reasoning, so very unphilosophical, that he concluded the necessity of the Sun's turning round on its Axis. Error accidentally conducted him to Truth; he conjectured the Rotation of the Sun on itself, above 15 Years before the Eyes of *Galileo* discovered it by the Help of Telescopes.

Kepler adds (in the same Book, p. 495) that the Mass of the Sun, the Mass of all the Ether, and the Mass of the Spheres of the fix'd Stars, are perfectly equal; and that
they

they are the three Symbols of the Holy Trinity.

The Reader, who, in reading over these Elements, shall have seen such extravagant Dreams, on the side of such sublime Truths, in so great a Man as *Kepler*, in so profound a Mathematician as *Kircher*, ought not to be surprized at it : A Man may be a great Genius with regard to Calculations and Observations, and make a wrong use of his Reason on other Accounts: There are Minds which have need of Geometry to support them, and which fall when they endeavour to proceed of themselves. It is not surprizing therefore that *Kepler*, in discovering these Astronomical Laws, did not find out the Reason of them.

*The true
Reason of
this Law
found by
Newton.*

This Reason is, that the Centripetal Force is precisely in the reciprocal Proportion of the Square of the Distance from the Center of Motion, towards which these Forces are directed : This is what we are to observe attentively: In a Word, we ought thoroughly to understand, that the Law of Gravitation is such, that every Body which approaches 3 Times nearer to the Center of its Motion,
gravi-

gravitates nine Times more ; that if it removes three times farther distant, it will gravitate nine Times less ; and that if it removes to an hundred Times the Distance, it will gravitate less 10,000 Times.

A Body moving circularly round a Center, gravitates then in the reciprocal Proportion of the Square of its actual Distance from the Center, as also in direct Proportion of the Quantity of its Matter : It is demonstrable then, that it is Gravitation which occasions its Revolution round the Center, since without this Gravitation it would remove from it, by describing a Tangent. This Gravitation therefore will be found to act most strongly upon a Body which revolves with most Velocity round the Center ; and the farther this Body shall be removed, the more slowly will it turn, for then it will become the less ponderous.

It is for this Reason that the Earth, tho' 1170 Times less than *Jupiter*, does nevertheless weigh but 8 Times less than *Jupiter* upon the Body of the Sun ; and this in direct Proportion of the Quantity of Matter in these Planets, and in reciprocal Proportion of the Squares of their Distances from the Sun.

Thus

Recapitulation of the Proofs of Gravitation.

Thus have we demonstrated this Law of Gravitation, in Proportion to the Squares of Distances ;

1. By the Orbit which the Moon describes, and by her Distance from the Earth, or Center.

2. By the Course of every Planet round the Sun in an Ellipsis.

3. By the Comparifon of the Distances and Revolutions of all the Planets round the common Center.

These Discoveries of Newton and Kepler serve to demonstrate that it is the Earth which turns round the Sun.

It will not be superfluous to remark, that this fame Rule of *Kepler*, which serves to confirm the Discovery of *Newton* concerning Gravitation, confirms also the System of *Copernicus* concerning the Motion of the Earth.

It may be said that *Kepler*, by this fingle Rule, has demonstrated what was discovered before him, and opened the Way to those Truths which were to be discovered in after Times. For as on the one Side it is demonstrable, that if the Law of centripetal Forces had no Place, *Kepler's* Rule would be impossible: On the other it is demonstrable, that according to the fame Rule, if the Sun turned round the Earth, we ought to say; As the

Revo-

Revolution of the Moon round the Earth, is to the pretended annual Revolution of the Sun round the Earth so is the square Root of the Cube of the Moon's Distance from the Earth, to the square Root of the Cube of the Sun's Distance from the Earth. By this Calculation it would be found, that the Sun is only 510,000 Leagues from us; but it has been proved, that he is distant at least about 30 Millions of Leagues: Thus the Motion of the Earth then has been strictly demonstrated by *Kepler*. Here follows another very simple Demonstration, drawn from the same Reasons.

If the Earth was the Center of the Sun's Motion, as it is of the Moon's, the Sun's Revolution would take up 475 Years, instead of one Year: For the mean Distance of the Sun from the Earth, is to the mean Distance of the Moon from the Earth as 337 is to one: Now the Cube of the Moon's Distance is 1, the Cube of the Sun's Distance is 38272753: Finish the Rule, and say, As the Cube 1 is to this Cube Number 38272753; so the Square of 28, which is the periodical Revolution of the Moon, is to a fourth Number:

Demonstration of the Motion of the Earth, drawn from the same Laws.

You

You will find that the Sun would employ 475 Years, instead of one Year, in making its Revolution round the Earth: Which demonstrates, that it is the Earth which turns.

It seems by so much the more proper to Place these Demonstrations here, as there yet are Men destined for the Instruction of Youth, in *Italy*, in *Spain*, in *France*, and even in *England*, who doubt, or who affect to doubt, of the Earth's Motion.

It is proved then by *Kepler's* Law, and by that of *Newton*, that every Planet gravitates towards the Sun, the Center of the Orbits which they describe: These Laws are fulfilled in the Satellites of Jupiter, with regard to Jupiter, their Center; in the Moons of Saturn, with regard to Saturn, and in our Moon, with regard to us: All these secondary Planets, which roll round their central Planets, gravitate also with their central Planets towards the Sun: Thus the Moon, which is drawn round the Earth by the centripetal Force, is at the same Time drawn by the Sun, round which she makes her Revolution. There is no Variety in the Moon's Course, in her Distances from the Earth, in the Fi-
gure

gure of her Orbit, sometimes approaching to an Ellipsis, sometimes to a Circle, &c. which is not from Gravitation, in proportion to her Distance from the Earth, and her Distance from the Sun.

If she does not always, in her Orbit, exactly describe equal Areas in equal Times, Sir *Isaac Newton* has calculated all the Cases where this Inequality must happen: They all depend on the Attraction of the Sun, which draws these two Globes in direct Proportion of their Masses, and in reciprocal Proportion of the Squares of their Distances. We shall see, in the next Chapter, that the smallest Variation of the Moon, is a necessary Effect of these united Powers.

C H A P. XXI.

New Proofs of Attraction. That the Inequalities of the Motion and Orbit of the Moon are necessarily the Effects of Attraction.

THE Moon hath only one equal Motion, that of Rotation round herself on her own Axis; and this is her only Motion which we cannot perceive: It is this Motion that presents us always, within a Trifle, with the same Disc of the Moon; so that while she really turns round upon herself, she appears not to turn at all, and to have only a small Motion of Balancing, of Libration, which she has not, but which all Antiquity attributed to her.

All her other Motions round the Earth are unequal, and ought so to be, if the Rule of Gravitation be true. The Moon, in her Monthly Course, is necessarily nearer the Sun in one certain Point, and at one certain Time of her Course: Now in this Point, and at this Time, her Quantity of Matter remains
the

the same: Her Distance only being changed, the Attraction of the Sun ought to change in reciprocal Proportion of the Square of this Distance: The Course of the Moon ought then to change; she ought to move swifter at certain Times, than the Attraction of the Earth alone occasions her to move: Now by the Attraction of the Earth she ought to pass over equal Areas in equal Times, as you have already observ'd in Chap. 19.

One cannot help admiring the Sagacity with which Sir *Isaac Newton* has cleared up all these Inequalities, and regulated the Course of this Planet, which remained a Secret before, after all the Researches of Astronomers: It is upon this Account, above all, that we may say :

Nec propius fas est mortali attingere Divos.

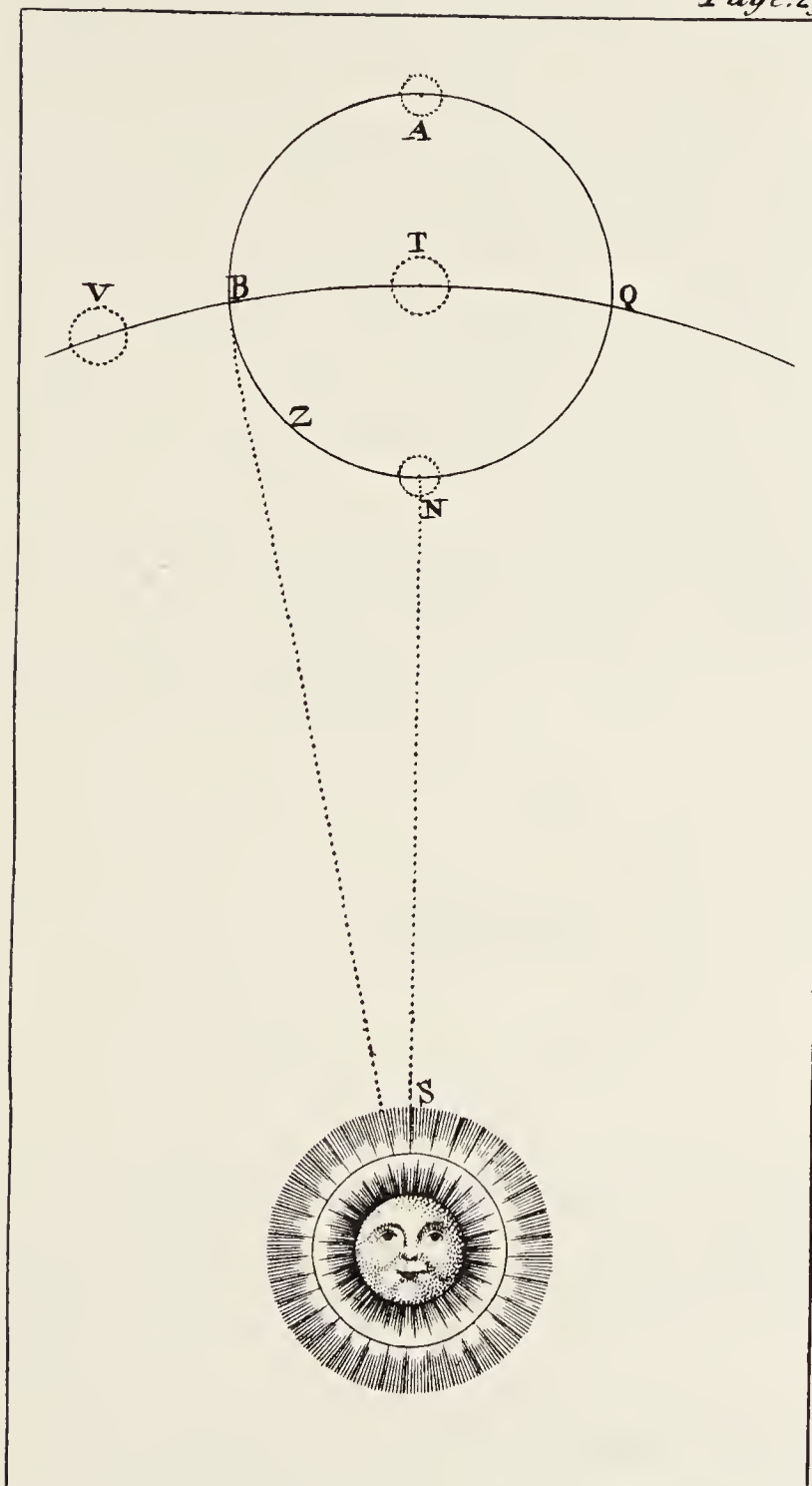
Among the Examples that may be chosen, *Proof by an Example.* let us take this: Let A be the Moon; A, B, N, Q, the Orbit of the Moon; S, the Sun; B, the Place of the Moon in her last Quarter.

She is now manifestly at the same Distance from the Sun as the Earth. The Difference of the Obliquity of her Line of Direction to the

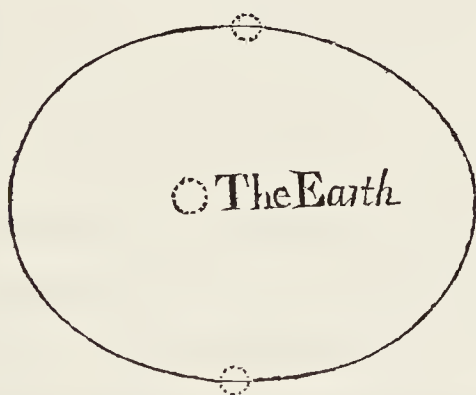
the Sun being counted for nothing, the Gravitation of the Earth and of the Moon towards that Luminary is apparently the same. The Earth, however, advances in its annual Course from T to V, and the Moon in her Monthly Course advances to Z. Now in Z it is manifest that she is more drawn by the Sun, S, to which she finds herself nearer than the Earth : Her Motion then will be accelerated from Z towards N, and the Orbit that she describes will be changed : But how will it be changed ? In being flattened a little, in approaching more to a right Line from Z towards N. Thus, from Moment to Moment, Gravitation changes the Course and Form of the Ellipsis, in which this Planet moves.

By the same Reason the Moon ought to slacken her Course, and to change again the Figure of the Orbit that she describes, when she returns from her Conjunction N, to her first Quarter Q ; for since from her last Quarter she accelerated her Course, by flattening the Curve towards N, her Conjunction ; she ought to slacken the same Course by swelling out the Curve, in returning from her Conjunction to her first Quarter.

But



But when the Moon ascends from this first Quarter towards her Full, A, she being then farther from the Sun, is less attracted by it, and gravitates more towards the Earth. Then the Moon accelerating her Motion, the Curve that she describes is again flattened a little, as in her Conjunction. And this is the only Reason for which the Moon is farther from us in her Quarters, than in her Conjunction and Opposition. The Curve that she describes is a kind of Oval, approaching to a Circle, almost in this Manner.



Thus the Sun then, to which she approaches, or from which she recedes at every Instant, must at every Instant vary the Course of this Planet.

She hath also her Apogæon and her Perigæon, her greatest and her least Distance from the Earth: But the Points, the Places of this Apogæon

The Inequalities of the Moon's Course all caused by Attraction.

gæon and Perigæon, must necessarily change.

She hath her Nodes, that is to say, the Points where the Orbit she describes meets precisely the Orbit of the Earth : But these Nodes, these Points of Intersection, must also continually vary.

She hath her Equator, inclined to the Equator of the Earth : But this Equator, sometimes more and sometimes less attracted, must likewise change its Inclination.

She follows the Earth notwithstanding all these Varieties, and accompanies it in its annual Course : But the Earth, in this Course, is found to be a Million of Leagues nearer the Sun in Winter than in Summer. What is the Consequence of this, independent of all these other Variations ? The Attraction of the Earth acts more fully upon the Moon in Summer, and then the Moon finishes her Monthly Course a little sooner : But, on the contrary, in the Winter, the Earth itself being more attracted by the Sun, and moving with greater Velocity than in Summer, suffers the Motion of the Moon to diminish, and her Winter Months to be a small Matter longer than her Summer ones. The little
that

that we say of them, may suffice to give a general Idea of these Changes.

If any one should here start the Difficulty, which I have heard sometimes proposed, why the Moon, when she is most attracted by the Sun, does not fall upon that Luminary? We have only to consider for the present, that the Force of Gravitation, which directs the Moon round the Earth, is only diminished here by the Action of the Sun *: We shall see farther in the Article of Comets, why a Body which moves in an Ellipsis, and approaches its Center, nevertheless does not impinge upon this Center.

From these Irregularities of the Lunar Course, caused by Attraction, you will reasonably conclude, that no two Planets sufficiently near, sufficiently large to act upon one another sensibly, can at any Time move round the Sun in Circles, or even in Ellipses absolutely regular. Thus the Curves described by Jupiter and Saturn, for Example, are subject to sensible Variations, when these Pla-

*Deduction
from these
Truths.*

* The Distance of the Moon from the Sun being vastly greater than from the Earth, she is attracted as much by the Earth as to overcome that of the Sun, and to balance the centrifugal Force.

nets are in Conjunction ; when, being the nearest that possibly they can be to each other, and the farthest from the Sun, their mutual Action augments, and that of the Sun on them diminishes.

Gravitation is not the Effect of the Planets Courses, but their Courses are the Effect of Gravitation.

This Gravitation then, augmented and lessened in proportion to the Distances, necessarily assigns an irregular elliptical Figure for the Way of the greatest Part of the Planets : Thus the Law of Gravitation is not the Effect of the Planetary Courses, but the Orbits which the Planets describe are the Effect of Gravitation. If this Gravitation was not, as it really is, in reciprocal Proportion of the Squares of Distances, the present Order of the Universe could not subsist.

If the Satellites of Jupiter and Saturn make their Revolution in Curves which approach nearer to a Circle, it is because being very near the great Planets that are their Center, and very far from the Sun, the Action of the Sun cannot change the Course of these Satellites, as it changes that of our Moon. It is manifest then, that Gravitation, the Name of which alone seems such a strange Paradox, is a necessary Law in the Constitution of the
World :

World: So true, very often, is a thing that hardly has the Appearance of Probability!

Let us remember here, how absurd the Opinion formerly seemed, that the Earth was not spherical; and yet it has been proved, that the Earth cannot have an entirely spherical Form; The like may be said concerning Gravitation.

There is not at present any good Naturalist, who does not acknowledge both *Kepler's Rule*, and the Necessity of admitting a Gravitation such as *Newton* has proved: But there are yet some Philosophers attached to their Vortices of subtile Matter, who would willingly reconcile these imaginary Vortices with these other demonstrable Truths.

We have already seen, how far these Vortices are from being probable: But this Gravitation itself, does it not furnish a fresh Demonstration against them? For supposing that these Vortices existed, they could not turn round a Center but by the very Laws of this Gravitation. We must have recourse to Gravitation, as the Cause of these Vortices, and not to the pretended Vortices as the Cause of Gravitation.

This Gravitation, this Attraction, may be a first Principle established in Nature.

If

If at last, being forced to abandon their imaginary Vortices, these Gentlemen are reduced to say that this Gravitation, this Attraction, depends on some other Cause, or some other secret Property of Matter; either that Property will itself be the Effect of some other Property unknown, or else it will be a primary Cause, a first Principle established by the Author of Nature: Now why may not the Attraction of Matter itself be this first Principle*?

