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TO

The Right Honourable

FRANCIS ANDREWS, LL.D.

PROVOST of TRINITY COLLEGE, DUBLIN.

AND

One of His Majesty's Most Honourable
PRIVY COUNCIL OF IRELAND,

THE FOLLOWING

ESSAYS

Are humbly inscribed,

By his most faithful

And obedient Servant,

The AUTHOR.

# National Oceanic and Atmospheric Administration

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# PHILOSOPHICAL ESSAYS

On the following Subjects:

I.

On the Ascent of VAPOURS, the Formation of CLOUDS, RAIN and DEW, and on several other Phœnomena of AIR and WATER.

II.

Observations and Conjectures on the Nature of the AURORA BOREALIS, and the Tails of COMETS.

III.

On the Principles of MECHANICKS.

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BY

HUGH HAMILTON, D.D. F.R.S.

Professor of Philosophy in the University of DUBLIN.

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# AN ESSAY ON THE ASCENT of VAPOURS, The Formation of CLOUDS, RAIN and DEW, And on several other Phænomena of AIR and WATER.

ON THE

# ASCENT of VAPOURS, &c.*

I Intend in this Eſſay to give ſome Account of the Nature of Evaporation, the Aſcent of Watery Vapours and ſeveral other Phænomena of the Atmoſphere. In explaining which I ſhall proceed upon a

* This Eſſay was read at a Meeting of the Royal Society on the 9th and 16th of *May*, 1765, communicated in a Letter to the Rev. *Charles Dodgſon*, D. D. F. R. S. now Lord Biſhop of *Oſſory*. *Vide Phil. Tranſ.* Vol. LIV. To which ſome Additions and Improvements have been ſince made by the Author.

Principle very different (as far as I can find) from any that has hitherto been uſed on this Occaſion; whereby I ſhall avoid thoſe Objections which late Writers have made to the former Accounts that have been given us of theſe Phænomena, and perhaps deliver ſomething on this Subject that may appear ſatisfactory.

In all the Accounts I have met with, Fire, or Heat and Rarefaction, by which Watery Vapours are ſuppoſed to become ſpecifically lighter than Air, are made to be the principal, if not the only Cauſes of their Aſcent into the Atmoſphere. Doctor *Niewentyt*, and ſome others ſuppoſed, that the Particles of Fire, by adhering to thoſe of Water, make up *Moleculæ* or ſmall Bodies ſpecifically lighter than Air. And Doctor *Halley* thought, that by the Action of Heat the Particles of Water are formed into hollow Spherules filled with a finer Air, highly rareſied, ſo as to become ſpecifically lighter than the external Air. This laſt was the Opinion moſt commonly received, as

Doctor

Doctor *Desaguliers* tells us in his Dissertation on this Subject (published in *The Philosophical Transactions*, in the Year 1729) in which he examines and refutes the two former Opinions, and endeavours to establish his own. He ascribes the Ascent of Aqueous Vapours to their being turned into an Elastic Steam, and always rarefied more than the Air is by the Degrees of Heat, to which Bodies are usually subject in the different Seasons of the Year.

This Opinion, I find, has been as ill received by subsequent Writers, as the former ones. Mr. *Clare*, in his *Treatise on the Motion of Fluids*, has brought many Objections against it; as Mr. *Rowning* has also done in his *System of Natural Philosophy*, not long since published; who says, that the Cause of the Ascent of Vapours has been much disputed, but not yet determined by Philosophers, and owns that he cannot think of any true Principle of Philosophy upon which it may be accounted for.

I ſhall not here repeat the Objections made by thoſe Gentlemen, but muſt beg leave to add the two following, which, among others that might ſtill be urged, they have not taken Notice of.

Firſt; If Heat was the only Cauſe of Evaporation, Water in a warm and cloſe Room would evaporate faſter than when expoſed in a colder Place where there is a conſtant Current of Air, which is contrary to Experience.

Secondly; The Evaporation of Water is ſo far from depending on its being rarefied by Heat, that it is carried on even whilſt Water is condenſed by the Coldneſs of the Air. For Water is gradually condenſed by Cold, 'till the Moment it freezes; and ſince it evaporates even when frozen into hard Ice, it muſt evaporate in all the leſſer Degrees of Cold. Mr. *Boyle*, having counterpoiſed a Piece of Ice in a Scale, hung it out in a froſty Night, and found next Morning that it loſt conſiderably of its Weight by Evaporation.

"Who

"Who would have thought, says he, that "so extremely hard and cold a Body "would evaporate so fast in the clear Air "of a freezing Night?" And since that Time others have observed the same Thing; which Fact seems to be an unanswerable Objection to all the Accounts in which Rarefaction by Heat is made to be the chief, if not the only Cause of Evaporation: and therefore we must have Recourse to some other Principle to assist us in accounting for this Phænomenon.

As the Author of Nature does not employ in his Works a greater Variety of Causes than is absolutely necessary, it is the Business of natural Philosophy to reduce as many Phænomena as may be, to some general well-known Cause; and this is to be done by comparing the Phænomena together in their several Circumstances, in which if they are found to agree, they are then to be considered as Effects of the same Kind, and ascribed to the same Cause; by which Means, the Causes, whose Existence is already proved;

will be rendered more general, and our Knowledge more extenſive. Now, as the Suſpenſion of the Particles of Water in Air, of Salt in the Waters of the Ocean, and of other heavy Bodies in the Fluids that diſſolve them, ſeem to be Phænomena of the ſame Kind, we might reaſonably ſuppoſe, that they ariſe from the ſame Cauſe, and that what we call Evaporation is nothing more than a gradual Solution of Water in Air. But that I may not propoſe this merely as an *Hypotheſis*, I ſhall endeavour to prove the Truth of it, by conſidering the Nature of Solution in general, and comparing its Properties and Effects with thoſe of Evaporation.

By Solution we underſtand, ſuch an intimate Union between the Particles of a Body and thoſe of a Fluid, that the Whole ſhall appear an homogeneous Maſs, as tranſparent as the Fluid was before ſuch Union, and ſhall ſo continue, 'till ſome external Cauſe produces a Change. The Nature of Solution has been

been explained by the Writers on Chymiſtry in this Manner: When the Particles of any Body ſurrounded by a Fluid are leſs ſtrongly attracted by each other than by the Fluid, they muſt ſeparate from each other, and join themſelves to thoſe of the Fluid, and remain ſuſpended therein: Thus various Salts are diſſolved in Water, eſſential Oils in Spirits of Wine, Gold in *Aqua Regia*, Mercury, Silver and other Metals in other acid Spirits; and indeed it ſeems to be with great Appearance of Reaſon, that the Attraction between the minute Particles of different Bodies (of which we have ſo many other Inſtances) is aſſigned as the Cauſe of that Union between them, which we experience in Solutions; the chief Properties of which I ſhall now mention, ſo far as may be neceſſary for the Purpoſe to which I mean to apply them.

In moſt Caſes a diſſolving Fluid, or *Menſtruum* as the Chymiſts call it, will diſſolve or take up only a certain Quantity of the Body which is ſoluble in it, and if any more

more of the ſame Body be added, it will fall undiſſolved to the Bottom, and then the Fluid is ſaid to be *ſaturated* with the Body it has diſſolved; yet a Fluid which is ſaturated with one Body may afterwards diſſolve others of different Kinds, and keep all their Particles ſuſpended together.

When any *Menſtruum* has entirely diſſolved a Body, it will continue as tranſparent as it was before; the Cauſe of which may be aſſigned from what Sir *Iſaac Newton* diſcovered by Experiments, *viz.* that the Particles of Bodies muſt be of a certain Size or Bigneſs to cauſe thoſe Reflections or Refractions of the Rays of Light at their Surfaces to which Opacity is owing; whence he gives the Reaſon, why ſome Bodies are opake and others tranſparent. He alſo obſerves, that the moſt opake Bodies (ſuch as Metals) being diſſolved in an acid *Menſtruum*, and thereby reduced to their ultimate and ſmalleſt Particles, do not take away the Tranſparency of the *Menſtruum*.