* Some tell us that Matter being purely passive cannot be an active Principle, else it might move itself as well as draw; we must then say it is so, because God would have it so, and so it's not an intrinsic essential Property; for the Sun repels the Light from it, and the Particles of Air one another in Rarefaction: Thus God the General in the Universe gives different Orders to different Bodies.

C H A P. XXII.

New Proofs and new Effects of Gravitation. That this Power is in every Particle of Matter. Discoveries dependent on this Principle.

WE may collect from all these Notions, that the Centripetal Force, Attraction, Gravitation, is the indubitable Principle of the Planetary Courses *, of the Descent of all Bodies, and of that Ponderosity which we experience in Bodies. This Centripetal Force, this Attraction, is not, nor can be, the simple Power of one Body to draw another to itself: We shall consider it here as a Power, from which results the Motion round a Center: This Power causes the Sun to gravitate towards the Center of the Planets, as the Planets gravitate towards the Sun, and draws the Earth towards the Moon, as well as the Moon towards the Earth.

One of the primitive Laws of Motion, is yet a fuller Demonstration of this Truth.

* It is in Conjunction with the Projectile Force.

This Law is, that Re-action is equal to Action: Thus if the Sun gravitates on the Planets, the Planets gravitate on the Sun; and we shall see at the Beginning of the following Chapter, in what manner this great Law operates.

Now this Gravitation acting necessarily in direct proportion of the Quantity of Matter, and the Sun being about 760 Times as massy as all the Planets put together (without reckoning the Satellites of Jupiter, and the Ring and Moons of Saturn) it follows that the Sun must be their Center of Gravitation, and consequently, that they must revolve round that Luminary.

*A general
and impor-
tant Re-
mark con-
cerning the
Principle of
Attraction.*

Let us carefully remark, that, when we say, the Power of Gravitation acts in direct Proportion of the Quantities of Matter, we always understand that this Power of Gravitation acts so much the more strongly on a Body, as this Body has a greater number of Particles; and we have demonstrated it, in shewing that a Straw descends as swiftly in the Machine purged of Air, as a Pound of Gold. We have said (making Allowance only for the small Resistance of the Air) that a leaden Ball, for Ex-ample,

ample, falls fifteen Feet in one Second upon the Surface of the Earth : We have demonstrated, that this same Ball would fall only fifteen Feet in a Minute, if it was removed from the Earth, as the Moon is, 60 of the Earth's Semidiameters : Therefore the Power of the Earth upon the Moon is to the Power that it would have upon a leaden Ball transported to the Elevation of the Moon, as the solid Body of the Moon would be to the solid Body of this Ball. It is in this Proportion that the Sun acts upon all the Planets; he draws Jupiter and Saturn, and the Satellites of Jupiter and Saturn, in direct proportion of the Quantity of solid Matter that is in each of these primary and secondary Orbs.

From hence flows an incontestible Truth ; that this Gravitation is not only in the whole Mass of every Planet, but in every Particle of that Mass ; and that thus there is not an Atom of Matter in the Universe, but what is invested with this Property.

From among the Methods in which *Newton* has demonstrated that Gravitation is equally in every Atom, we will chuse here the most simple. If all the Parts of a Globe had

Gravitation, Attraction, is equally in all the Particles of Matter.

not

not equally this Property, if there were some weaker and some stronger Particles, a Planet, in turning upon its own Axis, would necessarily present sometimes weaker and sometimes stronger sides at the same Distance: Thus the same Bodies, on all possible Occasions, would experience at an equal Distance, now one Degree of Gravitation, now another: The Law of reciprocal Proportion of the Squares of Distances, and the Law of *Kepler*, would be always inverted, or proved not to subsist: Therefore there is not, in all the Planets, any one Particle of Matter that gravitates more than another.

Here follows another Demonstration of the same Truth. If there were Bodies in which this Property was different, some Bodies would fall more slowly, others more swiftly, in the empty Air-Pump. But all Bodies fall in the same Time; and all Pendulums of equal Length, whether of Gold, of Silver, of Iron, of Maple-wood, or of Glass, make equal Vibrations in the Air in equal Times: Therefore all Bodies have this Property of Gravitation precisely in the same Degree, that is, precisely in proportion to their
 Mass,

Mafs; fo that Gravitation acts as a hundred upon a hundred Atoms, and as ten upon ten Atoms.

From Truth to Truth the human Mind riles infenfibly to fuch fublime Points of Knowledge, as feem to be entirely out of its Sphere.

Sir *Isaac Newton* has ventured, by the help only of the Laws of Gravitation, to calculate what muft be the Weight of Bodies in other Globes befides this which we inhabit; what the fame Body, for Inftance, which we here call a Pound, muft weigh in the Moon, in Saturn, in the Sun: And as thefe different Weights depend directly on the Quantity of Matter in thefe Globes, it was neceffary to calculate what that Quantity is. Let it not be faid, after this, that Gravitation, that Attraction is an occult Quality: Let not any one dare to call by this Name an univerfal Law, which leads to fuch aftonifhing Discoveries!

A bold and admirable Calculation of Newton.

There is nothing more eafy than to know the Magnitude of any Celeftial Orb, from the Moment that its Diameter is known: For the Product of the Circumference of the great Circle by the Diameter, gives the Surface of
the

the Globe; and the third of the Product of this Surface by the Semi-diameter, shews the Magnitude.

But by knowing the Magnitude, we learn nothing at all of the Quantity of Matter which this Orb contains. This too may be known, by that admirable Discovery of the Laws of Gravitation.

How to know the Quantity of Matter in a Globe, and what the same Bodies weigh upon distant Globes.

1st, *When the Density, or Quantity of Matter of any Globe is mentioned, we suppose that the Matter of this Globe is homogeneous; for Example, that every Cubic Foot of this Matter is equally weighty.*

2dly, *Every Globe attracts in direct proportion of the Quantity of its Mass: Thus, all things equal, a Globe which shall have 10 Times more Matter, will attract, at the same Distance, 10 Times more strongly than one of but a 10th Part of the Substance.*

3dly, *It is absolutely necessary to consider the Magnitude of the Circumference of the Globe under Examination: For the larger the Circumference, the more the Distance from the Center augments, and it attracts in reciprocal Ratio of the Square of this Distance. If the Diameter of the Planet A, for Instance, is four Times larger*

larger than that of the Planet B, both having an equal Quantity of Matter; the Planet A, will attract Bodies to its Surface 16 Times less than the Planet B, and that which weighs a Pound upon the Planet A, will weigh 16 Pounds upon the Planet B.

4thly, It must be known, above all, in how long Time the Bodies attracted by the Globe, whose Density we enquire after, make their Revolution round this Globe: For, as we have seen in Chap. XIX. every Body circulating round another, gravitates the more, the more swiftly it turns: Now it must be for one of these two Reasons that it gravitates the more, either because it approaches nigher the Center which attracts it, or because this attracting Center contains more Matter. If I would know, therefore, the Density of the Sun, in comparison with the Density of the Earth, I must compare the Time of the Revolution of some Planet, as Venus, round the Sun, with the Course of the Moon round our Earth, and the Distance of Venus from the Sun, with the Distance of the Moon from the Earth.

5thly, I proceed thus. The Quantity of the Sun's Matter, in comparison with that of the Earth,

The Elements of

Earth, is as the Cube of the Distance of Venus from the Center of the Sun to the Cube of the Moon's Distance from the Center of the Earth, (taking the Distance of Venus from the Sun to be 257 Times as great as that of the Moon from the Earth) and also in reciprocal Proportion of the Square of the periodical Revolution of Venus round the Sun, to the Square of the periodical Revolution of the Moon round the Earth.

This Operation being made, supposing always that the Sun is in Magnitude to the Earth as a Million to one, and counting still in round Numbers, you will find that the Sun, a Million of Times larger than the Earth, contains only 250,000 Times as much Matter, or thereabouts.

This being supposed, I would know what Proportion is found between the Force of Gravitation on the Surface of the Sun, and that same Force on the Surface of the Earth; I would know, in a Word, how much that Body which weighs a Pound here, would weigh upon the Sun.

To come at this, I say; the Force of this Gravitation depends directly on the Density of the

the attracting Globes, and on the Distance of the Center of these Globes from the ponderous Bodies on their Surface. Now the Distance between the Bodies and the Center, is precisely the Semi-diameter of the Globes : But the Semi-diameter of the Globe of the Earth is to that of the Sun as 1 to 100, and the respective Density of the Earth is to that of the Sun as 4 to 1 : Then I say ; as 100, the Semi-diameter of the Sun, multiplied by 1, is to 4, the Density of the Earth, multiplied by 1 ; so is the Weight of Bodies upon the Surface of the Sun to the Weight of the same Bodies upon the Surface of the Earth. This proportion between 100 and 4, being reduced to other Terms, is as 25 to 1 : A Pound, therefore, weighs 25 Pounds upon the Surface of the Sun ; which answers my Question.

I have supposed here the respective Densities of the Earth and Sun to be as 4 to 1 ; but this is not the exact Proportion : The Weight of Bodies, therefore, upon the Surface of the Sun, is to that of Bodies upon the Earth, not as 25, but as 24 to 1.

We cannot have the same Notions concerning all the Planets ; for those which have

no Moons, no Satellites, being destitute of Orbs of Comparison, cannot be subject to our Researches : Thus we know not the Proportion of Gravity, that subsists between Mercury, Mars, Venus, and us, but we know that of the other Planets.

I proceed to give a short Theory of all our Planetary World, such as the Discoveries of Sir *Isaac Newton* make it appear to us. Those who would become Masters of the more profound Reason of these Calculations, may read Sir *Isaac* himself, or Mr. *Gregory*, or Mr. *Gravesande*. The Reader need only be informed, that in following the Proportions discovered by *Newton*, we have kept to the Astronomical Calculation of the *Paris* Observatory. Whatever the Calculation may be, the Proportions and Proofs are the same.

C H A P. XXIII.

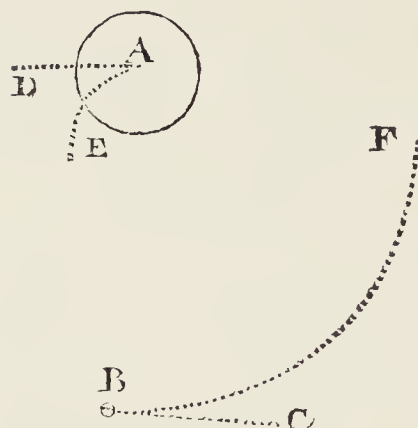
The Theory of our Planetary World.

The SUN.

THE Sun is the Center of our Planetary World, and ought necessarily to be there. We do not mean by this, that the middle Point of the Sun is precisely the Center of the Universe ; but that the central Point towards which our Universe gravitates, is necessarily in the Body of that Luminary, and all the Planets, having once received their projectile Motion, must continually turn round this Point, which is in the Sun. We prove it thus.

Let the greatest of these two Globes, A, and B, represent the Sun, and the least any Planet whatsoever. If they are both abandoned to the Law of Gravitation, and free from all other Motion, they will be attracted in direct Proportion of their Quantity of Matter ; they will be determined towards one another in a straight Line ; and A, being a Million of Times larger than B, will force B to move towards it a Million of Times faster than A will move towards B.

But



*Demon-
stration of
the Earth's
Motion
round the
Sun,
drawn
from the
Law of
Gravita-
tion.*

But let them both have a projectile Motion, in proportion to their Masses*, the Planet in the Line B, C, the Sun in the Line A, D, and then the Planet is under two Forces; it tends in the Line B, C, and gravitates at the same time towards the Sun in the Line A, B: It will therefore describe the Curve B, F; and the Sun, in like manner, will follow the Line A, E; and both, gravitating towards each other, will turn round a common Center: But the Sun surpassing the Earth in Magnitude a Million of Times, and the Curve A, E, which he will describe, being a Million of Times less than that which the Earth describes, this common Center is necessarily near the Middle of the Sun.

* The Sun can have no projectile Force, not from the Earth; for the Earth hath it not from the Sun, but from an intelligent Being.

It

It is hereby again demonstrated, that the Earth and the Planets turn round this Luminary: And this Demonstration is by so much the more beautiful and strong, as it is entirely independent on Observation, and founded upon the primordial Mechanism of the World.

If we make the Diameter of the Sun equal to 100 Diameters of the Earth, and if consequently, the Sun surpasses the Earth a Million of Times in Magnitude; it will follow, he is 760 times larger than all the Planets together, leaving out the Satellites of Jupiter and Saturn's Ring. He gravitates towards the Planets, and the Planets too gravitate towards him; it is this Gravitation that makes them circulate, by drawing them from a Tangent*; and the Attraction which the Sun exercises upon them, surpasses that which they exercise upon him, as much as he surpasses them in Quantity of Matter. Never lose Sight of this Truth, that reciprocal Attraction is nothing but the Law of moveable Bodies, all gravitating, and all turning round one common Center.

*The Sun's
Magni-
tude.*

* Nothing determines the Sun to move in a Tangent.

*He turns
on his own
Axis round
the common
Center of
the Plane-
tary World.*

The Sun then turns round this common Center, that is, upon his own Axis, in 25 Days and $\frac{1}{2}$. His middle Point is always a little distant from this common Center of Gravity, and his Body removes from it in proportion as several Planets in Conjunction attract him towards them: But if all the Planets were on one Side, and the Sun on the other, the common Center of Gravity would hardly be out of the Sun's Body; their united Forces being scarcely sufficient to disorder and remove the Sun one entire Diameter.

*He conti-
nually
changes
Place.*

He really changes Place then every Moment, according as he is more or less attracted by the Planets; and this little Approach of the Sun re-establishes that Disorder which the Planets operate on one another: Thus the continual Irregularity of this Luminary preserves the Order of Nature.

Tho' he surpasses the Earth in Magnitude a Million of Times, he contains not a Million of Times as much Matter, as was before said.

If he was actually a Million of Times more solid, more compact than the Earth, the Order of the World would not be what it now

is:

is: For the Revolutions of the Planets, and their Distances from their Center, depend on their Gravitation, and their Gravity is in direct Proportion of the Quantity of Matter in the Globe which is their Center: Therefore if the Sun surpassed our Earth and our Moon in solid Matter to such a great Excess, the Planets would be much more attracted, and their Ellipses much less regular, than they are at present.

In the second Place, the Matter of the Sun cannot be in proportion to his Magnitude; for his Globe being all on fire, its Rarefaction is necessarily very great, and the Matter ^{*His Density.*} is less in proportion as the Rarefaction is greater.

By the Laws of Gravitation it appears, that the Sun contains but 250,000 Times as much Matter as the Earth: Now the Sun, a Million of Times larger, being but the fourth Part of a Million more material than the Earth; the Earth, a Million of Times less, has in Proportion four Times as much Matter as the Sun, and is four Times as dense.

The same Body, according to this Computation, which weighs a Pound upon the
Sur-

Surface of the Earth, would weigh 25 Pounds upon the Surface of the Sun : But the true Proportion is only of 24 to 1, because the Earth is not in Effect four Times as dense as the Sun, and because the Diameter of the Sun surpasses that of the Earth only 95 Times and an half.

*In what
Proportion
Bodies de-
scend upon
the Sun.*

The same Body which descends here 15 Feet in the first second, would descend about 350 Feet upon the Surface of the Sun, all other things being equal.

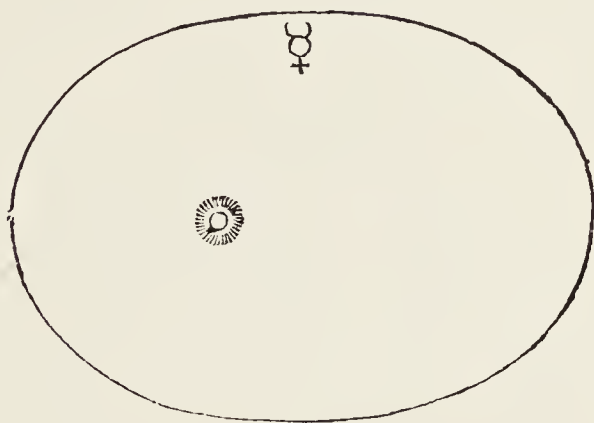
The Sun loses daily, according to Sir *Isaac*, a little of his Substance, and would be in the Revolution of many Ages reduced to nothing, if the Comets, which from Time to Time impinge on his Sphere, did not serve to repair his Losses ; for every thing in the Universe alters, and is repaired.

MERCURY.

From the Sun to the Distance of eleven or twelve Millions of *French* Leagues, or thereabouts, there does not appear any Globe.

At 11 or 12 Millions of Leagues from the Sun is Mercury, in his mean Distance. This is the most excentric of all the Planets ; he
turns

turns in an Ellipsis, which puts him in his Perihelion near a third Time nearer the Sun than in his Aphelion: Such is, within a Trifle, the Curve that he describes.



Mercury is almost 27 Times less than the Earth: He turns round the Sun in 88 Days, which constitute his Year.

His Revolution upon his own Axis, which makes his Day, is unknown; nor can either his Weight, or his Density, be ascertained. We only know, that if Mercury be an Earth exactly like ours, the Matter of its Globe must be about 8 Times more dense than ours: Otherwise, every thing there would be in such a Degree of Effervescence, as would destroy Animals of our Species in an Instant, and

Newton's
Idea con-
cerning the
Density of
Mercury.

cause

cause all Matter of the Consistence of the Waters on our Globe to evaporate.

Here follows a Proof of this Assertion. Mercury receives about 7 Times more Light than we, in Proportion to the Square of Distances, because it is about $2\frac{2}{3}$ Times nearer the Center of Light and Heat ; it is therefore 7 Times more suffocated, all things being equal. Now upon our Earth the great Heat of Summer being augmented 7 or 8 Times, makes the Water boil up immediately in large Bubbles : Therefore it is necessary that every thing should be about 7 Times more dense than it is, to resist 7 or 8 Times as much Heat as the most scorching Summer produces in our Climates : Therefore Mercury ought to be at least 7 Times more dense than our Earth, to make it possible for the same Things as subsist in our Earth to subsist in the Globe of Mercury, all things being equal. Finally, if Mercury receives about 7 Times more Rays than our Globe, because it is about $2\frac{2}{3}$ Times nearer the Sun ; by Parity of Reason, the Sun appears in Mercury 7 Times larger than on our Earth.

VENUS.

After Mercury is Venus, at between 21 and 22 Millions of Leagues from the Sun in its mean Distance: It is as large as the Earth, and its Year consists of 224 Days. We do not yet know the Length of its Day, that is, of its Revolution on its own Axis. Very great Astronomers believe this Day to be only 23 Hours; others lengthen it to 25 of our Days. There have not hitherto been made any Observations, sufficiently certain to shew on which Side is the Error: But this Error, wherever it be, can be only a Mistake of the Eyes, an Error of Observation, and not of Judgment.

The Ellipsis which Venus describes in its Year, is less eccentric than that of Mercury: One may form to himself some Idea of the Way of these two Planets round the Sun, from the subsequent Figure.

It



*Prediction
of Coper-
nicus con-
cerning the
Phases of
Venus.*

It is not foreign to our Purpose to remark here, that Venus and Mercury have different Phases with regard to us, as well as the Moon. *Copernicus* was formerly reproached, for that these Phases ought to appear in his System; which it was concluded was false, because no such Phases could be perceived. If Venus and Mercury, said his Antagonists, turn round the Sun, and we turn in a greater Circle, we ought to see Venus and Mercury, sometimes full, sometimes increasing, &c. but this is what we have never seen. It is nevertheless what really happens, answered *Copernicus*, and what you will see hereafter, if ever you find Means to make your Sight more perfect. The Invention of Telescopes, and the Observations of *Galileo*, conspired soon after to accomplish the Prediction of *Copernicus*.

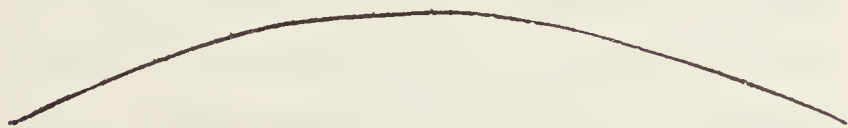
pernicus. As to other Particulars, nothing certain can be said concerning the Quantity of Matter in Venus, or the Ponderosity of Bodies on this Planet.

The EARTH.

Next after Venus is placed the Earth, at 30 Millions of Leagues from the Sun, or thereabouts, at least in its mean Distance.

It is near a million of Times less than the Sun, towards which it gravitates, and round which it revolves in an Ellipsis in 365 Days, 5 Hours, and 48 Minutes; travelling at least 180 Millions of Leagues every Year. The Ellipsis which it describes is very irregular, on Account of the Moon's Action upon it; so that while the common Center of the Earth and the Moon describes a true Ellipsis, the Earth actually describes the following Curve every Lunar Revolution.

The insensible Curve which the Earth describes each Lunation.



The

*What is
the Cause
of the Di-
urnal Ro-
tation of
the Earth.*

The Earth's Rotation upon its own Axis from West to East constitutes its Day of 23 Hours, 56 Minutes. This Motion is not the Effect of Gravitation. It seems impossible here, in particular, to have Recourse to that sufficient Reason spoken of by that great Philosopher *Leibnitz*. It is absolutely necessary to confess, that the Planets and the Sun might as well turn from East to West: Therefore we must allow, that this Rotation from West to East is an Effect of the Free-will of the Creator, and that this Free-will is the only sufficient Reason that can be assigned for it.

The Earth has another Motion, which is finished by its Poles in 25,920 Years. Its Gravitation towards the Sun and the Moon is evidently the Cause of this Motion, as we shall prove in the 25th Chapter.

The Earth has yet another Revolution, much more strange, the Cause of which is unknown, the Length of which astonishes the Imagination; and seems to promise a Duration to the human Species beyond what they dare think of. This Period consists, according to all Appearances, of a
million,

million, nine hundred and forty four thousand Years. It is here that we must insert what is known of this surprising Discovery, before we finish the Article of the Earth.

A D I G R E S S I O N.

*Concerning the Period of 1,944,000 Years,
newly discovered.*

Egypt and Part of *Asia*, from whence all the Sciences that now seem to circulate in the World devolv'd to us, preserved antiently an immemorial,extravagant,uncertain Tradition, but which could not be without some Foundation. They said, that prodigious Changes had been made in our Globe, and in the Heavens with regard to our Globe. The bare Inspection of the Earth gives great Weight to this Opinion.

We see that the Waters have successively covered and abandoned the Beds which contain them. The Vegetables and Fishes of *India*, found in the Petrifications of our *Europe*, the Numbers of Shells found in Ranges in the Mountains, render sufficient Testimony to this antient Truth.

Ovid,

Ovid, explaining the Philosophy of *Pythagoras*, and introducing a Discourse of that Pupil of the *Asian* Sages, speaks in the Name of all the Oriental Philosophers, when he says :

*Nil equidem durare diu sub imagine eâdem
Crediderim ; sic ad ferrum venistis ab auro
Secula, sic toties versa est fortuna locorum.
Vidi ego quod fuerat quondam solidissima tellus
Essè fretum : vidi factas ex æquore terras :
Et procul à pelago conchæ jacuere marinæ :
Et vetus inventa est in montibus anchora
summis.*

*Quodque fuit campus, vallem decursus aquarum
Fecit ; & eluvie mons est deductus in æquor,
Eque paludosa siccis humus aret arenis.*

Which Verses are thus translated by Mr. *Dryden* :

That Forms are chang'd I grant ; that nothing can
Continue in the Figure it began :
The golden Age to Silver was debas'd ;
To Copper that ; our Metal came the last.
The Face of Places, and their Forms, decay ;
And what was solid Earth, converts to Sea :
Seas in their turn retreating from the Shore,
Make solid Land, what Ocean was before :
And

And far from Strands are Shells of Fishes
 found ;
 And rusty Anchors fix'd on Mountain
 Ground :
 And what were Fields before, now wash'd
 and worn,
 By falling Floods from high, to Vallies turn,
 And crumbling still descend to level Lands ;
 And Lakes, and trembling Bogs, are barren
 Sands :
 And the parch'd Defart floats in Streams
 unknown ;
 Wond'ring to drink of Waters not her own.

This was the Opinion of the East ; and we
 do it no Injury by reporting it in Verse, the
 antient Language of Philosophy.

To these Testimonies which Nature gives,
 of so many Revolutions which have changed
 the Face of the Earth, corresponds an Idea
 of the antient *Egyptians*, a People formerly
 skill'd in Geometry and Astronomy, before
 Superstition and Sloth had reduced them to
 Contempt. This Idea was, that the Sun, in
 former Ages, rose in the West. It was a
 Tradition, indeed, as obscure as their Hiero-
 glyphicks. *Herodotus*, who may be looked
 upon

upon as an Author too modern, and consequently of little Weight with regard to such Antiquities, reports in his Book *Euterpe*, that, according to the *Egyptian* Priests, the Sun, in the Space of eleven thousand three hundred and forty Years (and the *Egyptian* Year consisted of 365 Days) had risen twice where he now sets, and set where he rises, without there being the least Change in *Egypt*, occasioned by this Variation of the Solar Course.

Either the Priests, who related this Event to *Herodotus*, explained themselves imperfectly, or *Herodotus* misunderstood them. For it might be a probable Tradition among Philosophers, that the Sun had changed his Course; but that the Cardinal Points should be twice changed in eleven thousand and odd Years, was a thing impossible. These two Revolutions, as we are going to make it appear, could not happen in much less than 4 Millions of Years. The entire Revolution of the Poles of the Ecliptic, or the Equator, is finished in about 1,944,000 Years; and this Revolution of the Ecliptic and the Equator alone, by the Help of the diurnal Motion of the Earth, is sufficient to turn our Globe
suc-

ſucceſſively to the Eaſt, to the South, to the Weſt, to the North. Thus it is in a Period of no leſs than 1,944,000 Years, that our Globe could twice ſee the Sun riſe in the Weſt, and not in 110 Centuries only, according to the wild Report of the *Theban* Priests, and of *Herodotus*, the Father of Hiſtory and Falſhood.

Befides, it is impoſſible that this Change could happen, and *Egypt* not be affected by it: For if the Earth, in turning daily on itſelf, had ſucceſſively finiſhed its Year from Weſt to Eaſt, from North to South, from Eaſt to Weſt, and from South to North, by raiſing itſelf on its Axis; it may be clearly perceived, that the Poſition of *Egypt*, and of all the Climates of the Earth, muſt have been changed. The Rains, which have ſo long continued to fall from the Tropick of Capricorn, and which fertilize *Egypt* by ſwell- ing the *Nile*, would have ceaſed. The Place of *Egypt* would have been removed into a frozen Zone, and both *Egypt* and the *Nile* would have diſappeared.

Plato, *Diogenes*, *Laertius*, and *Plutarch*, ſpeak not more intelligibly of this Revolution.

tion. Speak of it however they do, and are so many remaining Witnesses of a Tradition almost lost.

What follows is much more shocking, and more circumstantial. The Philosophers of *Babylon*, at the Time of *Alexander's* Entry into that City, counted four hundred and three thousand Years from the beginning of their astronomical Observations, the *Babylonian* Year being but 360 Days: But this Epocha of 403,000 Years has been regarded as a Monument of the Vanity of a conquered Nation, which was willing, according to the Custom of all Nations, and all particular Persons, to recover by its Antiquity the Glory that it had lost by its Weakness.

The Sciences, at last, having been brought among us, and being cultivated by Degrees, the Chevalier *de Louville*, distinguished among the Croud of them who did Honour to the Age of *Louis XIV.* went expressly to *Marseilles*, to see if the Obliquity of the Ecliptic appear'd the same there as it had been observed and fixed by *Pitheas*, above 2000 Years ago. He found this Obliquity of the Ecliptic, that is, the Angle formed by the Axis
of

of the Equator, and the Axis of the Ecliptic, to be 20 Minutes less than *Pitheas* had found it. How did this 20 Minutes Diminution of this Angle agree with the Opinion of antient *Egypt*, and with the 403,000 Years of which *Babylon* boasted? How, with a Period of the World of near 2 Millions of Years, and even, according to *Louville's* Observation, of above 2 Millions? We must see the Use he made of it, and how there is like to result from it, hereafter, an Astronomy altogether new.

If the Angle which the Axis of the Equator makes with the Axis of the Ecliptic be 20 Minutes less at this Day than it was 2000 Years ago, the Axis of the Earth, by rising upon the Plan of the Ecliptic, comes nearer it a whole Degree in 6000 Years.

Let this Angle, P, E, for Example, be about $23\frac{1}{2}$ Degrees at this Day, and let it continue to decrease till it becomes nothing; then let it begin again to increase and decrease, it will certainly happen, that in $23\frac{1}{2}$ Times 6000 Years, that is, in 141,000 Years, our Ecliptic and our Equator will coincide in all their Points; the Sun will be in the
Equator,

Equator, or at least will remove little from it, during many Centuries; the Days, the Nights, the Seasons, will be equal all over the Earth. It is found, according to the Calculation of the *French* Astronomer, a Calculation a little reformed since, that the Axis of the Ecliptic was perpendicular to that of the Equator about 399,000 of our Years ago, supposing the World to have existed so long. Take from this Number, the Time that is elapsed since *Alexander's* triumphant Entry into *Babylon*, and we shall see with Astonishment that this Calculation agrees very justly with the 403,000 Years of 360 Days, which were computed by the *Babylonians*: We shall see that they begun this Computation precisely at the Point where the Pole of the Earth was directed towards Aries, and when the Earth in its annual Course had revolved from South to North; in a Word, when the Sun rose and sat in the Regions of Heaven which now are the Poles.

There is some Appearance that the *Chaldean* Astronomers had made the same Operation, and consequently the same Deduction from it, as the *French* Philosopher? They had

had measured the Obliquity of the Ecliptic, and found it decreasing ; and rising in their Calculations to a Cardinal Point, counted from that Point when the Ecliptic and the Equator made an Angle of 90 Degrees ; a Point, which may be considered as the Beginning, as the End, as the Half, or as the Quarter of this enormous Period.

By this the Enigma of the *Egyptians* was unravelled, the Computation of the *Chaldeans* justified, the Relation of *Herodotus* clear'd up, and the Universe flattered with a long Futurity, the Idea of which pleases the human Imagination ; tho' this Comparifon makes our Life appear yet the shorter.

This Discovery of the Chevalier *de Louville* was strongly opposed, both because it was very strange, and because it did not yet seem sufficiently confirmed. An Academician had, in a Voyage to *Egypt*, measured a Pyramid : He found its four Sides opposed to the four Cardinal Points ; therefore the Meridian, said the Enemies of the Chevalier, has not changed during so many Centuries ; therefore the Obliquity of the Ecliptic, which by its Diminution must have changed all the Meridians,

dians, in reality has not been diminished. But this Pyramid was no impregnable Barrier against these new Discoveries: For, how are we sure that the Architects of the Pyramid were not some Minutes deceived? The most insensible Aberration, in laying a Stone, had alone been sufficient to occasion this Error. Or, if the Builders were right, might not the Academician himself neglect that little Diversity, which might be found between the Points where the Sun ought to mark the Equinoxes and Solstices upon this Pyramid, supposing nothing to have changed, and the Points where it now marks them in Fact? Could not he be deceived in the Fables of *Egypt*, where he operated out of pure Curiosity, when *Tycho-Brabe* himself was deceived 18 Minutes in the Position of the Meridian of *Uraniburg*, his heavenly City, for which he calculated all his Observations? Or was *Tycho-Brabe* in reality deceived 18 Minutes, as is pretended? May not the Truth be, after all, that this Difference found between the true Meridian of *Uraniburg*, and that of *Tycho-Brabe*, proceeds partly from the Change of Heaven itself, and partly from the almost inevitable

inevitable Errors committed both by *Tycho-Brabe* and by them that corrected him?

But the Chevalier *de Louville* might also be deceived himself; he might see a Decrease of Obliquity, which has no Existence. *Pitheas*, especially, was probably the Source of all these Errors: He, like most of the Antients, made his Observations with very little Exactness. It was worthy of that Prudence therefore, with which we now proceed in Physicks, to wait for new Illustrations of the Matter. Therefore it was proper that the few, who were able to judge of this grand Difference, should remain in Silence for the present.

Finally, in 1734, Mr. *Godin* (one of those Philosophers whom the Love of Truth has lately conducted to *Peru*) resumed the Thread of these Discoveries: The Examination of a Pyramid was now no more the Matter in Question, for concerning this there would be Difficulties always remaining; he was to proceed from the famous Meridian in the Church of St. *Petrionius*, traced by *Dominic Cassini* in 1655, with an Exactness of which we are more certain than that of the *Egyptian* Architects,

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The Obliquity of the Ecliptic which resulted from *Cassini's* Observation, was 23 D. 29'. 15". But the late Observations put it beyond all Doubt, that this Angle of the Ecliptic and the Equator is at present 23 D. 28'. 20". at least if the Refractions, which enter into the Determination of the Height of the Pole, made by the Polar Heat, and consequently into that of the Elevation of the Equator, and the Obliquities of the Ecliptic, are not a little changed since *Cassini's* Time : A Variation which many begin to suspect, from the Difference of the Elevations of the Pole, observed in the same Cities after some Space of Time, particularly in *London, Amsterdam, and Copenhagen*; tho' these Observations are not yet sufficient to assure us entirely, that from Age to Age the Air is found sometimes more, sometimes less transparent. It has indeed been lately discovered, and infallibly demonstrated, that the Refractions at two Places, a very little distant, will sometimes differ almost beyond Belief; which obliges an exact Observer, at present, to determine well, before every Thing else, the Refractions of his Horizon, if he would have his Observations credited:

But

But it is also known, that, according to the Experiment of Mr. *Huygens*, if a reflecting Glass be left in a constant Situation, directed towards the Top of a high Steeple, from Noon till Evening, that Top will appear more elevated towards the Close of Day than at Noon, and consequently there is an Alteration in the Transparency of the Air. As all this, however, contributes nothing to a Change, such as we have reason to suspect may produce the Phænomenon of this Question, we should be blameable to admit such a dubious Fact, of which we have not yet any convincing Proof, any Physical Reasons.

With regard to the Pyramids of *Egypt*, and the Invariableness of Meridians, which seems contrary to this Mobility of the Poles of the Equator; it is proper to take Notice farther, That supposing the Figure of the Earth to be not spheroidical, as it really is, but exactly spherical, this Motion of the Plan of the Equator, and its Poles, may be conceived two ways. For, either most of the Places, situated at present under the Equator, will, after some Ages, have a Meridional or Septentrional Latitude, the Equator

tor having quitted them to come nearer the Ecliptic ; (on which Supposition, all the Meridians will be disordered, and any two Cities, without having changed their Place, their Distance, or their first Situation upon Earth, will nevertheless have changed the Point of Compass, with regard to each other) or, the Equator will never abandon the Places, which have always been situated under it, but its Plan will turn with them round the Ecliptic, without any Change being made in the Meridians, their Invariableness not proving the same Thing against the Motion of the Equator as in the former Supposition. On the contrary, resuming the spheroidical Figure of the Earth, which is the true one, its solid Parts manifestly sustaining themselves, and not having a Power to quit one another, the most remote from the Center will remain always at the same Distance, and consequently the Circumference of the Equator, which has once environ'd them, will never quit them ; so that the Place of the Equator, whether moveable or immoveable, can never bring any Disorder on the Meridians. It appears by this, that tho' the *Egyptian Architects*

chitects might have had Orders to build the Pyramids parallel to the four Cardinal Points of the World, and they may have executed these Orders with the utmost Exactness, this does not hinder but the Angle of Interfection of the Equator and the Ecliptic may continually vary, as much as we please.