Hence

Hence we may always know how to distinguish a Solution from a Mixture. For, if a Body be reduced to Powder and thrown into a Fluid that will dissolve it, and they are then shaken suddenly together, the Fluid will continue somewhat opake, 'till the Solution be effected, or 'till what remains undissolved falls to the Bottom; for in this Case, the Particles are not at first reduc'd to their smallest Size, as they always are in a Solution. And therefore the Chymists consider the Transparency of an heterogeneous Fluid (or one that contains in it Particles of another Body) as the *Criterion* of a true Solution; and where that is wanting, it is only a Mixture; as when Water and Air appear together in Froth, or in a Cloud, or a thick Mist, it is only a Mixture of those Bodies, and not a Solution of one in the other.

This much being premised concerning the Nature of Solutions in general, I proceed to the Proof of what I proposed; and in Order to this, I shall shew that there

there is a mutual Attraction between Water and Air, the ſame that we obſerve between the Particles of any two Bodies, one of which diſſolves the other. I ſhall then compare, in ſeveral Inſtances, the Properties and Effects of common Solutions with thoſe of Evaporation; that from the exact Reſemblance between theſe two Phænomena, it may appear that they are Effects of a like Kind, and therefore to be explained upon the ſame Principle, or aſcribed to the ſame Cauſe. Thence I ſhall ſhew, how the Aſcent of Vapours, and ſeveral other Phænomena of the Atmoſphere may be accounted for. And laſtly, I ſhall add ſomething on the riſing of Steam from boiling Liquors, and ſhew wherein it differs from common Evaporation.

I am firſt to prove that there is an Attraction between the Particles of Air and Water. It is well known, that all Water contains a conſiderable Quantity of Air, that this Air retains its Elaſticity ſo that it may be ſeparated from the Water by boil-

ing

ing and including it in an exhausted Receiver. It has also been proved by Experiments, that Air extricated from Water by boiling, and restored to its usual Density, will occupy a Space greater than that possessed by the Water in which it was contained. Now since it is allowed that the Particles of so heavy a Body as Gold are suspended in *Aqua Regia* by their Attraction towards the Particles of that Fluid, it seems reasonable to suppose, that so light and elastic a Body as Air must be retained under Water by a like Force, without which it would always ascend to the Surface and escape. But that there is really such an attractive Force between Air and Water, may be fully proved by the following Experiment.

Let an Oil-Flask be filled almost full with Water, deprived of its Air as much as may be; let the Mouth of it be then stopped, until the Neck, being inverted, is immersed in a Vessel of Water; a Bubble of Air will then ascend into the upper Part of the Flask. When Things have stood

ſtood in this Way for ſome Days, the Water will be found to have abſorbed the whole Bubble of Air (if it was not too large) and entirely filled the Flaſk. But if the Bubble was too large, Part of it will be left; for the Water, after ſome Time, will abſorb no more Air, being then ſufficiently ſaturated with it. It is obſervable that the included Air enters pretty quickly into the Water at firſt, but afterwards very ſlowly. This Experiment ſhews that Water, when deprived of its Air, will again draw the Air gradually into its Pores; juſt in the ſame Manner as a Lump of dry Sugar will draw up Water into its Pores, which will aſcend pretty quickly at firſt, but very ſlowly after ſome Time. We have Reaſon therefore to conclude, that there is the ſame kind of Attraction between Air and Water, that there is between Water and any dry porous Body that will imbibe it.

As Water contains a conſiderable Quantity of Air, ſo does Air contain a good deal of Water, even when we think it quite

quite pure and dry; as appears from the Moisture drawn from it by dry Salt of Tartar, in such Quantity as to make the Salt become entirely fluid. Now since the Air is an heterogeneous Fluid containing in it Particles of another Body, and yet retaining a perfect Transparency, which is the *Criterion* of a true Solution in other Cases; why should we not infer from Analogy, that in this Case also there is a true Solution of Water in Air?

But the Truth of this will be confirmed by farther comparing the Properties of common Solutions with those of Evaporation; which I shall now do in several Instances.

First; When a Body is immersed in a Fluid that dissolves it, for Instance a Lump of Salt in Water, we see the Salt soon begin to dissolve, and impregnate with its Particles the Water that surrounds it, which will then appear thick and loaded, and if the Water be at rest the Solution will proceed very slowly; but if it be stirred about, the

the Salt will ſoon be entirely diſſolved. How exactly does this correſpond with what Dr. *Halley* remarked in an Experiment he made on the Evaporation of Water in a cloſe Room? (*Philoſ. Tranſ.* N°. 192.) "The ſame Obſervations, ſays he, "do likewiſe ſhew an odd Quality in the "Vapours of Water, which is, that of "adhering to the Surface that exhales "them, which they clothe as it were "with a Fleece of vapourous Air, which "once inveſting it, the Vapour riſes af-"terwards in much leſs Quantity." Here we ſee, that the Air which lay at reſt over the Water appeared thick and loaded with the aqueous Particles, and then the Evaporation proceeded very ſlowly; juſt as the Water that lies about the Salt, appears thick and loaded, and while it continues at reſt, the Salt is diſſolved but ſlowly. He alſo obſerves on the ſame Occaſion, that Evaporation is vaſtly promoted by a Current of freſh Air paſſing over the exhaling Surface: and this I have no Doubt happens for the ſame Reaſon that Solution is greatly promoted by Agitation, which

which continually brings freſh Particles of the Fluid into Contact with the Body it diſſolves, in the Place of thoſe that have been already ſaturated. [A]

Secondly; Into a Glaſs of clear cold Water throw a Lump of Salt, and when it has ſtood a little Time, ſtir it very gently, and the Water which is ſaturated with the Salt will riſe up among the reſt in curled Wreaths or long *Striæ*, which will render the Whole ſomewhat opake, cauſing it to refract the Rays of Light in different

[A] This Fleece of vapourous Air that ſometimes hangs over Water, is very diſcernable when we ſtand by the Sea-ſide in a hot calm Day, and is the Cauſe of ſome odd Appearances. For the lower Part of the Air, which is then much impregnated with Water, refracts the Rays of the Light more ſtrongly than at other Times, and by this unuſual Degree of Refraction, Houſes on the Shore at a Diſtance from us appear almoſt as high as Steeples, remote Ships and Iſlands and the extreme Parts of Head-lands or Promontories appear to be raiſed quite out of the Water, and to hang in the Air above its Surface.

Directions,

Directions, which will make an Object ſeen through it appear to have a tremulous Motion; this will continue until all Parts of the Water are equally impregnated with the Salt, and then its Tranſparency will be reſtored. As the Parts of the Water which are impregnated with the Salt are of different Denſities from the reſt, while they are mixing together, they muſt occaſion thoſe Refractions and this apparent tremulous Motion, which will ceaſe as ſoon as all the Water becomes of the ſame Denſity. The very ſame Appearances will attend the mixing together of any two Fluids which have different Denſities, and will thoroughly incorporate with each other.

In like Manner, when Smoke or Steam, iſſuing from the Pipe of a boiling Veſſel, firſt riſes into the Air, it appears in curled Wreaths, and renders the Air opake; but as ſoon as it is entirely diſperſed, the Tranſparency is reſtored. Thus alſo in a calm, hot, ſun-ſhine Day, when we look along a moiſt Piece of Ground, the Air and any Objects

Objects ſeen through it appear to have a tremulous Motion, like that which we obſerve in an Object, ſeen through two Fluids which are mixing together. Now, as the Vapours riſe here in great Abundance and the Air has but little Motion, thoſe Parts of it that are much impregnated with aqueous Particles are mixed gradually with the Air above it that is drier and of a different Denſity; which will occaſion Refractions of the Light, and that apparent tremulous Motion, juſt now mentioned; and in this Caſe, the Solution of Water in Air (if I may yet venture to call it by that Name) is carried on in a Manner viſible to the Eye, as Solutions are in other Fluids. The ſame tremulous undulating Motion is more obſervable, when we look in warm Weather through a Teleſcope, which magnifies the Vapours floating in the Air: and from this kind of Refraction the twinkling of the Stars ſeems to ariſe; with this Difference only, that the watery refracting Particles in the Day-time are paſſing into a State of Solution; whereas the Vapours already diſſolved are

by the Cold of the Night beginning to precipitate, and return into Particles large enough to cauſe Refractions in the Light of the Stars.