There can be no greater Pleasure, than to see the Credit of Truths, the most worthy of Respect for their Antiquity, re-established, after having been contested in Ages so circumpect, and so little credulous as ours. But it must be confess'd, that if the *Egyptians* and *Babylonians* were the first Discoverers of the Decrease of this Obliquity, they made the Discovery from Reasonings much less certain, than those from which we attribute this Discovery to them. *Herodotus* published his History about a hundred Years after *Anaximander*, the *Milesian*, first found out the means of measuring the Obliquity of the Ecliptic: And this Invention having soon after passed into *Egypt*, by the Voyages of *Cleostrates*, *Harpalus*, and *Eudoxus*, the *Egyptians*, who could not but find this Obliquity less than *Anaximander* had found it,

took

took the Advantage from thence to do honour to their Nation; as if the Diminution, and consequently the Measure, of the Obliquity of the Ecliptic, had been known among them for many thousands of Years, at the time when this latter was but just discovered by the *Greeks*. We have already said almost the same Thing of the *Babylonians*, who, equally jealous of the *Egyptians* and the *Greeks*, have advanced, by a parallel Calculation, to an Antiquity incomparably more absurd than that of the *Egyptians*.

But, whether this Motion of the Equator does, or does not exist, it is demonstrably certain, that it cannot be produced by any Mechanism, exactly the same with any discovered by the learned *Newton*. The Motion which most naturally resembles this of the Axis of the Earth, is the variation of the Moon's Inclination; which is of no less than 5 Degrees, 18 or 19 Minutes, when the Nodes of the Moon are in Conjunction, or Opposition with the Sun; and of 5 Degrees only, when these same Nodes happen in her Quarters. It is true indeed, that, by a natural Analogy, this great Philosopher attributes

butes a small alternative Motion to the Axis of the Earth, by which the Angle of Intersection of the Ecliptic and Equinoctial being found in the Equinoxes, for Example, to be 23 Degrees, 29 Minutes, and is straiten'd in approaching the Solstices, and enlarged again from the Solstices to the Equator; so that at the Solstices this Angle, in its smallest Dimension, is some Seconds less than 23 Degrees, 29 Minutes.

But these Alternatives of Diminution and Decrease produce not the circular Motion of the Plan of the Equinoctial, from one Pole of the Ecliptic to the other. This Circulation then must necessarily depend upon some other Cause, hitherto unknown, which we should endeavour to discover, provided the Phænomenon be real.

That the Diminution of this Angle may always equal its Increase, the absolute Center of Gravity of all the Mass of the Earth, must be the same as the Geometrical Center of its spheroidical Figure; but this, very possibly, is not the Case. For if the Earth be ever so little less material on the Northern, than on the Southern side of the Equator, and if
there

there arrive in the Body of this Planet, or on its Surface, any Change, which diminishes the Quantity of Matter in one Place, and augments it in another; it is evident, that the exterior Surface of the Earth, and the common Center of Gravity of its whole Mass, must change Position with regard to each other; and as the Geometrical Center of its spheroidical exterior Surface remains always the same, it is necessary that this Center also must change its Position, with regard to that of Gravity, whenever any Reason, manifest or not manifest, takes away ever so little Matter from one Place, and carries it to another. Now the two Centers, the Geometrical Center of its Oval Figure, and that of its general Gravity, should necessarily be in the same Axis of its Rotation, if this Rotation must be equal and uniform during 24 Hours, without being accelerated and retarded by Turns; which would be contrary to Experience.

To effectuate this Motion of the Plan of the Equator, it is sufficient then, that there should be, within the Earth, Matter which, by circulating continually, but slowly,

ly,

ly, may continually remove the common Center of Gravity, with regard to the Surface of the Earth, because the Axis of Rotation will always follow the same Road as this Center.

If this Matter be not supposod to circulate, but to have a very small irregular Motion, the Plan of the Equator will also change its Position with the Ecliptic, but without any certain Rule, and may be sometimes nearer, sometimes farther from the Center; which, perhaps, may be more probable than a perfect Circulation. But none of all this Reasoning can have Place, till it shall be proved in a manner altogether incontestible, that the Approximation of the Equator and the Ecliptic, which the most skilful Observers pretend now to perceive, is real; and that there is no Illusion, either from the Refractions of Light, or from the Instruments, in an Affair which is yet so delicate, and so little sensible in Modern Observations, as to relate only to a few Seconds of Diminution; so that it will not be till after many Ages of continued Observations, that any one will be able to say,
with

with full Certainty, whether the Obliquity is variable, or how it is so.

The most short and certain Method of terminating this Question, would be to measure exactly the Elevation of the Pole from the Ruins of the antient City of *Syene* in *Egypt*. It is known, from the Report of *Strabo* in the last Book of his Geography, that this City was situated precisely under the Tropic of Cancer, and that there was here a very deep Well, in which the Reflection of the Sun could never be seen, but just at Noon in the Summer Solstice, the Sun shining vertically over the horizontal Surface of the Water, at the Bottom of the Well. *Strabo* adds in the same Place, that in travelling from *Greece*, this City was the first to be met with, where the Gnomons, or Columns erected vertically, had no Shadow at Noon-day once in a Year: So that here are two different Proofs, which assure us that in the Time of *Strabo*, or some Time before him, the Tropic of Cancer passed over the vertical Point of this City.

Now if in measuring at present the Latitude of the Place where *Syene* formerly stood,
the

the Arctic Pole shall be found to be there elevated to 23 Degrees, 49 Minutes or more, this will be an indubitable Proof that the Chevalier de *Louville* has discovered the Truth, and that the Obliquity of the Ecliptic has diminished 20 Minutes in the Space of 18 Centuries. I say, 23 Degrees, 49 Minutes or more; for the Tower of *Syene* being renown'd before *Strabo*, on Account of this Property of which we are speaking, even as far back as the Time of the Prophet *Ezekiel*, who mentions it in the xxxixth Chapter of his Prophecy; it is apparent, that if the Obliquity of the Ecliptic was variable, it must have diminished five or six Minutes, in the same Proportion, from the Time of this Prophet to that of *Strabo*, during more than five Centuries; without reckoning what Diminution it might have undergone from the Foundation of this Tower to the Time of *Ezekiel*.

But if, on the contrary, the Pole is there found to be elevated but $23 \frac{1}{2}$ Degrees or thereabouts, we must conclude, without Hesitation, that, during all this Series of Ages, the Obliquity in question has been constantly the same, or that its Diminution has not
been

been any Thing considerable ; and that the Space comprized between the Equinoctial and the Ecliptic has been very little, if at all lessen'd. All the Difficulty would consist, in discovering exactly the Situation of this anti-ent City, in the neighbourhood of *Nile*, and the Island *Elephantine*. This Work would be a means to prevent the Cares of Posterity, and of which to make a Merit with regard to our Children, for presenting them with finished Demonstrations of a Truth, the clearing up of which may cost them many Centuries.

The Enumeration which we have undertaken to make here, of the principal Particulars which regard the Earth, with respect to the Rank that it holds among the Planets, engages us to examine the Proofs of its spheroidical Figure, which we have supposed true, and to shew the Impossibility of any Alteration of Meridians. We have already given a general Idea of it in Chap. XVIII. when, in proportion to the Extent and the divers Degrees of Gravity, we made mention of the Inundation of Waters towards the Regions of the Equator, which must necessarily result from the Rotation of the Earth round its Axis, if it was exactly spherical. But as that

was not the Place to prove that this Difference is so perceptible as to be measured, we proceed here to shew what is known of the Matter.

The Proofs, which we shall make use of, are drawn partly from physical Arguments, and partly from Experience itself. The physical Arguments, which prove to us the necessity of this Figure, suppose only, by way of Principle, the diurnal Motion of the Earth, of 23 Hours, 56 Minutes. If the Earth is exactly spherical, the Velocity of the Rotation of all weighty Bodies under the Equator will diminish their Gravity, or the Velocity of their Descent, in proportion as it will differ less from that which is necessary to make all weighty Bodies circulate under the Equator, without power ever to fall, or approach to the Center of the Earth; or, to cause that all Bodies which are under the Equator, should be so many Satellites, which should turn by their daily Motion in the Circumference of the Equator, as the Moon revolves in her Orbit. Now let us say, by the Rule of Three; as the Cube of the Moon's Distance, *viz.* 60 Semidiameters of the Earth, is to
the

the Cube of one only of these Semidiameters; so is the Square of 39,343 Minutes, which make a Lunar Month, to the Square of the Minutes of the Revolution of the Satellites, or weighty Bodies, in the Circumference of the Earth's Equator, supposing the centrifugal Force exactly to counterbalance the Gravity. The Product of this Calculation is, $84\frac{2}{5}$ Minutes of Revolution: So that if the Day of the Satellites consisted of $84\frac{2}{5}$ Minutes, instead of 23 Hours 56 Minutes, which is 17 Times as much, there would be neither Descent nor Weight under the Equator.

The same Number of $84\frac{2}{5}$ is found without making use of the Moon, if we follow the Theorem of Mr. *Huygens*, by which he has found, that a Body, to turn circularly, with a centrifugal Force equal to its proper Gravity, must surround the whole Circle in the same Time as a Pendulum, containing a Semidiameter of the same Circle in Length, would employ in making two Vibrations. Now to apply this Theorem to the Circle of the Equator, and the Semidiameter of the Earth, we need only say, As three Feet, and

$\frac{17}{288}$ of

$\frac{17}{288}$ of a Foot, the Length of a Second-Pendulum, are to the Square of a Second, so 19,615,800 Feet, the Semi-diameter of the Earth, according to Mr. *Picart's* Measure, are to 6,412,430, which is the Square of 2,532 Seconds, or of 42 Minutes, 12 Seconds. A Pendulum of the Length of the Earth's Semidiameter, therefore, would make every Vibration in 42 Min. 12 Seconds; and consequently, to equal the Gravity to the centrifugal Force of the diurnal Rotation under the Equator, this Rotation must necessarily be finished in 84 Min. 24 Seconds.

But, as it is found 17 Times more slow, it is evident, that supposing the Surface of the Earth exactly spherical, Gravity under the Equator exceeds its Diminution, or the centrifugal Force, 17 Times 17 Times, that is, 289 Times; which must occasion the Velocity of Bodies Descent under the Equator, to be to that of their Descent under the Poles, as 288 are to 289; and a Second-Pendulum, which under the Pole would make 86,400 Vibrations in a solar Day, would make under the Equator but about 86,250: In the same manner as a Second-Pendulum of *Paris*,
being

being transported under the Equator, and there making its curvilinear Descents, or Vibrations, a little more slowly than at *Paris*, would be retarded 2 Minutes, 5 Seconds, or thereabouts, in a Day.

Mr. *Richer*'s Experiment, made in the Island of *Cayenna*, Dr. *Halley*'s in the Isle of St. *Helena*, and those of the Persons mentioned Page 196, having verified, except in a few Circumstances, this Diminution of Gravity under the Equator, which is a necessary and indubitable Consequence of the Earth's diurnal Motion ; it remains, that we should survey the Disorder which the centrifugal Forces of this same Motion would cause under the Circles parallel to the Equator, if the Earth was exactly spherical.

Every one knows, that an exact Beam, being suspended in the Middle, and left in Repose, the Scales, or Weights, equally suspended by Cords at its two Extremities, make these Cords, or rather the Middle of them, take Situations perpendicular to their Horizons, and which tend directly to the Center of the Earth. But if we give to this Balance a circular Motion, the Center of which is
the

the Point of the Beam's Suspension, we shall see immediately that the Scales, or Weights, will fly out of the perpendicular Lines, in proportion to the Velocity of the circular Motion ; so that the Cords no longer follow the usual Direction of Gravity, towards the Center of the Earth.

Let us conceive now a great curvilinear Balance, whose Middle is suspended to one of the Poles of the Earth, and whose Extremities extend to an equal Elevation from the same Pole, on both Sides ; it is evident, that if the spherical Figure of the Earth, which we now examine, turns round on its Axis, and carries at the same Time this curvilinear Balance, in a circular Motion round the same Axis, the Weights, which being in Rest would incline towards the Center of the Earth, are removed from this Inclination, and out of perpendicular Lines, on both Sides. Thus the Sine of the small Angle of Deviation, comprized between the Perpendicular, and the new Direction of the Weights, will be near $\frac{1}{289}$ of the Product of the Sine, and of the Co-sine of the Elevation of the Pole, divided by the Radius.

It is manifest, that, without imagining this Balance curvilinear, this Reasoning may be equally apply'd to all Plummetts, which are used on the Surface of the Earth. It is in this manner that we find at *Paris*, and in a hundred other Places of the same Latitude, that a Pendulum in Repose would not tend perpendicularly to the Horizon, but would make with the Perpendicular an Angle of near 6 Minutes, which would be perceptible enough, if the Earth were exactly spherical: But as no Deviation is found in any Part of the World, it is sufficient Proof that the Face of the Earth is such as it ought to be, in order that the Direction of Gravity might be perpendicular, which can be only in a Spheroid*.

This spheroidical Figure produces yet another Change, with regard to Gravity, but of small Consequence. It is well known, that, without considering the Diminution of Gravity, of which we have been speaking, Gravity itself varies according to the Diversity of Distances from the Center of the Earth, even supposing there were no Rota-

* The Scales would fly out at the *Æquator*, whatever Figure the Beam is of, and so would not be perpendicular there.

tion. This is the Reason why the Experiments of Pendulums, transported into different Climates, answer not with the utmost Exactness to the Calculation which we have given above, tho' they all prove in general that Gravity differs sensibly, and that it is always weaker towards the Equator, than towards the Poles. It is this also, which divides the greatest Geometricians in their Sentiments concerning the Proportion of the Axis of the Earth's Rotation to the Diameter of its Equator. Mr. *Huygens*, and after him *James Herman*, in his excellent Work *de Phoronomiâ*, have determined this Proportion, as of 577 to 578 ; but Sir *Isaac Newton* gives it as of 229 to 230, about three Times more than the other. The Diversity of these Measures proceeds only from this, that Mr. *Huygens* considered Gravity merely as a Force which impels Bodies towards one only Center ; whereas Sir *Isaac Newton* considered it as a Force by which all Bodies, and all the Particles of the Earth, even to the most minute, are drawn towards one another *.

* Query then whether a Millstone within a Mile of the Earth's Center would not be drawn almost as much up as down, and so have less Gravity the nearer the Center, contrary to its Law of Increase. M A R S.

M A R S.

The fourth Planet of our System is Mars. His mean Distance from the Sun is about 46 Million of Leagues. Of all the superior Planets, it is this which has the greatest Excentricity ; nor do we know any one, among all the celestial Bodies, whose apparent Magnitude is more variable ; infomuch that his largest Phasis exceeds his smallest, no less than 7 Times. In the Month of *August* 1719, Mars being opposed to the Sun, at only 2 or 3 Degrees Distance from his Perihelion, we yet remember that many Persons, who had no Tincture of Astronomy, were astonished to see this Planet, and took it for a Comet, or a new Star, just produced in the Heavens ; in like manner as Venus was mistaken last Year, when in the Month of *May*, having attained her highest Meridian Elevation at the Beginning of Cancer, and yet being far enough from the Sun not to be eclipsed by his Light, she lanced her Rays along the shortest Road of the Northern Part of the Atmosphere.

As

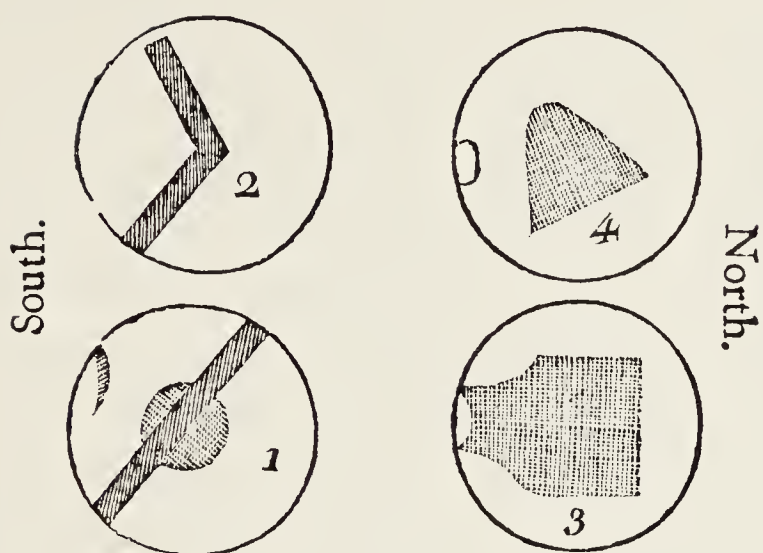
As the great Excentricity of Mars renders his Motion apparently very unequal, it was of him principally that *Kepler* made use, to examine and verify the Discovery he had made, of the Equality of Areas described by every Planet in particular, in equal Times: And it was also by Mars that he found out and proved the Necessity there was to admit but very small Excentricities throughout the Heavens, not above half as large as those that had been established by the Antients.

Mars likewise, of all the Planets, is he which has the largest Atmosphere, in proportion to his Body, at least according to what we know hitherto; which is proved by the Alteration of the Colour of a fixed Star observed by Mr. *Romer*, as it approached and quitted the Disk of Mars: It grew sensibly pale on approaching this Disk, being yet above two thirds of its Diameter distant; and coming from behind the Planet's dark Body, did not recover the natural and usual Vivacity of its Light, till it came to the Distance of two thirds of the same Diameter.