Thirdly; Heat promotes, and Cold in ſome Meaſure ſtops or checks both Solution and Evaporation. Very hot Water will diſſolve Salt ſooner and in a greater Quantity than cold Water; and if a ſtrong Solution of Salt be made in hot Water, the Water when cold will let go ſome of the Salt before diſſolved, which will fall to the Bottom in ſmall Particles or ſhoot into Chryſtals. Juſt ſo will Water evaporate faſter in warm than in cold Air; and the aqueous Vapours, ſuſpended in the Air during the Heat of the Day, fall down at Night and form themſelves into Drops of DEW, or if the Night be very cold appear next Morning chryſtalized, in a HOAR-FROST. And thus if in a hot Day a Bottle be filled with any very cold Liquor, and expoſed to the warm Air, which to us ſeems very dry, a Dew will be ſoon formed on the Outſide of the Bottle; for the

the Air about it being cooled will let go Part of its Moiſture, which will be attracted to the Surface of the Glaſs; for the ſame Reaſon a Dew is formed on the Inſide of the Windows of a warm Room, which on their Outſide are expoſed to the cold Air. In like Manner, the Moiſture breathed out from the Lungs of Animals becomes viſible in very cold Air, which cannot keep that Moiſture in a State of Solution, as warm Air will do. Hence alſo we may obſerve, that as there cannot be ſo continual and copious an Evaporation in cold Weather, the Air will then be generally clearer than it is in hot Weather.

Heat ſeems to promote Solution, becauſe it expands Bodies, and thereby enlarges their Pores, and leſſens the coheſive Attraction of their Particles; ſo that a Body, when hot, will more eaſily admit a diſſolving Fluid into its Pores, and its Particles, cohering together leſs ſtrongly than when cold, will more readily quit each other, and unite themſelves to the Particles

of the Fluid by which they are attracted; and for the ſame Reaſon Heat will alſo promote the Evaporation of Fluids.

But fourthly; The Quantity of a Body diſſolved, and of a Fluid evaporated, in a given Time, depends *(cæteris paribus)* on its Quantity of Surface. Thus a Body reduced to Powder is ſooner diſſolved than it is in a concrete Form; and thus Smoke or Steam (which is Water reduced to very ſmall Particles by Heat) is much ſooner diſperſed and incorporated with Air, than Water in its uſual Form. Thus likewiſe the Moiſture, which adheres to a cold poliſhed Plate of Glaſs or Metal, when we breathe upon it, is immediately dried up by the Air, becauſe it is exceedingly thin and has a very great Surface.

Fifthly; Chymiſts obſerve, that when Sea-Salt, *Sal Ammoniac*, or Nitre, is diſſolved in Water, or eſſential Oils in Spirit of Wine, ſome Degree of Cold is produced in the immediate Act of Solution; and the quicker the Solution, the greater is the Cold.

Cold. By diſſolving pounded Ice, or rather Snow (whoſe Particles have a greater Surface) in Spirit of Nitre, a Degree of Cold has been produced ſo great as to freeze Quick-ſilver. Cold is likewiſe produced in the Act of Evaporation. For if Spirit of Wine, or Æther, be rubbed lightly with a Feather over the Ball of a Thermometer, it will ſink as the Spirit evaporates; and the quicker the Evaporation, the faſter will the Thermometer ſink; thus I have made Water freeze in a thin Glaſs merely by the Evaporation of Æther promoted by a Current of Air. That Cold is produced by the Evaporation of Water appears from the Practice of Sailors, who, in hot Climates, cool their Liquors by wrapping the Veſſels in wet Cloths, and hanging them up where they are much expoſed to the Wind, and wetting the Cloths again when they become dry.

This Obſervation ſhews a very remarkable Agreement between the Natures of Solution and Evaporation: How the Cold is produced in either Caſe, I cannot pre-

tend to ſay; but I muſt beg leave juſt to apply this Fact, to account for a Thing which I believe moſt People have taken Notice of. If we rub Hungary Water, or any other volatile Spirit over our Hand, it will feel much colder than Water, tho' they will both feel equally cold, if we dip our Finger into each. The Reaſon of which is, that the Spirit evaporating much quicker than the Water, produces thereby a greater Degree of Cold. And ſo Æther, if it be applied in the ſame Way, will feel colder than any other Spirit on Account of its more ſudden Evaporation.

Sixthly; It is known, that rectified Spirit of Wine, when purged of Air, will imbibe a large Bubble of Air in a much ſhorter Time than Water will do, and I have myſelf experienced the Truth of this, which ſhews that there is a ſtronger Attraction, or *Affinity* (as the Chymiſts call it) between Spirit of Wine and Air, than between Water and Air, and ſince the Spirit evaporates much faſter than the Water, I think we may conclude from hence, that the

the Evaporation of Fluids arifes from an attractive Force between their Particles and thofe of Air. [B] But here it muft be

[B] As Water and Spirit of Wine are in no Degree vifcid, they may evaporate in Proportion to the Attraction between them and Air. But the Cafe is very different in fuch Fluids as are vifcid; for tho' I found that Oil of Olives, when purged of Air, will imbibe a Bubble of Air almoft as foon as Water does, yet the Evaporation of Oil is fcarcely (if at all) fenfible. The Reafon of which muft be, that the Attraction between Air and the Oil is not able to overcome the Tenacity of its Particles and feparate them from each other, tho' it is fufficient to draw into the Oil the Particles of Air, which have no Attraction towards each other; juft as Water is drawn into a Sponge, tho' the Attraction of the Water is not able to feparate the Particles of the Sponge from each other. It might perhaps be fuppofed that the Water contained in the Air may defend the Oil from the Attraction of the Air, and thereby prevent the Oil from evaporating; but if this were the Cafe, the fame Water would alfo defend the Air from the Attraction of the Oil, which we fee it does not. The Particles of Oil, like thofe of all other Fluids, may indeed be feparated from each other and driven into the Air by a violent Heat; but this Effect muft be diftinguifhed from common Evaporation, as will appear from what is faid in the latter Part of this Effay.

obſerved that the Spirit is not only more ſtrongly attracted by the Air than Water is, but, being alſo more eaſily rarefied by Heat, its Particles ſeem to cohere together more ſlightly than thoſe of Water, and therefore may be more eaſily ſeparated by the Attraction of the Air.

Seventhly; If into any *Menſtruum* we throw a Body, which it diſſolves, and afterwards add another, to which the *Menſtruum* has a greater Affinity than it has to the firſt, it will diſſolve the ſecond Body, and let go the firſt, which will be precipitated and fall to the Bottom. In the very ſame Manner will a Fluid let go the Air it contains, upon the Addition of another Body to which it has a greater Affinity than it has to the Air. Thus if to well rectified Spirit of Wine we add an equal Quantity of clear Rain-water, theſe Fluids * (which ſo readily incorporate,) having a greater Affinity to each other than to the Air they contain, will let go a great Part of that Air, which will riſe to the Top, or adhere in ſmall Bubbles

to

to the Sides of the Veſſel. This, I think, ſhews that Air is contained in theſe Fluids, in the ſame Manner that the Particles of a Body are contained in a *Menſtruum* that diſſolves it; and hence I conclude that the Air which is imbibed by any Fluid is, properly ſpeaking, *diſſolved* in that Fluid; and conſequently that any Fluid which evaporates, or is imbibed by the Air, is alſo, properly ſpeaking, *diſſolved* in Air. Upon this Principle we may ſay, that Water is drawn out of Air by dry Salt of Tartar, from its having a greater Affinity to that Salt than to the Air.

I ſhould not have been ſo tedious in comparing together the Natures of Solution and Evaporation in ſo many Inſtances, but that it gave me an Opportunity at the ſame Time of explaining ſome of the Phænomena that I at firſt intended to conſider; which Explanations I believe will be admitted, if I am right in the main Point I have endeavoured to prove. And really when we conſider how exactly Solution and Evaporation agree, in their ſeve-

ral Appearances, Properties and Effects, I think we muſt be convinced that they are natural Operations of the ſame Kind, and that what we call Evaporation, is nothing more than a gradual Solution of Water in Air, produced and promoted by the ſame Means (to wit) Attraction, Heat, and Motion, by which other Solutions are effected.

I ſhall now endeavour to account for ſeveral Phænomena of the Atmoſphere upon this Principle, which will be ſtill further confirmed, if it be found to anſwer the Purpoſe to which it is applied.

The loweſt Part of the Air being preſſed by the Weight of the Atmoſphere againſt the Surface of the Water, and continually rubbing upon it by its Motion, has thereby an Opportunity of attracting and diſſolving thoſe Particles with which it is in contact and ſeparating them from the reſt of the Water. And ſince the Cauſe of Solution in this Caſe is the ſtronger Attraction of the Particles of Water

ter towards the Air, than towards each other, thoſe that are already diſſolved and taken up, will be ſtill further raiſed by the Attraction of the dry Air which lies over them, and thus will diffuſe themſelves, riſing gradually higher and higher, and thereby leave the loweſt Air not ſo much ſaturated, but that it will be ſtill able to diſſolve and take up freſh Particles of Water. And thus Ice or Snow will evaporate as well as Water, its Particles being attracted and diſſolved by the Air, which is ſtrongly preſſed againſt its Surface; for tho' Heat promotes both Solution and Evaporation, yet we do not find that in either Caſe any ſenſible Degree of it is abſolutely neceſſary.

In this Manner will AQUEOUS VAPOURS ASCEND ſlowly into the Atmoſphere, even when we ſuppoſe the Air almoſt at reſt, for I believe it is never perfectly ſo. But the Solution of Water in Air, and the Aſcent of Vapours, is greatly promoted by the Motion of the Winds, which bring freſh and drier Air into the Place of that,

which may be already ſaturated and loaded with Moiſture, carrying it, together with its Moiſture, into the higher Parts of the Atmoſphere, and diſperſing it into all Quarters.

If we ſhould now ſuppoſe the Atmoſphere to remain always in the ſame State as to Heat and Cold, and to have always the ſame Denſity; when it was once ſaturated with Water, all Evaporation would ceaſe, and the Vapours already raiſed would always remain ſuſpended; for a Fluid, while it retains the ſame Heat and Denſity, will never let go the Particles of a Body that it has diſſolved. We muſt therefore conſider what are the Cauſes which occaſion the Air ſometimes to part, with the Water it has diſſolved, and which thereby keep up a continual Circulation of Vapours; and theſe I ſhall ſhew to be the frequent Viciſſitudes of Heat and Cold, Condenſation and Rarefaction, to which the Atmoſphere is ſubject.

As to the Effects of Heat and Cold, I have

have already ſhewn that the former promotes, and the latter checks, or in ſome Meaſure hinders Evaporation as well as other Solutions; of which I gave an Inſtance in the Vapours that are ſuſpended during the Heat of the Day, but by the Cold of the Night are precipitated and ſuffered to coaleſce into Drops of Dew. From the Snow's lying ſo long on the Tops of Mountains, we find that the higher Parts of the Atmoſphere are much colder than the lower. Now tho' Vapours are firſt raiſed, and abound moſt in the lower Parts of the Atmoſphere, yet they cannot there be formed into Clouds, becauſe the Heat that helped to diſſolve them, helps alſo to keep them diſſolved. But when they are carried by the Winds into the higher Parts, where the ſame Heat is wanting, the cold Air will not be able to keep in a State of Solution all that are carried up, but muſt ſuffer ſome of them to coaleſce into ſmall Particles, which ſlightly attracting each other and being intermixed with Air will form CLOUDS, having the very ſame Appearance with

Steam or Smoke, which alſo conſiſts of ſmall Particles of Water *mixed* with Air, and not yet *diſſolved* in it. Theſe Clouds, when firſt formed, will remain ſuſpended, tho' they conſiſt of Water, as well as Air; becauſe the Weight of their Particles will not be able to overcome the Reſiſtance they muſt meet with in deſcending through the Air. For when Bodies are diminiſhed their Quantities of Matter to which their Weights are proportional, decreaſe faſter, or in a greater *Ratio*, than their Surfaces to which the Reſiſtance they meet with is proportional, and therefore in very ſmall Particles, this Reſiſtance may become greater than their Weight. The different Heights at which Clouds are formed, depends on the Quantity of Vapours carried up, and the Degrees of Heat in the upper Parts of the Atmoſphere; for the Vapours may always aſcend till they meet with Air ſo cold or ſo thin that it is not able to keep in a State of Solution all that are carried up; hence Clouds are generally higher in Summer than in Winter. When Clouds are much increaſed by a continual Addi-

tion of Vapours, and their Particles are driven close together by the Force of the Winds, they will run into Drops heavy enough to fall down in RAIN. Sometimes the Clouds are frozen before their Particles are gathered into Drops, and then small Pieces of them, being condensed and made heavier by the Cold, fall down in thin Flakes of SNOW, which appear to be Fragments of a frozen Cloud; but if the Particles be formed into Drops, before they are frozen, they become HAIL-STONES.

When the Air is replete with Vapours, and a cold Breeze springs up, as it often does from the Sea, the Solution of these Vapours is checked, and Clouds are formed in the lower Parts of the Atmosphere, and compose what we call a MIST or FOG. This generally happens in a cold Morning, but when the Sun has been up for some Time, the warm Air again dissolves those watery Particles, and it frequently clears up.

In

In a hot Summer's Day, the Air lying over wet Marſhy Ground is copiouſly filled with aqueous Vapours, 'till the Air growing cooler after Sun-ſet will not be able to keep all thoſe Vapours diſſolved, but muſt let ſome Part of them unite quickly into very ſmall viſible Particles, and form thoſe Miſts which appear to riſe from Marſhy Grounds in a Summer's Evening. The Vapours near the Ground being more denſe and copious, will be firſt affected by the Cold, and afterwards thoſe that are thinner and higher up, ſo that the Miſt will be low at firſt, but will encreaſe in Height afterwards.

After a warm and unclouded Day in Summer there falls Abundance of Dew, and the Air ſcarce recovers its Clearneſs 'till towards Morning, when it is pretty well cooled; but on the firſt Return of Heat, at Sun-riſe or a little before it, the Water, which is then plentifully ſpread over the Ground and the Leaves of Trees and Plants in very ſmall Drops, begins again

again to diſſolve, and while it is diſſolving occaſions that HAZINESS ſo obſervable in a hot Summer's Morning about Sun-riſe, and for ſome Time after. Here it may be proper to obſerve, that when the Particles of Water are of a certain Size, they will render the Air equally opake, whether they are paſſing into a State of Solution, or returning from it.