Without

Without the Planet Mars, we should be altogether ignorant of the Distance and true Magnitude of the heavenly Bodies: And it was the celebrated Mr. *Cassini* the Father, who first thought of making use of the apparent Distance of this Planet from the nearest fixed Stars, when he is in Opposition to the Sun, in order to find the true Dimensions of our System. His horizontal Parallax, which in this Situation is large enough to be observed and calculated, without Danger of any remarkable Error, that is, between 26 and 27 Seconds in his Perihelion, furnishes us with a Method of calculating the horizontal Parallax of the Sun, and of the other Planets, which cannot be observed by themselves, on account of their Smallness. By the Spots in Mars, which we represent here as they appeared in 1719, it has been discovered, and we are convinced of it, that she turns round upon an Axis always parallel to itself, (like that of the Earth) in 24 Hours 40 Minutes.

Or,



Or, that 36 Revolutions of Mars on his Axis, equal 37 diurnal Revolutions of the Earth.

The Spots of this Planet seem to be more variable than those of all the others. The obscure Bands, which were observed in 1704, 1717, 1719, do not agree among themselves, neither with regard to their Situation, nor to their Figure. In 1704 and 1717, an obscure Band was seen, occupying more than a Hemisphere of Mars, with this Difference, that in 1704 it had a Point in the Middle, which was not found in 1717; and that in 1717 it was farther from the Equator of Mars, and nearer his Meridian Pole, than in

*Remarks
on the Spots
of Mars.*

in 1704. In 1719, a crooked Band was seen, formed only after the Month of *July*, the most Southerly Part of which, with regard to our Eyes, extended obliquely over half of the Hemisphere of Mars, and equalled about a Quarter of a Circle, beginning between the Meridional Pole and the Equator of the Planet, and ending between his Equator and Septentrional Pole, where the two Parts of this Band, joining together, made an Angle, as represented in Figure 2. Before the 13th of *July*, only an obscure rectilineal Band was observed, such as may be seen in Figure 1.

Besides these obscure Bands, certain confused Spots, of an irregular Figure, as in Fig. 3 and 4, were discovered. These were also but temporary, and had hardly any thing in common with those that were observed before, except their Inconstancy.

But the most considerable Spots of this Planet, are those which are observed near his two Poles, of which however only one is seen at a Time, and which are commonly more clear than the rest of the Body. These Spots have been known near these 70 Years, and almost always either one or the
other

other of them may be seen ; which proves that they are permanent, and that the Vicissitudes of Apparition and Occultation that they undergo, proceed only from some Change in the Atmosphere of Mars, like to that of ours, caused partly by the different Constitution of the Air in Summer and Winter, and partly by the different Quantity of Rain and fine Weather, in different Parts of the same Climate. It was thus that from the 17th of *May* to the Month of *November* 1719, the Pole, which with regard to us is the meridional, being illuminated by the Sun, and consequently Summer reigning there, and the Atmosphere there being rarified as much as it could possibly be, the sparkling Light of that pure Zone could strike our Eyes, while that of the opposite Pole, which appeared to the Observators in 1704 and 1717, with a Lustre equal to that of the other, was hid from our Sight by the Clouds, and congealed Vapours, which there changed the Atmosphere, and rendered it less transparent. The Difference of the Splendour of this Zone, one half of which constantly preserved the same Degree of Light, and the other on the contrary diminished,

minished, disappear'd, appear'd again, seems no ill Resemblance of the diversity of Weather on the Andes of *Peru*, where it never rains, and in the Island of *Borneo*, where it rains almost every Day. This Effect may possibly be produced by other Causes; but it is always certain in general, that such a diversity of Appearances proceeds from the different Constitution of the Atmosphere.

J U P I T E R.

Jupiter, the largest of all the Planets of our System, describes in 4,331 Days, or (to count by a round Number) in 12 Years, an Orbit, the Semidiameter of which, in its mean Quantity, or mean Distance from the Sun, is 156 Millions of Leagues. His Diameter is ten times larger than that of the Earth. The Weight of Bodies, which tend towards the Center of this Planet, or the Way that they make in falling directly upon his Surface, may be calculated.

*Manner of
calculating
the Weight
of Bodies,
which de-
scend upon
the Sur-
face of Ju-
piter.*

For this Purpose, we are to search first the Periodical Time of a Satellite, that should glance along the Surface of Jupiter, which is found by this Rule: As the Cube of $25\frac{1}{3}$
Semi-

Semidiameters of Jupiter, (the Distance of his 4th Satellite) is to the Square of its Periodical Time, which is $16 \frac{2}{3}$ Days; so the Cube of a single Semidiameter of Jupiter, is to the Square of the Periodical Time sought for. By this it is found, that such a Satellite, near the Surface of Jupiter, would finish its Revolution round that Planet in 193 or 194 Minutes.

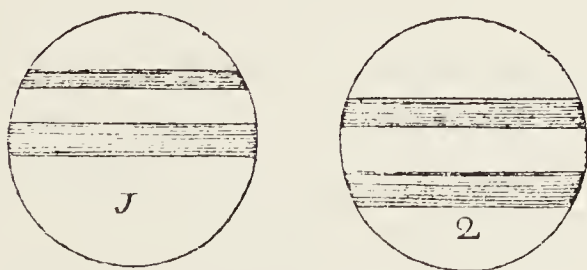
As all sorts of Gravities are in direct Proportion of the Radii of the Circles, which the ponderous Bodies describe, without falling, and in reciprocal Proportion of the Squares of the Periodical Revolutions, the Quantity of the Gravity of these Bodies upon Jupiter is determined in this manner: As 1 Semidiameter of the Earth is to $10 \frac{1}{2}$ of the same Semidiameters, which are the measure of that of Jupiter; so $15 \frac{1}{2}$ Feet of Descent upon the Earth, during the first Second, are to $158 \frac{3}{8}$ Feet of Descent on Jupiter during the first Second; if the Periodical Times of the Satellites, at the Surfaces of Jupiter and the Earth were equal. But having found above, that the Periodical Time of a Satellite of the Earth, near its Surface, is $84 \frac{2}{5}$ Minutes,

minutes, we must proceed thence to this last Rule: As the Square of $193 \frac{1}{2}$ Minutes, is to the Square of $84 \frac{2}{3}$ Minutes; so $158 \frac{1}{8}$ Feet of Descent, (if the two Periods are equal) are to 30 Feet of the true Descent upon Jupiter. The second Pendulum then, in Jupiter, must be $7 \frac{1}{2}$ Feet in Length.

The same Considerations shew us also, that Jupiter's polar Diameter, or Axis of Rotation, is shorter than that of his Equator, and that this Difference must be much more sensible upon the Surface of Jupiter, than upon that of the Earth. The diurnal Revolution of Jupiter is 9 Hours and 56 Minutes; and the Revolution of the lowest Satellite, which could possibly glide round him, having been found to be 194 Minutes, which is in a manner but the third of his diurnal Revolution; its remaining Gravity, that is, as diminished by the Centrifugal Forces under the Equinoctial of Jupiter, will be to its primitive Forces supposing the Figure of Jupiter exactly spherical) as 8 are to 9. This then shews the Proportion of his shortest Axis to his longest, to be, within a Trifle, as 17 are to 18, if we calculate according to the Principles

ples of Mr. *Huygens* and *Herman*, and as 7 are to 8, if we follow those of *Newton*, founded upon the mutual Gravitation of all the interior Parts of the Planet. The Sentiments of Sir *Isaac* seem to be supported by the Observations of Mr. *Cassini* the Father, reported at the End of the 19th Proposition of the 3d Book of his *Philosophy*, where it is said, that the Diameter of Jupiter from East to West, is visibly greater than from South to North.

The obscure Bands of Jupiter, extended along his Disk, and always parallel, in a manner, to his Equator, are represented in the two following Figures.



This Equator makes with the Orbit of Jupiter, an Obliquity but of 2 Degrees 55 Minutes; whereas ours is of $23\frac{1}{2}$ Degrees. These Bands seem to be nothing but Exhalations, which in rising, and joining together, take

take a Circular Figure. It is true, they never are visible all entire at a Time; witness, in particular, that Meridional Band, which is produced, as it were, every six Years, and which always exhibits to us a black Spot, situate on its Northern Border; as it was observed in the Years 1665, 1677, 1713, in the Month of *December*, and in *April* of the Years 1672 and 1708. By comparing the antient Observations with those that have been lately made, it is remarked that these Bands, which at first appeared subject to Alterations altogether unaccountable, and which followed no Rule, have nevertheless Returns very regular, which may put us in a Capacity, hereafter, to predict their Appearances with the same Certainty, as we now calculate the Eclipses.

*Remark on
the black
Spot of
Jupiter.*

The Band which we have been speaking of, accompanied with a black Spot, appears commonly when Jupiter is in the last Degrees of Virgo and Pisces, near the Time of his Opposition with the Sun. What is most particular in it is, that these Appearances follow the true, rather than the mean Motion of Jupiter: For we are very sure, that from the
Oppo-

Opposition of this Planet with the Sun in Pisces, to that which happens in Virgo, there are six Years and a half, and five and a half only from this to the Return of the former, the whole together making 12 Years, the Time of Jupiter's periodical Revolution. This shews us, that if we could remark all the Mutations that happen to these Bands, and which, without doubt, are effected at certain Signs of the Zodiack, as well as the Phænomenon of the black Spot, there would be room to hope, that the Order of their Return might be predicted, as well as that of the black Spot.

It is principally to this same Spot, that we owe the Knowledge we have of the diurnal Revolution of Jupiter; the Velocity of which, in proportion to the Magnitude of his Body, would, doubtless, surprize us, if Mr. *de Mai-ran* had not demonstrated the Possibility of it, in a learned Memoir, inserted among those of the Academy in the Year 1729, where he shews, that the Difference there is between the Weight of the inferior Part of a Planet, which is turned towards the Sun, and that of the superior Part, which is turned from
it,

it, is capable of producing such a Rotation from West to East.

This Spot is as well known to Astronomers, as the Situation of a celebrated City is to Geographers; and its Meridional Latitude upon the Surface of Jupiter, is determined at about 16 Degrees, as that of any remarkable Place may be upon Earth. It is true, that in observing the Revolutions of Jupiter, at the middle of his Parallel exposed towards us, they have not always been found quite the same, by the Difference of a few Seconds; though it be very natural to suppose them always equal to one another, as are those of the Earth: But this is of no great Consequence; and in an Enquiry of such a Nature, far from blaming the Astronomers, we ought to admire their Sagacity, and be very well pleased that they differ only in a few Seconds.

*Why the
Satellites
of Jupiter
appear
sometimes
less than
ordinary.*

The Satellites of Jupiter, and chiefly the fourth being turned towards us, exhibit obscure Spots, which makes them sometimes appear much less than they usually seem: They even occasion the fourth, between whiles, to disappear entirely, when it is far distant

distant from the Body and Shadow of Jupiter. But Astronomers have not yet determined, whether these Spots are produced suddenly, or whether it be the Rotation of the Satellites on their Axis, that discover them to us at one Time, and hides them at another: Though there seems to be much odds on the side of the Rotation, because of the periodical Circumstances that are said to have been observed in the fourth Satellite. Or, perhaps, the Shadows of the Satellites themselves occasion mutually small Eclipses among them, which we can perceive only by a Diminution of their Lustre: But this is a Point that has not yet been examined.

S A T U R N.

Saturn finishes his Course round the Sun in 29 Years and an half. If, counting roundly, the mean Distance of the Earth from the Sun is, as we have every where said, 30 Millions of Leagues, it follows, by parity of Reason, that the mean Distance of Saturn from that Luminary is between 285 and 286 Millions of the same Leagues. This is the last Planet, and the most distant from the Sun,

Sun, of any we know : At least, there has not yet been discovered any Body beyond it in the Heavens, that has a constant Orbit, and turns circularly. The Comets, it is true, journey through Regions much more remote than Saturn : But as their Excentricity is much greater than that of the ordinary Planets, they make no Part of the Planetary System which we consider in this Chapter. For even if we were to suppose that any one of them regularly revolved round the Sun, for Example, at 600 Millions of Leagues distance from the universal Center of our System, of what use would the Light and Heat of that Luminary be to it, at a distance where he could not appear larger than Jupiter and Venus appear to us ? I have supposed 600 Millions of Leagues for the mean Distance of this pretended Body from the Sun, because if this Distance were less, the Planets would embarrass and attract one another too much by their reciprocal Gravitations.

Calculation of the Weight of Bodies, which fall upon the Surface of Saturn.

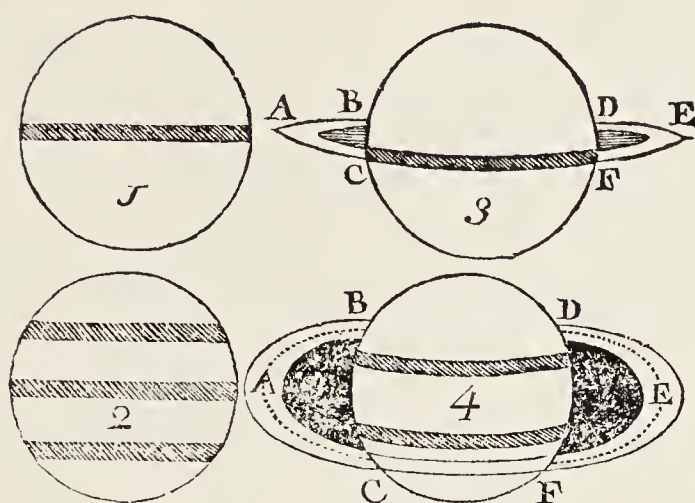
The Diameter of Saturn is near 10 Times larger than that of the Earth. By means of this we may calculate the Proportion of Gravity upon Saturn, with that which we experience

perience upon our Earth. His last Satellite being distant from him between 53 or 54 of his Semidiameters, that is, the Radius of its Orbit being between 53 and 54 Times greater than the Semidiameter of Saturn, its Revolution ought to be made in 79 Days, 22 Hours, or 1918 Hours. I say then; as 157,464, the Cube of 54 Semidiameters of Saturn, are to one, or to the Cube of a single Semidiameter of the same Planet; so 3,678, 742, the Square of 1918 Hours, are to about $23\frac{2}{3}$; the Square Root of which being extracted, the periodical Time of this Revolution is found to be 4 Hours, and $\frac{2}{3}$, or 4 Hours, 50 Minutes. Therefore a Body, which surrounded the Surface of Saturn, without being entirely drawn to it, would require 4 Hours, 50 Minutes for that purpose, as we have just now seen.

To find, in the next Place, how many Feet the ponderous Bodies on the Surface of Saturn descend in the first Second of Time, I proceed thus. As 1 Semidiameter of the Earth, divided by the Square of 84 Minutes, and $\frac{2}{3}$, the Number found Page 282 is to $9\frac{1}{2}$ Semidiameters of the Earth, or to one Semidiameter

diameter of Saturn, divided by the Square of 290 Minutes, which we have just found ; so 15 Feet, the Descent of one Second upon the Earth, are to 12 Feet of Descent upon Saturn during the first, and somewhat more. But this Gravity of Bodies towards the Center of Saturn, suffers a considerable Diminution, by their Gravitation in a contrary way, towards the Cavity of Saturn's Ring, as we shall prove in the Sequel.

The following Figures represent to us the different Configurations of Saturn : 1. His round Phasis, with a single obscure Band in the middle, caused by the Shadow of the Ring, and its obscure Part, that receives no Rays from the Sun. 2. The same round Phasis, with other Bands, in the manner they were seen in 1715. 3. The Phasis of his Ring, which disappears, and appears again after having been some Time invisible. 4. That Ring in its greatest Magnitude, with Bands that environ the Disk of Saturn, as they were seen in 1696.



The exterior Diameter of Saturn's Ring, from one Extremity to the other, is to the Diameter of that Planet as 9 to 4, according to the Measure of Mr. *Huygens*, or as 11 to 5, according to that of Mr. *Cassini*. The interior Diameter, comprized between the two opposite Cavities, is to that of Saturn as $6\frac{1}{2}$ to 4: For from the Body of Saturn to the Cavity of his Ring, there is just as much Space as from that Cavity to the outward Circumference. If Saturn himself be 30,000 Leagues in Diameter, then from his Surface to the Cavity in Question will be 9,375 Leagues, and from thence to the Extremity 9,375 Leagues also, instead of 8000, the usual Computation.

The

The fourth Figure represents to us the greatest opening of this Ring, when its Breadth, from B to C, or from D to F, appears equal to half its Length from A to E. From this Proportion of Length and Breadth is calculated the Angle that this Ring makes with the Orbit of its Planet, which is from 30 to 31 Degrees. It is remarkable, that in the midst of its apparent Breadth is observed an obscure Line, such as is marked out by the Points in the Figure. The Colour of its interior Part, which is nearest the Body of the Planet, appears more lively and luminous than that of its exterior Part, which is farthest from the Body of the Planet, and the black Line, we just now mentioned, makes the Separation of these Parts. Thus every Time that this Ring disappears, its exterior Part disappears first; for the other continues visible some Days after.

In the Years 1714 and 1715, when this Ring was twice seen to disappear and appear, it was observed, that its Oriental Part withdrew from Sight a Day or two sooner than the Occidental, and, on the contrary, that this same Occidental Side discovered itself a Day or two
 sooner

fooner than the Oriental. Mr. *Cassini*, the Father, had before observed somewhat like it in 1671; which made him judge, with Reason, that the Parts of this Ring which are of the same side, for Instance A, B, and D, E, of the 3d Figure, are not in the same Plane, and consequently that this Ring is thinner, and more sharp at its Extremities A and E, than towards the inward Cavity B, C, or D, F.

There are two different Causes, which occasion our losing Sight of this Ring. The first is, that its Plan returning from being opposed to the Sun, its two Sides receive the Rays of Light but very obliquely; which occasions that Light to become too feeble to strike our Eyes. This happens when Saturn, with regard to the Sun, is in 19 Deg. 45 Min. either of Pisces or Virgo. If there were no other Cause that produced the round Phasis of Saturn but this, it would never continue above a Month; as was proved by Observations made in the Years 1685 and 1701. Towards the End of the Appearance, the Shadow of the Ring upon the Body of Saturn was perceived more clearly, and appeared

*Reasons of
the disap-
pearing of
Saturn's
Ring.*

ed a little above or a little below the middle of his Disk, as represented in Fig. 1.