Thoſe cold thick Morning Fogs I mentioned juſt now are often attended with a very light ſmall Rain; for the Vapours are then returning faſt from a State of Solution, and we ſee the Drops, at their firſt Formation, and they are ſuch as we generally meet with in paſſing over high Mountains, where we are in or near the Clouds. So that it ſeems the Drops of Rain are very ſmall when firſt formed in the Clouds; but being driven about by the Motion of the Air in their Deſcent, ſome of them will touch each other and run into a Drop of a larger Size, and the greater Space they fall through, the more will their Size be encreaſed before they come

come to the Ground. And for this Reason, the Drops which fall from the higher Clouds in Summer are found to be generally larger than they are in Winter, when the Clouds are low. It has been likewise observed, that the Drops of Rain are remarkably large that fall in sudden Thunder-Showers; of which the Reason may be, that the Lightning bursting from a Cloud and expanding itself greatly, will suddenly remove the Air from its Place, which Air must therefore return to its Place with great Violence, so that the watery Particles in the Clouds, strongly agitated and driven against each other, will form themselves into larger Drops than at other Times. Or perhaps it may be said, that when a Cloud is filled with Lightning, which is the same as the electric Matter, the watery Particles, like other electrified Bodies, will repel each other, but being suddenly deprived of this repelling Matter, will by their mutual Attraction come together again with some Velocity, and therefore will run into Drops larger than usual.

When

When the Wind blows from the South, it is generally warm and comes replete with aqueous Vapours which it has diſſolved, but coming into a colder Climate it cannot there keep the ſame Quantity of Vapours in a State of Solution as it did before, and conſequently muſt part with ſome of them and let them precipitate; and therefore Southerly Winds generally bring us Rain. On the other Hand, when the Wind blows from the North, or any Point near it, as it is very cold it cannot have diſſolved a great deal of aqueous Vapours where it came from, and therefore coming into a warmer Climate it is ready to diſſolve more. And on this Account theſe Winds, if they continue long, are found to be very dry and parching, and are generally attended with fair Weather.

Thus we ſee that the Air, according to its different States in reſpect to Heat and Cold, will diſſolve and take up, or let go and precipitate the aqueous Vapours, in conſequence of which we ſometimes perceive Changes

Changes of the Weather, even when there is no Change in the Denſity of the Air, or conſequently in the Height of the Barometer.

But Condenſation and Rarefaction will alſo have the like Effects in promoting the Solution of Water in Air, or in occaſioning ſome Part of what has been diſſolved to return again into Water and precipitate. It ſeems reaſonable to ſuppoſe, that denſe Air in which the Particles lie near each other, will be better able to diſſolve and keep ſuſpended a Quantity of Water, than the ſame Air when diffuſed through a greater Space. And that this is really ſo, we have an experimental Proof. For when a Receiver is partly exhauſted, we ſee the rarefied Air begin to let go the Water it contained, which gathering into ſmall Particles appears like Steam or Smoke falling to the Bottom. In order to prove the ſame thing by other Experiments, when a Cup of Water, or rather Spirit of Wine (which evaporates faſter) had ſtood for ſome Time in a cloſe Re-

ceiver

ceiver full of Air, I rarefied this Air ſuddenly, by letting it ruſh into another Receiver that was exhauſted, and immediately the Vapour, that was before ſuſpended, gathered into ſmall Particles and fell down in a very viſible Shower. I alſo took from the Air-pump a large exhauſted Receiver 20 Inches long, having at the Bottom a Braſs Plate, with a Stop-cock in the Middle of it, when the Stop-cock was opened, the external Air ruſhing in violently, and being much rarefied, let go the Water it contained, and threw it againſt the other End of the Receiver, where it ſtuck on the Glaſs, and covered it with a thin Dew, which I found to encreaſe until the Receiver was almoſt full of Air.

Theſe Experiments prove, that Air, when rarefied, cannot keep as much Water diſſolved as it does in a more condenſed State. And hence we muſt conclude, that when the Atmoſphere is ſaturated with Water, and changes from a denſer to a rarer

rarer State, the higher and colder Parts of it especially will begin to let go some of the Water before dissolved; which will form new Clouds, or add to the Size or Number of the Particles before formed, and thereby render them more apt to fall down in Rain. On the contrary, when the Atmosphere changes from a rarer to a denser State, it will then be able to stop the Precipitation of the Water, and again dissolve in the Whole, or in Part, some of those Clouds that were formed before, and consequently will render their Particles less apt to run into Drops and fall down in Rain. And thus we generally find by Experience, that the rarefied and condensed States of the Atmosphere are respectively attended with Rain or fair Weather. Though this does not happen at all Times, for the Air, tho' rarefied, may not then abound much with aqueous Vapours, having already parted with a good deal of them. So likewise when the Air is dense and heavy, it may be then so much loaded with aqueous Vapours, that we may have

Rain

Rain even before we can perceive by the Barometer, that the Atmosphere changes to a rarer State. [D]

[D] The Vapours raised into the Atmosphere will certainly add somewhat to its Weight, but the Difference of the Quantity of Water contained in the Air at one Time and at another cannot make any considerable Change in its Weight. For the Quantity of Rain has been accurately measured that falls *(communibus annis)* in several Parts of Europe, and by taking these Quantities at a Medium, I find that in any one Place there will generally fall, one Year with another, as much Rain as would amount altogether to the Height of 28 Inches, which is equivalent in Weight to two Inches of Mercury; if therefore we were to suppose this whole Quantity of Rain to be suspended in the Air at one Time, and then to fall before any more Vapours were taken up, the Mercury in the Barometer would, on that Account, fall two Inches. But we cannot make such a Supposition, for the Rain falls in small Quantities and at different Times, and the aqueous Vapours are again taken up into the Air immediately; so that the Difference in the Quantity of Water sustained in the Air, at one Time more than at another, can add by its Weight but very little to the Height of the Mercury in the Barometer, probably not so much as the tenth Part of an Inch.

Upon

Upon this Principle, I think we may account for the Changes of the Weather, which uſually attend the riſing and falling of the Mercury in the Barometer, better than by ſaying, that when the Air grows rarer and lighter, it cannot, by the Laws of Hydroſtatics, ſo well ſupport the Clouds and Vapours, and therefore muſt permit them to fall down in Drops of Rain. For when the Air grows rarer, although the Clouds will deſcend into a lower and denſer Part of it, yet they will be there ſupported, and I do not ſee why their Particles ſhould be more apt to run into Drops there, than when they were higher up, unleſs they received ſome Addition from the Water depoſited among them by the rarefied Air, in the Manner I have juſt now mentioned. For ſince the Air is rarefied gradually, the Clouds can deſcend but very ſlowly, and therefore their Particles will not be ſo much preſſed together by the Reſiſtance they meet with in their Deſcent, as they generally are by the Winds which blow upon them.

When

When the Atmosphere is saturated with Water, and grows colder and rarer than it was before, we shall then perceive the lower Air begin to part with some of the Water it contains, which will fall insensibly to the Ground, or adhere to the Walls of Houses, or other Bodies exposed to it, and make them become damp or wet. And if the Moisture settles on the smooth Surfaces of cold Bodies, such as Marble or other Stones, whose Pores cannot imbibe it, it will cover them with a kind of Dew, and then these Bodies are vulgarly said to SWEAT. At this Time the Hygrometer being affected by the Moisture will point to *WET*, and as we perceive from thence, that the Air is disposed to part with the Water it contains, we may generally expect Rain. But when the Air again grows warm or dense, it will be able again to dissolve and take up the Water it before deposited, and the Moisture on the Bodies exposed to it will disappear, the Hygrometer will point to *DRY*, and we may then promise ourselves fair Weather.

I observed

I obſerved before * that if a Bottle be filled with a very cold Liquor and expoſed to warm Air, a Dew will ſoon be formed on its Surface, by the Moiſture which the cooled Air depoſites. Now if we ſuppoſe this Body ſtill to retain the ſame Degree of Cold whilſt the Air paſſes over it, the Dew on its Surface will continually encreaſe and run down its Sides in ſmall Streams of Water. This ſeems to be exactly the Caſe of Mountains whoſe Tops reach into the colder Parts of the Atmoſphere, and which therefore are themſelves colder than the Air in general. For when the Wind blows the lower Parts of the Atmoſphere (which are the warmeſt and moſt replete with Vapours) againſt the Sides of the Mountains, it being there ſtopped in its Courſe, muſt neceſſarily aſcend and paſs over their Tops; this Air will therefore be conſiderably cooled in its Progreſs up the Sides and over the Tops of the Mountains, and conſequently muſt let go a great

* Page 18.

Part

Part of the watery Vapours it contains; which will be precipitated in Dew and Moiſture, upon the Surface of the Mountains where it will ſink into the earthy Parts, or inſinuate itſelf into the Chinks and Crevices of Rocks, and being there collected will afterwards break out in SPRINGS and FOUNTAINS, and become the Source of RIVERS, which are known to take their Riſe in Mountainous Countries. And on this Account we might have ſmall Springs and Rivers near Mountains, tho' there were neither Clouds nor Rain. But the Moiſture which the Air uſually depoſites on the Mountains muſt be conſiderably encreaſed by the Clouds which are driven againſt them, and accumulated by the Winds, for their Particles being then preſſed together will run into ſmall Drops of Rain. Beſides, it is well known that Mountains gather and retain the Clouds about them by their Attraction, in Conſequence of which we often ſee ſome Clouds continue at Reſt on the Mountains, whilſt others at a Diſtance are carried on gently by the Wind.

Hence it is that Countries in the Neighbourhood of high Mountains are the most subject to frequent Rains.

Thus I have shewn how the Ascent of aqueous Vapours and their constant Circulation, by precipitating again in Moisture and Drops of Rain, will arise from the dissolving Power of the Air, influenced by the Vicissitudes of Heat and Cold, Condensation and Rarefaction; which Causes, as they take Place in different Degrees, will occasion those various States of the Atmosphere in Respect to Dryness or Moisture, which we experience in the several Changes of the Weather. To which the Winds contribute very much by heating or cooling, condensing or rarefying the different Parts of the Atmosphere, and by promoting the Solution of Water in Air, as they mix those Fluids together, or (when the Air is already saturated with aqueous Vapours) by pressing together the Particles in the Clouds, and thereby causing them to run into Drops.

If

If we may thus, from the known Properties of Solution, account in a ſatisfactory Manner for the Aſcent and Circulation of aqueous Vapours, and the ſeveral Phænomena of the Atmoſphere ariſing from thence; it muſt be a great Confirmation of the Arguments brought to prove that Evaporation is only a particular Species of Solution; and therefore that they both proceed from the ſame Cauſe, *viz.* the Attraction that obtains between the minute Particles of different Bodies, which is the Means of carrying on ſo many other Operations of Nature.

And indeed upon this Principle, Air ſeems better fitted to be a general *Solvent* than any Fluid we know of; becauſe its Particles, not attracting each other, are more at Liberty to unite themſelves to the minute Particles of ſuch Bodies as they do attract. And accordingly we find the Atmoſphere contains in it Matter of all Kinds. The odoriferous Particles of Bodies ſeem to be ſtrongly attracted by the Air, as they are ſo very readily

dispersed thro' it; and Camphor, which is a very light volatile Body, may be entirely dissolved in Air without leaving any Remainder. The Air abounds with Vitriolic and other Acids, as is plain from the rusting of Iron exposed to it. It abounds also with sulphurous, nitrous, and other inflammable Particles, as appears by the frequent Meteors kindled in it. For we have many Substances, such as strong Acids and essential Oils, which being thrown together will unite with such Violence as suddenly to burst into a Flame, and therefore when the Particles of those Bodies, floating promiscuously in the Air, happen to come together in a sufficient Quantity by their mutual Attraction, (which we know is very strong) they must kindle into a Flame, and if many Particles of the inflammable Kind lie contiguous, the Fire will run in a Train and Form, what we call, shooting Stars, and other blazing Meteors. In short, the Atmosphere may be considered as a Chaos containing Particles of all Sorts of Bodies; and as the great Instrument

ment of Nature for keeping up a general Circulation of Matter; and by which not only Water is every where dispersed, but oftentimes the Eggs of Insects and the Seeds of Plants are conveyed from Place to Place, both which have been found in Rain-water, on examining it carefully just after it had fallen; and indeed we sometimes find Insects and Plants in some Places where their Appearance cannot well be accounted for, otherwise than by supposing their Eggs and Seeds to be conveyed thither by the Air.

I shall now mention two other Instances in which this dissolving Power of the Air produces Effects of the utmost Importance. Dr. *Boerhaave*, speaking of that Power or Quality of Air, which makes it necessary for the Preservation of Animal Life, calls it a certain hidden Virtue, not to be accounted for from any of the Properties of Air then discovered. Perhaps we may be led to some Knowledge of it, by considering on what Account Air may become unfit for Respiration by passing

two or three Times thro' the Lungs of an Animal, for we find that an Animal inclosed in such Air will soon expire. I think we may be sure that one Purpose, at least, for which Air was designed, is, the carrying off that Moisture and other perspirable Matter which constantly exhales from the Lungs, for this we know it actually does. Now as Air loses nothing of its Elasticity by passing thro' the Lungs, an Animal might still continue to breathe the same Air, and it would still continue fit for all such Purposes in the Animal Oeconomy as may be answered by the alternate Expansion and Contraction of the Lungs in Respiration. But this Air must in a short Time become saturated with that Moisture and other perspirable Matter which it meets with in the Lungs, and must then lose its Power of dissolving and carrying off any more of that Kind of Matter; which Nature intends should be constantly discharged, and which will therefore continually encrease and thereby oppress the Lungs, heat the Blood, or produce such other noxious Effects as are more imme-

immediately fatal than thoſe ariſing from the Stoppage of external Perſpiration. So that an Animal incloſed in ſuch Air cannot live long, and will perhaps die ſomewhat in the ſame Manner as if it had been drowned. [E] Whether the Air we breathe may depoſite, in our Lungs, any Kind of Matter neceſſary to the Support of Life, I cannot pretend to judge, nor is it

[E] *As* Air even when incorporated with Water retains its Elaſticity, I took it for granted that it would not become leſs elaſtic by paſſing thro' the Lungs of an Animal. But finding that the contrary Opinion was held by ſome, who ſuppoſed that Air, having paſſed thro' the Lungs of an Animal, became unfit for Reſpiration by loſing its Elaſticity, I reſolved to try how the Fact was by the following Experiment. In a Receiver, eight Inches in Diameter and twelve Inches high, having under it a Piece of oiled Leather, I included a pretty large Chicken, and tied the Receiver cloſe down to the Table; thro' a Hole in the Top of the Receiver went a Glaſs Tube, open at both Ends, cemented round the Hole with Wax; the lower End was immerſed in Water, (tinged blue) which ſtood in a Glaſs under the Receiver.

In about an Hour after the Chicken was included it grew much diſtreſſed, gaped wide and breathed

it my Design to enquire; what has been said shews the Necessity of fresh Air in Respiration, and by what Property it is

breathed with great Difficulty, and in half an Hour more it seemed almost ready to expire; the Inside of the Receiver was then covered with Moisture, which in some Places ran down in Drops.

Now if the included Air had lost any of its Elasticity by passing thro' the Lungs of this Animal, it could not have pressed so strongly on the Water in the Glass as it did at first, and then the external Air would have pressed thro' the Tube, and appeared coming up through the Water in Bubbles. But no such Thing happened, for as soon as the Receiver was tied down, the Water in the Tube rose about one fifth of an Inch above the Water in the Glass, and so continued during the whole Time of the Experiment, except that it rose and fell near one tenth of an Inch every Time that the Chicken breathed; and these Vibrations of the Water in the Tube I observed grew slower, and moved thro' a greater Space towards the latter End of the Time; which shewed that the Chicken then took in more Air every Time it breathed, than it did at first, endeavouring thereby to throw off the Moisture which then oppressed its Lungs. After Things had stopped thus above an Hour and a Half, those who saw the Experiment, were convinced that the included Air had not lost any of its Elasticity, though grown quite unfit for Respiration, the Animal being ready to expire in it.

adapted

adapted to anſwer one very important Purpoſe, and alſo how Air may ſoon become unfit for that Purpoſe. But here I will venture to aſk, whether it is not probable, that, in the conſtant and quick Evaporation of Moiſture from the Lungs, ſome Degree of Cold may be produced, as in other Evaporations, which, together with the freſh Air taken in, may ſerve to cool the Lungs and the Blood paſſing thro' them? We may ſee from hence that moiſt Air muſt be very unwholeſome by its not ſufficiently promoting the neceſſary Perſpiration, both internal and external.