The second Cause which renders the Ring invisible, is the Coincidence of its illuminated Part with the visual Ray, which passes on the Side which is not illuminated *. The Terms of this Appearance are less limited than those of the other before spoken of: However, one is always sure of seeing it twice, when Saturn, opposed to the Sun in 19 Deg. 45 Min. of Pisces or Virgo, is retrograde with regard to us. His Latitude, being observed from the Earth, can differ one Time from another but very little; but this little is nevertheless sufficiently perceptible, to advance or prorogue these Terms. In 1671, there were more than six Months between the two Disparitions of the Anſæ, computing from the End of *May* to the 8th of *December*. The Place of Saturn, with regard to the Sun, was the first Time in 13 Degrees of Pisces, and the 2d Time in the Beginning of the 20th Degree. In 1714, Oct. 12, the Day on which the Anſæ disappeared, Sa-

* The two Causes are, the Plane of the Ring passes either through the Sun, or through the Earth, in both which Cases it becomes scarce visible.

turn with regard to the Sun was in the beginning of the 17th Degree of Virgo ; and the 22d of *May* 1715, the Day of the second Disparition, he was advanced to 21 Degrees and an half of the same Sign ; but the Time which elapsed between these two Disparitions, was not more than 5 Months and some Days. Thus the round Phases towards the beginning of *July* 1744, and in the Month of *May* 1760, were not redoubled at all ; and we ought, consequently, to leave to Posterity the Observation of the Return of this Phænomenon.

Many People are curious to know if this Ring be a continuous or solid Body, or if it be not composed of Satellites, which are so near the one to the other, that our Sight cannot distinguish them. The last of these two Conjectures seems to me very probable. For if it be objected, that the Motion of all these Satellites, in one common Orbit, cannot subsist without their interrupting each other, let them be ever so little excentrical ; it will be sufficient to answer, that this Motion is not excentrical at all. If it be said farther, that the superior Satellites cannot finish their Periods

riods in the same Time as the inferior ones, because the Gravity, or centripetal Force of their circular Motion, diminishes in reciprocal Ratio of their Distance from the Center of Saturn; I answer again, that this Difference of their Periods is in reality what is pretended, but that the exact resemblance of all the Satellites of one and the same Order, makes us regard this Collection of separate Satellites as one continued Body.

There remains yet one small Difficulty more to be removed. That Orbit, it will be said, far from being exactly circular, is elliptical, its Grand Axis being always perpendicular to a Line drawn from the Center of the Sun to that of Saturn; because, as all the Satellites are but so many Moons, they must, for this Reason, obey the same Laws of Gravitation as our Moon. Now as the Orbit of the Moon is necessarily flatten'd a little in the Conjunctions, as well as the Oppositions, and is more curve in the Quadratures, as we have proved in Chap. XXII. it follows that the same Variation must needs arrive in that of the other Satellites. The Matter, therefore, depends only upon the Difference of Saturn's
Gravi-

Gravitation upon the Sun, and that of his Satellites upon him; and it is of this Difference that we shall give the Measure in Chap. XXV.

The Bands of Saturn, which, being parallel with his Ring, shew us, that what causes them is elevated to a great Distance above the Surface of that Planet, because their Curvature is little or not at all sensible; prove indubitably, that Saturn is encompassed with an Atmosphere much more extensive than ours. But supposing, as above, that this Ring is composed only of an infinite Number of Satellites, it will not be necessary to extend it so far as them. And how vast soever this Atmosphere may be, it must be incomparably more transparent than ours, since the Fixed Stars, which are sometimes seen between the Ansæ and the Body of Saturn, suffer there neither Refraction nor Change of Figure, as in all other Atmospheres.

It is a very remarkable Thing, that among the 5 Satellites of Saturn, there are 4 which make their Revolutions in the same Plane with his Ring, and that only the 5th has a particular Orbit. The Inclination of the Orbit of
this

this last, from that of Saturn, is but between 15 and 16 Degrees; whereas the 4 others circulate in a Plane, whose Inclination from that of their principal Planet is 30 Degrees, or more. The Nodes therefore, of the one and the four, are a little different. These latter have the same Nodes as the Ring, namely, in 19 Degrees, 45 Minutes of Pisces and Virgo; but the other cuts the Orbit of Saturn rather at 15 Degrees, that is, in the 4th, or 5th Degree of the same Signs.

Diminution of Saturn's Motion.

Before we leave Saturn, it is necessary to remark one Particular more concerning his Motion, which has not yet been observ'd with regard to the other Planets. All the more antient Observations, being compared together among themselves, as well as with those of modern Date, give us an Estimate of his mean annual Motion at 12 Degrees, 13 Minutes, and between 33 and 36 Seconds, at most. But the modern Observations only, compared with one another, give that same Motion as diminished some few Seconds, reducing it to 12 Degrees, 13 Minutes, and between 20 and 29 Seconds. Other small Inequalities have been observed in the Motion

tion of Saturn, since the Time of *Tycho-Brabe* ; but which all agree to shew us, that his mean Motion is less speedy at present, than it was in the Time of the *Egyptians* and *Chaldeans*. Mr. *Cassini* has proved this beyond Dispute, in a Memoir presented to the Academy, *January* 10, 1728, by comparing the modern Observations, as well as those of *Ptolemy*, with a very antient Observation made the 1st of *March* of the Year 4485 of the Julian Period.

Though Sir *Isaac Newton* has proved, that when Jupiter is the nearest to Saturn that he possibly can be, he produces a manifest Change in the Motion of that Planet ; yet the Diminution of Saturn's Motion is too sensible, and of a Nature too different from what it ought to be, for us to suppose that Jupiter is the only Cause of it. In fact, if there were not other Bodies that contributed thereto, how could it happen, that, in the greatest Proximities of these Planets, the Motion of Saturn should be sometimes accelerated, and sometimes retarded, as it undoubtedly is, according to the Observations reported by Mr. *Cassini* ?

I believe therefore, that the Diminution of Motion, which Saturn more sensibly experiences than all the other Planets, is caused by the Attraction of many Comets *, which traverse immense Regions of the Universe, beyond the Orbit of Saturn. Their Number and Magnitude are considerable enough to have a sensible Effect, with regard to the Gravitation of Saturn upon the Sun, which is equal but to a 9th Part of the Earth's Attraction towards the Center of our System. Thus the Inequalities of this Diminution are more commodiously explained by the different Proximities of the Comets, than by any other Cause; and if the inferior Planets feel less than Saturn from their approaches, it is because the attractive Power of the Sun has much more the Advantage over that of the Comets in these lower Regions, than it has in that of Saturn; as we have before said.

* This may be true; but that is no reason to believe it; and it may not be true, for the Comets being near to, or far from Saturn, are very accidental, and may cause, increase, as much as Diminution of Motion; for the Moon moves faster in Conjunction when nearest the Sun, than in her Quadratures *cæteris paribus*.

C H A P. XXIV.

*Of the Zodiacal Light, the Comets,
and the fixed Stars.*

Of the Zodiacal Light.

CERTAIN Hypotheses, by which the Phænomenon of the Zodiacal Light is explained, seem contrary to Sir *Isaac Newton's* Demonstrations concerning the Motion of Bodies in resisting Mediums. This is what we must endeavour to clear up; and it is principally for this Reason, that we make any mention of the Zodiacal Light in the present Work.

The Zodiacal Light is a Brightness like that of the *milky Way*, and sometimes more luminary: It extends almost the whole Length of the Zodiack, to 50, 60, 70, 80, 90, and sometimes to 100 Degrees and more from the Place of the Sun, on one Side and the other. Its Points, and a great Part of its luminary Arch, when it is not obscured by, or intermixed with our Twilight, seem to have an annual and diurnal Motion round the Earth.

Earth, similar to that which is vulgarly attributed to the Sun. According to the learned Remarks of Mr. *De Mairan*, drawn from the Observations of Mess. *Cassini*, *Eimmart*, *Kircher*, and others, 'tis at about the End of Winter, and the Beginning of the Spring, that the Evening is most proper in our Climates to take a good Observation of this Light; and the Morning towards the End of Summer, and the Beginning of Autumn. This Difference is an Effect of the different Position of the Ecliptic upon the Horizon, which occasions the Point of Light in Question to fall sometimes higher, sometimes lower.

The Angle at the Point, where the two Sides reunite, is very unequal; varying from 20 Degrees, to 8 only. Mr. *de Mairan*, moreover, reports certain Observations of Mr. *Cassini*, who had found it of an irregular Figure, and curve like a Sickle; and of Mr. *Facio de Duilliers*, who describes the Sides with such Points as are called in Geometry Points of *Re-curvedure*, or contrary Reflection, like those of two Conchoids upon the same Asymptote.

One of the most essential Particulars, that we know concerning this Phænomenon, and for which we are indebted to the great Sagacity of Mr. *de Mairan*, is, that the middle Section of this Light, or of the Matter that reflects it towards us, is the same as the Plan of the Sun's Equator, they both having the same Nodes with our Ecliptic, with which they make an Angle of 7 Degrees and a half. This is, at least, a probable Demonstration*, that this Matter belongs naturally to the Sun: It is not without Reason, therefore, that the Name of solar Atmosphere has been given it. Tho' we must not confound it with the Atmosphere that encompasses the Sun nearer his Body, and in which swim the solar Spots, making with it their periodical Revolution in 25 Days and an half.

The Figure of this outward Atmosphere is a very flat Spheroid, whose greatest Diameter is often 5, or even 8 or 9 Times larger, than that which is imagined from one Pole to the other. Its Extent at different Times is so unequal, that its superior Point is some-

* Demonstration must be taken here in a large Sense Extending to a probable Conjecture.

times much below the Orbit of the Earth, and sometimes much above it. This inclined Mr. *de Mairan* to believe, that this Spheroid was very excentrical, and that its Apfides had a Motion much more quick, and perhaps less regular, than those of the planetary Orbits. It is evident then, that the Aphelion of this Spheroid must extend to between the Orbits of Mars and the Earth, and that its Perihelion must terminate above the Orbit of Venus, without reaching to that of the Earth.

On this Occasion it is pertinent to enquire, How it comes to pass that the Earth and the Moon, which both enter this solar Atmosphere, feel no Resistance from Matter, that must necessarily have some sort of Density? Why the Velocity of their Motion is not retarded? Why, in a Word, the Orbit of the Earth becomes not gradually less, from Age to Age, as it must infallibly do, if this Motion was made in a Medium that resists?

It is an incontestible Truth, and demonstrated by Sir *Isaac Newton* in the 4th Section of the 2d Book of his Philosophy, that the Density of a Medium being laid down in reciprocal

ciprocal Proportion of the Distances from the Center of Motion, and the Gravity in double reciprocal Proportion of these same Distances, the circular Motion must change into that of spiral ; and that this Spiral is precisely the same that *Descartes* and Father *Merfenne* first discovered ; namely, that which divides all the Radii proceeding from one only Center, under an Angle always equal. Therefore, if the solar Atmosphere envelops the Earth and the Moon, the Years ought continually to grow shorter, because the Orbit is continually contracted ; the Velocity both of the annual and diurnal Motion, must always diminish ; the apparent Diameter of the Sun will grow larger to our Eyes ; his Heat, with regard to us, will augment, till at last it destroys every living Creature upon Earth.

I think myself able to solve this Difficulty, in the following manner. All the smallest Parts of this Atmosphere are as so many little Planets, which turn round the Sun almost in the same manner, and the same Sense, as the great ones which we have hitherto known under that Name. Hence it follows, that they have themselves, continually, Velocities
very

very little different from those of the Earth at the same Distances from the Sun.

Every one sees, that an Assemblage of Particles, which turn with the same Rapidity as a Body of considerable Magnitude, that is encompassed by them, cannot make any Resistance to the Motion that this Body makes from the same Principles. Every one sees also, that the Velocities of this Assemblage of minor Planets, if they sometimes resist a little the Motion of a greater that happens to be among them, these Velocities being increased on the opposite Side, will soon make it regain what it before had lost.

We are obliged, particularly, to the celebrated *Facio de Duilliers* for this Idea. Tho' that great Geometrician did not foresee the Inconvenience, that would arise from the Resistance of this Matter with regard to the Motion of the Earth, the Moon, Venus, and Mercury ; he was yet the first who let us know, that this Light was probably a spheriodical Collection of small Planets ; as the Milky Way is only an infinite Number of fixed Stars, so small that we cannot distinguish them.

But

But how is this? Some one will say, You have destroy'd the Vortices of *Descartes* in your 16th Chapter, and would you now establish another Vortex, entirely contrary to your Principles? This Atmosphere, which, according to you, turns incessantly round the Sun, and whose Motion extends beyond the Orbit of the Earth, is it not a new Tourbillon, which you substitute in the Place of that you have taken so much Pains to annihilate, in favour of *Newton's* Philosophy? And, *Vortex* against *Vortex*, why is not that of *Descartes* as good as yours?

*The first
Objection
against the
Sentiment
of Mr. de
Duilliers.*

To this I answer, That the Vortices of *Descartes* are very different from the circular, or elliptical Motion of the small Planets of this Atmosphere; to which I consent that the Name of Vortex may be given, if any one approves of it, provided he allows me at the same time, that it has no Resemblance with those of *Descartes* *. It is not necessary to repeat here all the Inconveniences of these Vortices, which we have examined in the preceding Chapters; we will be content with

* Of that there must be special Care taken.

mentioning only one Thing, in which they differ from that we are treating of. That the Vortices of *Descartes* may, in Fact, have Force sufficient to carry round the Planets that swim in them; it is necessary that the Planets should never have either more or less Matter than the Part of the Vortex that puts them in Motion; which is contrary to Experience; for their Motion in their Aphelia is much slower than in their Perihelia, and yet the Quantity of Matter which they contain, is always the same. That which gives them their Rotation, therefore, is not a Power imprinted on them by any foreign Matter; for if it were, that Matter being more large in their Aphelia, and more close in their Perihelia, it would produce a quite contrary Effect*. But our Vortex must not be taken for a primary Spring of the planetary Motion, because we consider Gravity, or Attraction, towards the Sun, as the true and primitive Cause of that Motion. All the Use we make of it, in short, is only to retard the Motion

* But if the Distance between the Sun and the Earth in the Vortex be sometimes greater, the Earth having broader Space will move slower therein.

of the Earth, and the inferior Planets *; which is very different from imprinting a Motion on them, like the Vortices of *Descartes*.

An Objection much more real may be made, from the Nature of circular or curvilineal Motion, caused by some central Body towards which all others are attracted. There is no Doubt but that the Center of Powers must be always in the same Plane in which the Motion is made ; for this is a necessary Consequence of the Demonstrations, by which, in the 19th Chapter, we proved the Equality of Areas described in equal Times. How then, it will be said, can it be possible that two or more Bodies, whose Circulation begins in different Planes, but at equal Distance from the Sun, should avoid clashing together somewhere, before they finish even their first Revolution ; since it is impossible that two different circular Planes, which have the same Center, should avoid intersecting each other in two Points of their Peripheries? We do not see, however, that this happens with re-

*A second
Objection.*

* But the Particles about it moving equally fast, as Page 319, Line *ult.* they can be no Hinderance. See also Page 327. l. 9.

gard to the Matter that produces the Zodiacal Light, because such a Clashing as this would soon reduce it into one Mass, and make of it a new Planet, according to the Theorems of Motion caused by Percussion, demonstrated so clearly by Mess. *Mariotte*, *Huygens*, and *Herman*. Tho' certain Sparks of this Light observed by Mess. *Cassini* and *de Quilliets*, demonstrate pretty clearly that this Clashing of the little Bodies that compose the Matter of it, is a very common Thing, this does not hinder that Matter from continuing to subsist, or from having its Vicissitudes of Diminution and Increase. But a Clashing in the Intersection of two, or more Plans, such as that we have just been speaking of, has never been remark'd, and certainly never will be.

To solve this Difficulty, we must consider what would happen if there was a second Earth, of the same Figure and Magnitude with ours, and if these two Earths were so to touch one another at the two Poles of their common Orbit, as that the meridional Pole of the one was applied immediately to the septentrional Pole of the other : It is certain that the Center of the one and the other would

would describe a particular Orbit, whose Plane would not only not pass thro' the Center of the Sun, but would even be distant from it the whole Semidiameter of each.

I proceed farther. If in the Room of these two Earths we suppose 4, 6, 8, or more, we must necessarily recur to the same Reasoning; and the Multiplication of these Bodies on every Side, will produce only a Multiplication of particular Orbits. But the common Center of Gravity of all these Earths joined together, situated at the Point of Contact of the two middle Poles, will at the same Time describe an Orbit that shall hold the middle Place of all the rest, and pass unavoidably thro' the Center of the Sun *.

To return to the little Bodies that compose this Atmosphere; let us suppose all those which are at the same Distance from the Sun to touch one another, and there is no Doubt but they will unite eternally, as would do a Row of Earths, which had all equal Revolutions round the Sun. A superior or inferior Order of these Bodies, it is true, would make

* These are like the ingenious Hypotheses of *Descartes*, that will not solve Difficulties except they be proved true.

a particular Revolution in a Period of Time
 fferent from that of the preceding ; but
 they would be always in Union among them-
 selves, and without ever quitting those of the
 same Rank. It signifies little whether the
 different Ranks, superior and inferior, touch
 one another, or not, provided there be nei-
 ther Inequality nor Friction, which may re-
 tard their Motion.

*A third
 Objection.*

A third Objection, that may be made a-
 gainst the Motion of the solar Atmosphere,
 we imagine is this: The periodical Revolu-
 tion of the Sun's Spots, and consequently of
 the lower Part of this Atmosphere, with which
 these Spots evidently make their Revolution,
 consists of 25 Days and an half, which are
 counted from the Time that one Part of this
 Atmosphere is under any particular fix'd Star,
 to the Return of the same Part under the
 same Star.