Air is not leſs neceſſary for the Support of Fire than of animal Life; for Fire will not long continue to burn without a Circulation of Air. Now I ſuppoſe this happens, not from its adding any Thing to the *Pabulum* of Fire, (for Fire ſeems to be otherwiſe ſufficiently provided with *Pabulum*) but rather on this Account; that the Air immediately about a Body on Fire is heated and made ſpecifically lighter than

the Air at ſome Diſtance from it; This hot Air muſt therefore aſcend and carry with it all thoſe minute Particles of different Kinds which are thrown off from the burning Body, and which would otherwiſe reſt upon its Surface, and thereby clog and ſtop the ſubtile Vibrations of the burning Matter, in which the Nature of Fire partly conſiſts. If therefore Fire be confined in a cloſe Place, where there can be no Circulation of freſh Air, the Air about it, being ſoon ſaturated with the Particles ariſing from the burning Matter, will not be able to take up any more of them, and therefore the Fire muſt go out, ſmothered as it were with ſuch Particles as are no longer combuſtible. And hence it is that Fire burns faſter when Air is ſtrongly blown upon it, for then the Aſhes are carried off as faſt as they are formed on the Surface of the burning Body, and thereby the Particles that have juſt taken Fire are kept quite free from any Thing that can impede and clog their vibratory Motion. The Air in this Caſe will alſo ſpread the Fire quickly thro' the Fuel, by blowing

blowing the Particles that are already kindled among those that are not; and perhaps the Motion of the Air in this Case may promote the subtile Vibrations in the burning Matter by which the Fire is propagated thro' its Parts. As the Air contains many subtile Particles of the inflammable Kind, it is not improbable that these mixing with the gross burning Matter may help to preserve and enliven the Fire; but I think it most probable that Air supports Fire chiefly by carrying off such Particles as are burned out, and would therefore obstruct the Progress of the Fire; because we find that the strong elastic Steam of Water driven violently out of the Pipe of an [F] *Æolipile*, which will carry off those Particles, will also blow up and increase the Fire as well as Air driven from the Bellows, although the Steam does not contain any inflammable Particles.

[F] An *Æolipile* is a hollow Globe of Iron or Copper, into which is screwed a long Pipe, whose End is commonly bent into a Curve: it has a very small Orifice, out of which the Steam issues with great Violence, when Water is boiled in the *Æolipile*. See it delineated in Fig. 1.

To this general Obſervation, that Air is neceſſary for the Support of Fire, we muſt admit one Exception; for Nitre will burn in a cloſe Veſſel, or in *Vacuo*. The Cauſe of this ſingular Phænomenon I ſhall endeavour to aſſign from what has been ſaid. Nitre, when ſet on Fire, burns with more Rapidity and Violence than any Body we know of, its burning is a kind of Exploſion, and produces a very fierce and elaſtic Flame, for which Reaſon it is a neceſſary Ingredient in Gun-powder, *Pulvis fulminans*, and all other fulminating Compounds. When therefore a Piece of Nitre takes Fire, its elaſtic Flame drives off the Fumes and Vapours (with which the Air in the Veſſel may be then ſaturated) and defends the burning Matter, ſo that they cannot ſettle upon it and extinguiſh it, as they do other Bodies that burn ſlowly and without any Exploſion. And on this Account Nitre, and other inflammable Matter mixed with it, will burn in cloſe Veſſels, or even in *Vacuo*. This will further appear from conſidering the Manner in which Nitre firſt takes Fire, and the Reaſon

ſon of its exploding Quality. Nitre will not burn by itſelf tho' melted and made red hot, but when it comes in Contact with any Body actually on Fire, and which therefore contains an inflammable Matter, or (as it is called) the *Phlogiſton*, it burſts into a Flame. Here the Chymiſts ſay, that the acid Spirit of the Nitre unites ſo rapidly with the *Phlogiſton*, which is detached from the burning Matter, that by the Violence of their Congreſs they both vaniſh together in a Flame. And they prove this to be ſo, by throwing ſtrong Acid of Nitre on any thick eſſential Oil, which conſiſts almoſt wholly of the *Phlogiſton*, for then the Mixture will ſuddenly burſt into a Flame with a violent Exploſion. Therefore ſo long as Nitre and the inflammable Matter are thus in Contact, no Fumes or Vapours floating about them can prevent that rapid Union between their Parts which muſt neceſſarily make them continue to burn. The Air, which is produced from burning Nitre, may poſſibly add to the Elaſticity of its Flame. But I do not think it probable

bable that this Air can contribute much to keep a large Quantity of Nitre burning ſo long as it will do in a cloſe Veſſel.

Having thus ſhewn by what Property Air produces the Evaporation of Fluids and ſeveral other Effects, I come now to treat of thoſe Vapours that are raiſed merely by Heat. Although the Particles of Fluids in common Evaporation are raiſed into the Atmoſphere by the attracting and diſſolving Power of the Air, yet in ſome particular Caſes Vapours will be raiſed by other Cauſes. For in ſome Places the Earth often ſends forth hot elaſtic Vapours that riſe into the Air by means of their Elaſticity, and carry up with them Mineral and Foſſile Particles of different Kinds. Fermentation generates elaſtic Vapours which expand themſelves into the Air. And the Particles of Water and other Fluids, when ſufficiently heated, acquire a repelling Force which ſeparates them from the Surface, and throws them upwards into the Air.

But

But all these Vapours soon lose that Elasticity by which they were at first raised, and they must then be retained and kept suspended in the Air by the same Power that keeps up all the Vapours that rise without any Elasticity in common Evaporation.

That the Particles of Steam which rise from hot Water are endued with a repelling Force, appears plainly when Water is boiled in a close Vessel, for then the Steam becomes so exceedingly elastic that it will burst the strongest Vessel. In this Case the boiling Water, being strongly pressed by the Force of the included Steam, conceives a much greater Heat than it will ever do in an open Vessel; for even when Water is boiled in the open Air it is somewhat hotter when the Atmosphere is heavy, than when it is light, which shews that Pressure upon boiling Water encreases its Heat; the Reason of which we may perhaps see presently. But the most remarkable Phænomenon that attends the boiling of Water,

ter, is the large Bubbles which continue to rise from the Bottom so long as the Water boils,* and long after all the Air is driven out of it, concerning which there have been various Opinions. Dr. *Boerhaave*, in his *Elements of Chymistry*, proves by several Arguments, that these Bubbles do not arise from Air, and with Regard to their Production, he seems to be of the same Opinion with *Stairs*, (to whose Work he refers) that they arise from some active Fires residing in the Water. *Marriotte*, whom he also mentions on this Occasion, calls these Bubbles *Fulminations*, and supposes that they may proceed from some Kind of saline Particles contained in the Water, which, being heated, act in the same Manner that the *Aurum fulminans* does when heated. It has been also a received Opinion that these Bubbles are occasioned by some subtile elastic Fluid transmitted from the Fire through the Bottom of the Vessel, and this, I think, was the Opinion of *Homberg*. However I conceive that a Fluid so subtile as to pass thro' the Bottom

tom of the Veſſel, would paſs alſo thro' the Water ſo eaſily as not to diſturb it; and therefore I have for ſome Time ſuſpected, that theſe Bubbles are formed only by an elaſtic Steam, in the Manner I ſhall now deſcribe. The Particles on the Surface of the Water, long before it boils, will, by means of the repelling Force which the Heat introduces among them, riſe in Steam, and will inſinuate themſelves into the Air which yields eaſily to them; but thoſe Particles that are preſſed againſt the Bottom, by the Weight of the Atmoſphere, and of the incumbent Water, will require a greater Degree of Heat to render them ſo elaſtic that they ſhall be able to overcome this Preſſure, and expand themſelves into a greater Space. Now ſince Heat expands Water and makes its Particles repel each other, according to its different Degrees, we muſt ſuppoſe that theſe Particles, from their being in Contact with the Bottom of the Veſſel, will at length acquire ſuch a Degree of Heat as will give them a repelling Force ſufficient to overcome the

Preſſure

Preſſure they ſuſtain, and to expand them ſuddenly into thoſe large Bubbles that aſcend thro' the Water when it boils violently.