Let us now compare the periodical Revo-
 lution of the Sediment of the solar Atmo-
 sphere with the Time employ'd by the Parts
 situated in an Elevation equal to that of the
 Earth. To effect this, we begin by laying
 it down as a Principle, that all Planets, both
 great

great and small, make their Revolutions in the same Region of Heaven in equal Times*. This is what no Person can deny, without contradicting Experience itself, which proves that the Disproportion of the Masses of Jupiter, Mars, and Mercury, creates no Disproportion in the Times of their periodical Revolutions.

The planetary Bodies or Particles of this Atmosphere, being at an equal Distance with the Earth, will make their Revolutions then in a Year ; but to explain the Thing fully, we must have Recourse to this Rule of *Kepler* : As the Cube of 213 Semidiameters of the Sun, which make the mean Distance of the Earth from that Luminary, is to the Square of 525,949 Minutes, or a Year ; so is the Cube of one single Semidiameter of the Sun, to the Square of between 169 and 170 Minutes. The Bottom, or Sediment, of the solar Atmosphere, ought then to turn in between 169 and 170 Minutes ; but Experience teaches us, that its Revolution takes up 25 Days

* Abstracting from the Vicinity of other Planets, and Comets.

and $\frac{1}{2}$, as we have already seen; which makes a Disproportion too obvious.

To shew that this Objection has in it more Appearance than Solidity, it will be sufficient to say that the solar Atmosphere is separated into two Parts by a Vacuum so large, that the superior Part can have no Communication with the inferior. Now as this Separation permits the inferior Atmosphere to follow the Motion of the Sun round his own Axis, and to have the same periodical Time, it gives us a Right to maintain that the superior Part, that it may not fall upon the inferior, has need of a planetary Motion, whose centrifugal Forces may counterbalance the centripetal. Every one then must be obliged to allow, that this superior Atmosphere ought to have different Degrees of Velocity in its different Parts; otherwise the lowest would continually descend toward the Sun, and the highest in like manner might be elevated above Saturn.

Of COMETS.

Sir *Isaac Newton* was the first that gave us a true Idea of the Comets Motion. Nevertheless

theless Mr. *Cassini*, the Father, had before found the way to predict their apparent Situation, when they are not too near the Sun. For, though he knew very well that their Motion is curvilinear, he yet supposed the Curvature to be so little sensible, that it might be look'd upon as a right Line; and by the Help of this Supposition, he found out a Calculation that differs little or nothing from Sir *Isaac's*; since the more the equal Segments of a Parabola remove from its Summit, the more they approach to a right Line.

When Sir *Isaac Newton* invented the Hypothesis of the parabolical Motion of the Comets *, to render its Calculation more geometrical and less perplex'd, he did not actually believe that the Curvatures of their Way were true Parabola's. On the contrary, in the 42d Proposition of the 3d Book of his *Philosophy*, he teaches the manner of finding by Approximation the grand Axis of their elliptical Orbits; with this Restriction however, that these Orbits are of a Figure so oblong, that we cannot see them all entire. We do not see the Comets therefore, but

* It was found to be matter of Fact from Observations, and no Hypothesis invented by him.

when they are in their Perihelia, because all the rest of their Course is made in Regions so remote, that our Sight cannot extend so far. What we see of the Orbit of a Comet, is often not equal to an hundredth Part of what we do not see. For as the Comets do not usually begin to appear till they are descended to a Distance nearer the Sun than Jupiter, and farther from him than Mars. When they return into the superior Regions, and attain a Distance from the Sun equal to that of Jupiter, their Light is so weak that it is perceived with the utmost Difficulty.

As a Parabola is nothing else but an Ellipsis, whose Center is infinitely remote from its Focus, this Term is used, according to Sir *Isaac's* Rules, in the room of Ellipsis, when the precise Measure of the two Axes is not known, provided that the greater Axis exceeds the lesser at least 20 Times. Otherwise, it would not only be a considerable Fault to prolong the parabolical Motion beyond the Distances in which Comets are visible, but we should moreover deprive ourselves thereby of the Hope of ever seeing them again.

Thus

Thus the Motion of the Comets round the Sun so far resembles that of the Planets, that though the former approach much nearer that Luminary than the latter, they are not liable to impinge upon him, when the Curve of their Motion becomes perpendicular to its Distance. For the centripetal Force being less than a third, in proportion to the Distance of the Sun and the Velocity of the Perihelion, the Planet or Comet is no sooner arrived at its greatest Proximity to the Sun, but it begins to recede from that Luminary again *.

Why the Comets and the Planets do not impinge upon the Sun in their Perihelia.

Its Atmosphere, Duration, Tail, and Return, are the most remarkable Particulars relating to a Comet.

The Atmosphere of a Comet differs from that of an ordinary Planet, in that it is larger in proportion to the Body it surrounds. Some of them have 15 Times as much Diameter as the Comets themselves. Likewise the same Atmosphere is not always equally extended, because it diminishes and increases by Fits.

* But when its near the Aphelion the centrifugal Force is far greater than the attractive Force, but all on a sudden the attractive Force exceeds the former.

It

It is not well known yet, whether these Diminutions and Augmentations return regularly at the same Distances from the Sun and the Perihelion. For, according to the Observations of *Hevelius*, cited by *Newton*, these Atmospheres diminish in proportion as they come nearer the Sun, and augment according as they remove from him. On the contrary, Mr. *de Mairan* assures us, that they encrease on approaching the Sun, by the Parts of the solar Atmosphere that they carry away with them as they pass along : Both these Opinions seem founded on this, that the Atmospheres of the Comets probably diminish till they meet that of the Sun, from which they acquire new Materials. Moreover, these Atmospheres, containing an Air like ours, must always occupy more Space when they descend towards the Sun, than when they ascend from him ; because this Air rarifies extremely when they descend, and condenses in like manner when they ascend.

The Duration of the Comets is proved, according to Sir *Isaac's* reasoning, by the Degrees of Heat they undergo in their Perihelia.

This

This Philosopher made a Calculation, that the Comet in 1680, which passed by the Sun's Surface at the Distance only of a 6th Part of his Diameter, must contract a Heat 2000 times greater than that of red hot Iron. Whence he concluded that this Body must be very compact, and as antient as the World; otherwise it could not have resisted the Rays of the Sun, in that Proximity, but must have evaporated.

As the Sentiment of Sir *Isaac* is a kind of Paradox to those who have made no Progress in these Matters, it is proper to see how he supports it. The Line comprised between the Center of the Sun and the Comet in Question, in its Perihelion, was to the Radius of the Earth's Orbit as 600 to 100,000. The Heat perceived on Earth then, was to that of the Comet as 360,000 to 10,000,000,000, or as 1 to 28,000. Now as the greatest Heat in Summer is to that of boiling Water but as 1 to $3\frac{1}{2}$, and as this last is yet four Times less than that of red hot Iron, he found that the Iron's Heat was to that of the Comet as 14 to 28,000, or as 1 to 2000.

If

If a Ball of red hot Iron loses its Heat in one Hour, and the Time necessary to cool the heated Spheres be in proportion to their Diameters and Degrees of Heat ; it will require 108 Millions of Years to cool the Body of that Comet, provided it be so large as our Earth.

*Why the
Orbits of
the Comets
are so ex-
centrical.*

This Reflection discovers to us, and makes us equally admire, the Wisdom of the Creator. Nothing could subsist in the Comets, if they had not a Heat sufficient for the Preservation of their Matter. Nature, to the End she might give them as much Heat as they have need of, even in Regions the most remote, where a circular Motion, or one but little excentrical, would have deprived them of the Sun's Heat, has augmented so considerably their Excentricities, that they contract such a Heat in a very short Time, as makes them enjoy a temperate Warmth during the rest of their Revolution. But if, on the other Side, there are animate Creatures in the Comets, as Mr. *Huygens* has proved there are in the Planets, they must of necessity retire into the interior Cavities of these Comets,

to

to fecure themfelves from that general Conflagration on their exterior Surfaces.

To confider the irregular Figure of fome Comets, one would judge that they do not turn upon their Axes ; becaufe they cannot have this Rotation without having at the fame Time a fpherical, or a fpheroidical Figure, and one Body only enclosed in their Atmosphere. But fome of them have been feen, that were neither exactly fpherical nor fpheroidical ; others, that feemed to be an Affemblage of divers Bodies, of different Figures and Magnitudes ; which no Ways agrees with a diurnal Motion, and renders the Pofition of their Axes extremely variable. Befides this, their Tails, which are very unequal, and change almoft every Moment, muft either fenfibly retard, or totally flop the Rotation in Queftion ; which has not yet been obferved.

But if the Comets do not turn round on themfelves, the fame Part, before and after their Conflagration, muft be almoft always expofed to the Sun ; and confequently, one Part only of their Spheres can be habitable, becaufe that continually fees the Sun, and the
other

other is buried in a Night of many Years, or many Ages Duration ; which, nevertheless, does not hinder but this Hemisphere may have as much Heat as that which is illuminated. To explain this Paradox, we will add to what has been said concerning their Excentricity, Page 334, that the Heat which they may receive from the Sun in their Aphelia, is not the 10,000 Part of what is felt at the Poles of the Earth ; and that the Heat contracted in their Perihelia, must afterwards continue equal over all their Surface.

The Smoke which issues from the Comets, and which disperses itself in the Regions of Heaven that they traverse, composes their Tails. They begin to form themselves a little before the Comets arrive at their Perihelia, and from the Time that the Sun's Heat is intense enough to enflame the combustible Matters on their Surfaces, when the Smoke makes a Breach through their Atmospheres. It is true, however, that this Conflagration begins a little before we perceive the Smoke ; but we consider here only the Instant when we first discover their Tails.

They are never longer than when the Comets ascend from their Perihelia, after which they diminish daily, even at the Time that they approach the Earth. From these Degrees of Augmentation and Diminution, the learned *Newton* found that the Tails of Comets were only Smoke. This was farther confirmed by their Direction, which extends always towards the Parts opposite to the Sun. We cannot give a more sensible Comparison of the Times, than that which our Philosopher has given, tho' it will require to be a little more circumstantiated.

Let us conceive to ourselves the Idea of a lighted Torch, with the Wick reversed, that, by a projectile Motion, surrounds the Earth; all its Smoke will ascend, and endeavour to get away from the Center of the Earth, notwithstanding this Inversion. Farther, this Smoke will so incline towards the Regions contrary to the Motion of the Torch, that the upper Part of it will seem to move more slowly than the lower: And, what is yet more remarkable, the Smoke will appear broader at Top than at the Bottom; as we see by that which issues out of Chimnies, which al-

ways

ways occupies more Space than it did before. All this agrees perfectly with the Phænomena of these Tails. The kindled Part of a Comet, which is that towards the Sun, drives its Smoke to the Parts opposite to that Luminary.

This Smoke has always some Curvature at its Extremity, which is reclined, or beat backwards, in proportion to the Length of the Tail; the longer this, the greater the Curvature; and the Curve Extremity is also larger than that which adheres to the Body of the Comet. This Comparison is so exact, that it leaves no Room to question but the Tails of Comets are real Smoke, caused by their Conflagration on approaching the Sun.

Mr. *de Mairan* very ingeniously assigns another Cause to the Tails of Comets, which we shall here insert, and endeavour to reconcile, as much as possible, with that which *Newton* has just now furnished us with. He remarks, that the Comets, as they pass by the solar Atmosphere, amass not only Particles which incorporate with them, as was before observed, but others also, which cannot suddenly follow the Comet, but detach themselves from it,

it, to form behind it a kind of Cone: Which Figure, according to that great Philosopher, being rejected or pushed by the celestial Matter, takes a Rout contrary to that of the Comet, as the Hair of a Man's Head, when he walks, or runs, against the Wind, takes a Direction contrary to that of the Head.

This Comparifon is good with regard only to the growing Tails of Comets, which have not yet attained their Perihelia. For the conic Collections from the folar Atmosphere, drawn by the Comets after them, and the Beginning of their Smoke, which are the two Causes affign'd, as they both produce the fame Appearances, fo they both muft have the fame Effects upon our Sight. But beyond their Perihelia, the celestial Matter directs that which hangs on the Comet towards the Sun. Therefore no one ought to be furprifed, if the Smoke of Comets is much more eafily obferved, than this little Affemblage of Matter that they carry along with them.

The periodical Revolutions of the Comets, is what at prefent engages the principal Attention of many Philofophers. The Return of that which appear'd in 1682, may be predicted

dicted for the Year 1757 or 1758. There is the greatest Room to believe it was the same that was seen in 1607; for there was so little Difference found between the Velocity, the Nodes, and the Inclination of the one and the other, that it may be considered merely as an Effect of the Attraction of the Planets, and the other Comets.

Mr. *Cassini* has discovered, that almost all these transient Bodies have a Road different from that of the Planets. It has hitherto been unknown of what Consequence this new Zodiac, and this periodical Return of the Comets, may be for the Preservation of the human Species. Imagine, for Example, that there are fortuitous Bodies, which accidentally fall in with our Ecliptic: What a Disaster would it be for our Earth, if unhappily she should find herself in the same Point? The Idea of two Bombs, which burst on clashing together in the Air, is infinitely below what we ought to have of such a Rencontre as this. Happily for us, it has been discovered that the greatest Part of the Comets, in the Nodes of their Orbits, are much less remote from the Sun than either our Earth,

Earth, Venus, or Mercury. This is the whole Foundation of our Security, and hence we learn how many Thanks we owe the supreme Being for so great a Benefit.

The Comets, by their unexpected Returns, sometimes produce Phænomena altogether surprising, when their Cause is unknown. Such was, according to Mr. *Whiston*, that extraordinary Eclipse of the Sun spoken of by *Herodotus*, which arrived in the Spring of the Year 4334 of the *Julian* Period, when *Xerxes* departed from *Sardis*, the Capital of *Lydia*, where he had spent the Winter. Such was also, according to *Wolf*, that of the Moon, which happened in the 14th Century, that celebrated Mathematician having shewn in his Elements of Physic, after *George Phranza*, that this Phænomenon could not happen naturally, the Moon being then in one of her Quarters. To conclude, such was that of which *Gregory Abulpharachius*, an *Arabian* Author, makes mention in his History of the oriental Dynasties, where he remarks, that under the Emperor *Heraclius* the Sun appeared all over the Earth, for the Space of three Days, as red as Blood, which might well

well happen, by the Interposition of a Comet's Tail.

Of the FIXED STARS.

A seeming Contradiction of the Newtonian System, with regard to the fixed Stars.

As Sir *Isaac Newton's* System seems to contradict itself with regard to the fixed Stars, which, according to him, attract one another, and yet remain immoveable; we must begin with explaining his Sentiment, and shewing, that it does not imply any Contradiction at all.

The Distance that there is between one fix'd Star and another is so immense, that they could not descend towards each other so much as one single League in a Year. This is what will be seen in the following Calculation. 1st. Ponderous Bodies, according to our Computations, Page 244, descend (if we keep to round Numbers) at least 1,260,000 Feet upon the Surface of the Sun, during the first Minute. 2dly, According to *Huygens*, the nearest fixed Stars to the Sun are distant 28,000 Semidiameters of the Earth's Orbit, or thereabouts, that is to say, above 5,600,000 solar Semidiameters, the Square of which is 31,360,000,000,000. The nearest fixed Star to the Sun, therefore, advances towards him
the

the $\frac{1260000}{31350000000000}$ Part of a Foot, during the first Minute. But if, instead of this Fraction, we reckon the $\frac{1}{25000000}$ Part of a Foot, we shall find for the first Year 11,000 Feet, which is very near the exact Number, with regard to the Sum total.

Sir *Isaac Newton* has demonstrated, in the 12th Proposition of the 3d Book of his *Philosophy*, that the common Center of Gravity of our planetary System, would be distant one solar Semidiameter from the Center of the Sun himself, that is about 4,000,000,000 Feet, if all the Planets were on one Side, and this Luminary on the other. What Disproportion then, between the Disorder of the Sun, occasioned by the Planets that encompass him, and that which proceeds from the fixed Star that is nearest to him ! even no less than between 11,000 and 4,000,000,000 Feet !

Now as the Sun is sometimes on one Side of the universal Center of his proper System, and sometimes on the other, and as the same thing happens to every fixed Star, with regard to the unknown Planets that surround it, the manifest Result is, that these luminous Bodies are reciprocally attracted by Forces
much

much weaker than those which sometimes draw them from each other. These Vicissitudes then, of Proximity and Distance, are what always retained the fixed Stars in their natural Situation, without any Possibility of their ever falling upon one another.

As certain fixed Stars, which, according to the Observations of *Montanaro*, have disappeared within some Years past, and have not destroy'd the Stability of those which remain, it may be proper to enquire what may be the Causes of their disappearing *. The celebrated *Wolff* specifies three of these Causes in his *Physicks*. 1st. They may, according to him acquire Motion, and thereby withdraw themselves from our Sight. 2dly, By falling back into Chaos, they may burst, and evaporate entirely. 3dly, They may lose their Light, either altogether, or in such a Degree as to make them invisible to us.

The first of these Causes appears by so much the less probable, as the Attraction of

* The Stars that disappear cannot be called fixed; they are more likely Planets revolving about a fixed Star, which appear when they come near the Earth, with their luminous Part towards it, as that in the Whale, the Swan, and Hydra, which have their periodical Returns.

the fixed Star, which should disappear, would become stronger, and would precipitate all the Bodies that might environ it, one upon another. The second is not more probable, since this pretended Diffolution must change the reciprocal Gravitation of the Stars that were nearest to that which should evaporate; so that, for the future, they would have nothing to keep them in Equilibrium. We will therefore adopt the third, because by supposing the Stability of the* fixed Star, we suppose it to preserve all its attractive Force.

The same Judgment should be made of the periodical Returns of the Apparition and Occultation of certain Stars, that have been observed in the *Whale*, the *Swan*, and the *Hydra*. For tho' the Part which is towards us be more or less luminous, and we sometimes lose Sight of it entirely, yet they never quit their Places, but their Attraction continues to preserve the Equilibrium of the Universe.

It follows, from all these Arguments, that the reciprocal Gravitation of two fixed Stars, does not diminish precisely in the inverse or reciprocal Proportion of the Squares of their

* Then they disappear, because their Light is put out; but what puts it out?

Distances, especially near the common Center of their Gravity. It follows also, that the Law of Gravitation may vary, as may be seen at the End of Chap. VII. where the different sorts of Attraction are spoken of. The Action of the Loadstone upon Iron * in inverse Reason of the Cubes of their Distances, and that of transparent Bodies upon the Rays or Atoms of Light, sufficiently prove, not only the Possibility, but the Reality of what is here advanced.

* Action of the Loadstone on Iron, being mechanical, cannot be called Gravitation.

C H A P. XXV.

Of the second Inequalities of the Motion of the Satellites, and the Phænomena that depend thereon.

AFTER having given the Reader, in the XXIst Chapter, several Particularities of the Moon's Motion, to establish the Necessity of Attraction; it remains that we should shew in this, that the Theory of these Inequalities, caused by this Mechanism, is entirely conformable to Observations.

Sir *Isaac Newton* has assigned three Causes of these sorts of Irregularities. He maintains, 1st. That the Force which draws the Moon towards the Earth, is less than that which draws these two Planets towards the Sun; 2^{dly}, That, considering the Orbits as exactly circular, the Force which attracts the Earth towards the Sun is always equal, whereas that which draws the Moon towards the same Luminary is greater in her Conjunction than in her Opposition: and 3^{dly}, That the Lines of Attraction, which tend towards the Sun, contract

contract themselves in Proportion as they come nearer him, and always augment the Gravitation of the Moon towards the Earth, especially when that Planet is in her Quadratures.

If we suppose, for Example, that the Moon is in Conjunction with the Sun ; it will appear, that, by her Gravitation only towards the Earth, she will describe, in 10 Hours 20 Minutes, a small Arch, of 100 such Parts, whereof 1000 compose the Radius of her Orbit, and 336,000 make her Distance from the Sun. Now if, during this Time, the Moon describes 100 Parts of her Radius, it follows that (according to the Rule of circular Motion, mentioned Page 331, Line 7.) as 1000 Parts of this Radius are to 100 (a Line which differs little from the Arch in Question) so the Number 100 is to 10, the uniform Descent of the Moon towards the Earth. But if we would determine the Descents of the Earth and the Moon towards the Sun, we must conform to the Rules given Page 233, and proceed by this short Operation. 1st. As 1 (the Moon's Distance from the Earth) divided by the Square of a periodical

dical

dical Month, is to 337, divided by the Square of a Year ; so 10 (the Descent of the Moon towards the Earth) is to 19, the Earth's Descent towards the Sun. 2dly, As the Square of 336,000 is to the Square of 337,000 ; so 19 (the Earth's Descent towards the Sun) is to $19\frac{1}{168}$, the Moon's Descent towards that Luminary. There must then be $\frac{1}{168}$ of one single Part of the Moon's Radius, taken from 10 Parts of the same Radius, to find her true Descent towards the Earth ; which will in Fact be only $9\frac{1}{168}$; whereas it would be 10, without the particular Action of the Sun upon that Satellite. By the same Reason the Moon's Distance from the Earth, which was laid down at 1000 Parts, will be found to consist of $1000\frac{1}{168}$ Parts ; which contributes yet more to the Diminution of her Gravity.

Whilst the Moon is yet so little distant from her Conjunction, the Force which impels her towards the Line of the Syzigiaë is not at all considerable ; but it augments in proportion as this Planet comes nearer her Quadrature. When, on the contrary, she has attained her Quadrature, that second force, which
acts

acts in the same Sense as her Gravity towards the Earth, drives her always towards our Globe, till, being in her Opposition, she finds herself distant from it only 1000 Parts.

By the Mixture of these two Forces, the Distance of the Moon from the Earth, in her Quarters, will be from 1023 to 1024 Parts, continuing the Calculation, which we have before sketch'd out, and remembering the Obliquity arising from the Configuration of that Satellite with the Sun. As for the rest, we do not here any longer admit of Excentricity ; if we did, the Orbit would be always oval, tho' of different Breadth and Figure, according to the Capacity of the Angle comprised between the two Lines of the Apfides and the Conjunctions. For supposing this Angle nothing, the Excentricity becomes larger than if we suppose it of 90 Degrees ; since in the first Case, the grand Axis is 2000, and in the second, 2047. Our Dimensions, it is true, are not the same with those of *Sir Isaac Newton* : But as that great Man acknowledges, towards the End of his Preface, that his Lunar Theory hath its Imperfections, we have thought it sufficient to keep close
to

to his Principles, without subjecting ourselves to his Menfurations.

As to the Satellites which compofe Saturn's Ring, we fhall find, by a fimilar Calculation, that the grand Axis of their Orbit is to the fmall, as $1000\frac{1}{2}$ to 1000, and that, confequently, this Orbit is 2,250 Times lefs elliptical than that of the Moon.

But to fatisfy thofe who may doubt whether our Calculation be conformable to Observations, let us return to the Excentricities, which we have only pointed out before, and fhew, by a new Computation, that they agree with the apparent Diameters, and horary Motions of the Moon.

When the Apfides fall in the Syzigie, the greateft Excentricity of the Orbit being, according to the moft famous Astronomers, to the mean Distance of the Moon, as 67 are to 1000, one may eafily conceive that the Apogæon is diftant from the Earth 1067, and the Perigæon 933. By the fame Reason, when the Apfides are at the Quarters, the Excentricity in queftion being but 44, and the mean Distance 1024, that of the Apogæon to the Earth ought to be 1068, and that of the Perigæon 980. Now

Now the apparent Diameter of the Moon in her Apogæon, consists (to count without Fractions) of 29 Minutes and 40 Seconds, and never varies more than from 1067 to 1068. On the contrary, it varies always in her Perigæon from 34 Minutes to $32\frac{1}{2}$ Minutes, that is, in reciprocal Proportion of 933 to 980. Therefore the Distances of the Apogæon and the Perigæon are precisely, according to our Calculation, in reciprocal Proportion of those apparent Diameters, that have hitherto been found by Observation.

The Exactness of these Relations is no less proved by her horary Motion. For while the Areas described are equal, these Motions are always in reciprocal Proportion of the Squares of Distances. Thus, as the Square of 933 is to 29 Min. 20 Seconds, the Horary of her Apogæon ; so is the Square of 1067, agreeably to Observation, to 38 Minutes, the Horary of her Perigæon in the Syzigie. And if the Square of 980 produces 29 Min. 20 Sec. that of 1067 will produce, conformably to Observation, 35, for the Horary of her Perigæon in the Quarters.

It appears also, that, by the same Laws of Gravitation towards the Sun, the Moon, which is not in the Ecliptic, ought to approach it even to the Syzigiaë; because, according to the Angle of her Orbit with ours, her Latitude continually grows less than it ought to be. This Latitude then diminishes every Moment; and whereas in the Quadratures, near the Nodes, it was of 5 Deg. 18 Min. it is barely of 5 Deg. both in the Conjunctions and Oppositions; which renders the Surface of the Orbit curvilinear. If, on the contrary, the Nodes are in the Syzigiaë, the Action of the Sun doth not diminish the Latitudes, the Angle in question remains always the same, and the Orbit becomes a plain Superficies. As to their Motion, it is then extremely slow, because the Action of the Sun, which, during a pretty considerable Space of Time, is almost parallel to the Distance of the Moon and the Earth, never slackens at all: But it is not the same in the Quadratures, where they have a considerable Retrogradation. For the Moon meets them every Month about three Hours sooner, especially at the Middle both of her Increase and Decrease, where the Difference

rence of her Gravitation, and of that of the Earth, towards the Sun, augments and diminishes more swiftly than any where else.

*Motion of
the Terres-
trial Poles,
Page 258.*

The Precession of the Equinoxes, as well as the Retrogradation of the Nodes, is moreover an Effect of these Irregularities, tho' much more slow; because the Quantity of terrestrial Matter, which is under the Equator, differs very little from that of the Meridians; and because that little *Excess*, under the Equinoctial, supplies the Place of a Satellite, or a Ring, such as that about Saturn.

There are some other Causes, which render the Motion of the Satellites a little irregular, but whose Effect is not considerable, except with regard to themselves. It has been remarked, that the Apogæon of the first and fourth Satellite of Jupiter is constantly the same with that of their central Planet; and that it is not till after many Revolutions of this latter, that the Orbit of the 3d Satellite returns to the same Inclination. Thus the Nodes of these four little Bodies have not varied,

varied, at least since they have been observed, which is more than a hundred Years. In a Word, all these Inequalities are far short of those of the Moon ; not to mention her Rotation, which differs considerably from what some have thought they have perceived in the other Satellites.

After having run thro' all these different Motions, we can by no Means excuse ourselves from shewing their Cause ; which is not so obscure as many People may have imagined. Take it in a few Words. The reciprocal Attraction of these Planets, occasioned by their Number and Proximity, is much superior to the Action of the Sun upon them. By this it is easy to judge, that the Ring of Saturn must extremely disorder the Satellites which make their Revolution round it, especially the smallest and most excentrical of them. In like manner we may judge, that the Attraction of this Ring must considerably retard the Descent of Bodies upon the Surface of Saturn. In fine, the Example of the Flux and Reflux of the Sea, will not suffer us to doubt of this Truth. For it is a Consequence of all that was said in Chap. XVIII.

that

that the Gravity of the Center of the Earth towards the Moon is always the same; whereas the Waters that happen to be between this Center and the Planet, are there attracted with more Velocity, than when the diurnal Rotation of the Earth has transported them to the Point diametrically opposite.

This is what we had to say concerning the principal Effects of the *Newtonian* Attraction, such as it was imagined by that famous Mathematician; by regarding it as the only Cause of the Refraction of Light, and as the first Spring of the Mechanism of the Universe. In Quality of a Philosopher, it is true, he assigned to it an Empire in Nature yet much more extensive, by reducing under its Laws all the Operations of Heat, the Composition and Decomposition of Mixts, the Electricity that is remarked in Amber, the Diamond, Spanish Wax, and other Bodies of like Nature: But we will not enter into this Detail, because it would carry us too far, and has besides no Relation to Geometry, which we have never lost Sight of in all this Work. We will finish it then, without speaking of the double Refraction of the Islandish Chrystal,
of

of the Diminution of the Density and Elasticity of the Air, of the Tenacity of viscous Mediums, in which any Body whatsoever may move ; and many other similar Matters. It is for the same Reason that we have but lightly touched on certain Things, such as the Precession of the Equinoxes, and the periodical Return of the Tides ; Phænomena, in which there must be yet some other mix'd Cause, that has been hitherto unknown. For if we are ignorant of what occasions the Equality of the Motion of Jupiter's equinoctial Points, and of the Nodes of his Satellites, we are no less ignorant why the Flux and Reflux of the Sea follows rather the Mean, than the true Motion of the Moon. At least we must confess, that the Concurrence of the Sun's Action with that of a Satellite, upon a principal Planet in the Syzigixæ, or their Difference in the Quadratures, cannot furnish us with the Reason of these two Effects.

Explanation of the hard Words used in this Treatise.

A.

ANecdote, is a secret History, or private Memoirs.

Attraction is the Effect of a Power in Matter, by which all Bodies tend to one another, with a Force in Proportion to the Quantity of their Matter.

Atmosphere is all that Air that surrounds the Earth, which rises 50 Miles above its Surface, as appears by the Mercury in the Barometer.

Aries is the first of the 12 Signs in the Ecliptic, each containing 30 Degrees.

Area is a Space inclosed on any Superfice.

C.

CUBE is a solid Figure, in which all the Dimensions, Breadth, Height and Depth are equal, or a Number arising from its Square, multiplied by the Root, as 27 comes from 9 by 3.

Convex is the Outside of a curve Line, or Superfice.

Concave, the Inside thereof.

Cone is a solid Figure, wherein its circular Base tapers, till it come to a Point, as a Sugar Loaf.

Converge. Lines are said to converge, when they come nearer to one another the more they are continued, and do at last meet in a Point.

Catoptricks is a Science, in which the Laws of the Reflection of Rays are explained and demonstrated, as why an Object appears in one Part of a Looking-Glass, and not in another, &c.

Cataract is a Distemper in the Eyesight, arising from a thick Crust on the Pupil of the Eye.

Centrifugal Force, is that whereby Bodies moving circularly, tend to go from the Center of the Motion called sometimes a projectile Force.

Centripetal is a Force whereby Bodies tend to the Center of this Earth, or any spherical Body by Attraction, called sometimes Gravity.

D.

Diverge. Lines are said to diverge, when coming from a Point, they go further from one another the longer they are continued.

Dead Force, is that which inclines Bodies to Motion, tho' there be none, as a Stone presses with a dead Force to the Center of the Earth.

Disc is that Part of a Globe that appears to our Eye, as in an Eclipse of the Sun the Moon covers a Part or the whole of its Disc.

E.

Ellipsis is such an oval Figure as would arise by cutting a Cone through its two Sides obliquely, such as that in our Tables that are near, but not quite round.

Equator is an imaginary Circle at equal Distance from the two Poles of the Earth, which if enlarged would reach to the equinoctial Line in the Heavens.

Ecliptic is a Circle cutting the Equator, with an Angle of 23 Deg. and 29 Min. through which the Sun seems to move in a Year.

F.

FOCUS is a burning Point near the middle of a Piece of Glass in the Form either of a Globe, where the Rays of Light would meet, or of an Egg, if its longest Diameter were directed to the Sun, it is applied to a Point in the Axis of the Section of a Cone.

G.

G*ROUP*, or Bundle, its applicable to a Pencil of Rays that come from the Sun, which may contain either the same or different sorts of Rays.

H.

H*Emisphere* is the half of a Globe, either of the Earth or Heavens, &c.

I.

I*Ndefinite* is that which, tho' it hath Limits, yet they cannot be conceived by us.

Inflection is bending, which the Rays of Light make in passing by the Edges of sharp Bodies.

L.

L*IVING* Force is that which actually produces some Motion.

Latitude is the Distance of a Place from the Equator in Degrees and Minutes.

Longitude is the Distance of the Meridian of a Place from that which is called the first Meridian, counted on the Equator in Degrees.

M.

M*icroscope*, is an Instrument in which are two or more convex Glasses, through which an Object is greatly magnified.

Meridian, is an imaginary Circle passing through both Poles, which may be conceived either in the Heavens, or on the Earth; if it pass through our Place or over us, it is called our Meridian.

N.

N*ODES* are the two Points in which one great Circle cuts another, as the Orbit of the Moon cuts the Ecliptic in two Points, that are the Moon's Nodes.

O *Orbit*

O

O *RBIT* of the Moon is not the Circumference of her Disc, but the Circle her Center describes round the Earth, or rather the Ellipsis; Allowance being made by the Attraction of surrounding Bodies.

Oscillation is the same with Vibration, or swinging of a Pendulum, or any heavy Body, hung on a Point.

Opticks is the Doctrine and Vision in which the Parts of the Eye, their Use and Manner of seeing, is described

P.

P *LANET* is a dark Globular Body, revolving about the Sun, or some other Planet, which being illuminated by the Sun, appears luminous as the Planets Jupiter, Saturn, Mars, Venus, that appear like fixed Stars, but are not.

Plenum is a Space quite void of Matter.

Parallelogram is a Figure of four straight Sides parallel, and the two opposite Sides equal.

Polar Circles are small Circles, within 23 Deg. and $\frac{1}{2}$ of each Pole.

Prism is a solid Figure, inclosed by parallel Planes, of the same Length, and is called either triangular or square, according as the two Ends are. In a triangular Prism of Glass the different Kinds of Rays are parted by their different Rarefactions.

Pores are small Spaces in Bodies thought to be void, or that do contain a fine Fluid.

R.

R *Etina* is a fine Net on the back Part of the Eye, on which the Images of Objects are painted.

Ray of Light is a most swift Motion of its Atoms from the Sun, tho' it comes also from some Flies, rotten Wood, dry'd Fish.

Refran-

362 *Explanation of the hard Words*

Refrangibility is a certain Power, by which a Ray of Light is turned out of its Course passing from one Medium into another, as from Air to Glass or Water, which Power arises from some Quality in the Ray which denominates it either Red or Green, &c.

Ratio is the Proportion between one Number, superficies, or Body and another ; two Ratio's are said to be inverse or reciprocal, when more gives less, or less gives more.

S.

Satellite is a secondary Planet, revolving about a primary one, as those of Jupiter, Saturn, and that of the Moon about our Earth.

Spheroid is an Egg-like Figure, in which one Diameter is longer than the other.

Square Number, is the Product of one Number multiplied by another, as 9 is the Square of 3, and 3 the Root of 9.

Solstice is the farthest Point the Sun goes to from the Equator, either North or South.

Sine of an Angle or Arch, is a Line from the End of it perpendicular to the Diameter.

T.

Transparent is that which admits the Light to pass easily through it.

Telescope is an Instrument in which are two or more Glasses, of such a Figure, that the Rays are brought thereby to our Eye, so as to see Objects far off distinctly, and as it were near us.

V.

Vacuum is a Space in which there is no Matter, either in the Pores of Bodies, or beyond the Limits of the World.

Z *Zenith*.

Z.

Z*Enith* is the Point in the Heavens exactly over our Head, and *Nadir* the Point opposite to it.

Zodiac is a broad Circle in the Heavens, in which all the Planets move, being about 8 Deg. broad on each Side of the Ecliptic.

Zone is all that Space comprehended either between the Poles and Polar Circles, and is called the frigid Zone; or between the two Tropicks, which is called the torrid or burning Zone; or between the Tropicks and the polar Circles, and is called the temperate Zone.

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