I have lately made ſome Obſervations and Experiments which ſeem to confirm this Opinion. Theſe Bubbles which aſcend from the Bottom, I obſerved, always grow leſs in their Progreſs upwards, and thoſe ſmall Bubbles that adhere to the Bottom for ſome Time before they aſcend, often diſappear entirely before they reach the Surface, which ſhews that when the Matter they contain, or any Part of it, loſes the Heat it had at firſt, it is again turned into Water.

When Water that has juſt boiled, or is even conſiderably leſs hot than boiling Water, is poured into a Glaſs and ſet under the Receiver of an Air-pump, and the Air is almoſt drawn out, the Water will boil more violently than it does on the Fire, the Bubbles breaking out from all Parts of it. In this Caſe, no ſubtile

Fluid

Fluid can be ſuppoſed to riſe thro' the Bottom of the Veſſel, but the Heat which the Water retains will then give its Particles an elaſtic Force ſufficient to overcome the Preſſure of what little Air remains in the Receiver, and will expand them into Bubbles. And that theſe Bubbles are compoſed of Steam appears plainly from this Experiment, for as ſoon as they begin to aſcend the Receiver is filled with Steam, which being condenſed by the Cold runs plentifully down its Sides in Water. From hence we ſee the Reaſon why Water in *Vacua* boils with a very ſmall Degree of Heat.

After a Veſſel of Water had boiled 'till all the Air-Bubbles were driven out of it, I turned upon its Mouth a large Glaſs that lay on its Side under the Water; the Bubbles, that aſcended under the Glaſs, remained in the upper Part of it, and forced out the Water it before contained, and then the elaſtic Matter in the Glaſs overturned it, and aſcended to the Top in one large Bubble, upon which the

the Steam on the Surface was much encreaſed. Now this ſhews that the Matter contained in theſe Bubbles, which at firſt is quite tranſparent, being a very rare and homogeneous Fluid, appears afterwards like Steam when it is mixed with the Air. But I thought I ſhould make a concluſive Experiment if I could obſerve the Effects of a very hot Steam conveyed under boiling Water. Therefore when an *Æolipile* had boiled till all the Air was driven out of the Water it contained, without taking it off the Fire, I immerſed its Pipe into a Veſſel of Water which had juſt been boiled, and immediately the Steam that iſſued from the Pipe roſe up in very large Bubbles thro' the Water, and made it appear to boil violently. I then held a large Glaſs of cold Water, ſo that the Pipe of the boiling *Æolipile* was immerſed in it; at firſt none of theſe Bubbles appeared, for the Steam, being then condenſed by the cold Water, was mixed thro' it, making a very loud and uncommon Noiſe: but as ſoon as the Water in the Glaſs grew very hot, this Noiſe

Noiſe ceaſed, and the Steam, being no longer condenſed, roſe in large Bubbles, as before, and made the Water appear to boil with great Violence.

Theſe Obſervations and Experiments ſeem to diſcover fully to us the Nature of thoſe Bubbles that aſcend thro' boiling Water; and lead me to make ſome further Remarks on the Degrees of Heat that different Liquors acquire in boiling.

The Parts of a Fluid neareſt the Bottom of a Veſſel grow hot firſt, and being then expanded and made lighter, they aſcend and change Place with the colder and heavier Parts, which occaſions that inteſtine Motion we perceive in Liquors while they are growing hot. And thus the Heat of the Whole will continue to increaſe, until thoſe Particles, that are in Contact with the Bottom of the Veſſel, acquire ſuch a Degree of Heat as will give them a repelling Force ſufficient to overcome the Weight of the Atmoſphere, the Weight of the incumbent Fluid, and the

the Tenacity of its Particles, and then they will be ſuddenly expanded into Bubbles of Steam, and aſcend quickly to the Top, without communicating this Heat to the ſurrounding Fluid. For as theſe Bubbles have a Degree of Heat but little ſuperior to that of the Fluid, and juſt ſufficient to keep them expanded, if they were to loſe any of it, by communicating it to the Fluid in their Aſcent, they would all diſappear before they got to the Surface, as the very ſmall ones do which aſcend but ſlowly; or if the whole Fluid was to grow at once as hot as the Bubbles, it would, like them, be all turned into an elaſtic Steam. And therefore the Fluid itſelf cannot grow hotter than it was when theſe Bubbles began to aſcend; but muſt all boil away in the ſame Degree of Heat. [G] Provided it be ſuch

[G] That theſe Bubbles are really hotter than the other Parts of the Fluid, I found by immerſing a Mercurial Thermometer with *Fahrenheit's* Scale into a Veſſel of boiling Water, for it roſe one Degree higher when held among the Bubbles, where they were moſt numerous, than it did in the other Parts of the Water.

a Fluid

a Fluid as will not grow denſer or more viſcid and tenacious by boiling, and of this Kind are Mercury, Water, Spirit of Wine, and ſeveral others, for theſe Fluids are found to boil reſpectively with 600, 212, and 175 Degrees of Heat, and afterwards they do not grow hotter. The Reaſon of which is plain, for whilſt the Preſſure upon a Fluid, and its Denſity and Tenacity continue the ſame, the ſame Degree of Heat will always be ſufficient to ſeparate its Particles and expand them into Steam; which is the greateſt Effect that Fire can produce on any Fluid without actually inflaming it. Hence it is obvious that an additional Preſſure on boiling Liquors, or an Encreaſe of their Denſity or Tenacity, will, by keeping their Particles more ſtrongly together, enable them to bear a greater Degree of Heat before they are expanded into Steam and begin to boil. It is very obſervable that all oily Liquors, which refract the Rays of Light more ſtrongly than others do, acquire alſo a much greater Heat in boiling. Thus

Oil

Oil of Turpentine and other thin eſſential Oils, that are procured by Diſtillation, boil with about 560 Degrees of Heat, which however as the boiling continues is always encreaſing; the more volatile Parts flying away, and leaving the Reſidue thicker, more viſcid, and ſuſceptible of greater Heat.

Common vegetable and animal Oils begin to boil with 600 Degrees of Heat, which is the ſame with that of boiling Mercury, and therefore is the greateſt Heat that can be meaſured by a Mercurial Thermometer. But it has been found, by the Expanſion of an Iron Rod, that Oils grow continually hotter by boiling, and at length their Heat encreaſes ſo much that they burſt into Flame.

There is indeed one Obſervation, which, if true, would contradict what I have ſaid as to the Heat of boiling Liquors being in ſome Meaſure owing to their Viſcidity; for it is commonly

ſaid that Tar, which is a viſcid Liquor, boils with ſo ſmall a Degree of Heat, that the Workmen ſkim the Droſs off it with their Hands. But this I found to be only the Appearance of boiling, for having placed a Veſſel of Tar on the Fire; as ſoon as the Thermometer ſhewed it to be a little hotter than the human Blood, a great Quantity of Air roſe out of it in Froth and Bubbles, carrying up ſome Droſs with it, and then I could eaſily bear to hold my Finger in it; but ſoon after, when the Tar began really to boil, the Thermometer roſe as high as it does in boiling Water, and was ſtill riſing. For Tar, when one Half of it is boiled away, becomes Pitch; and it is well known that boiling Pitch is hotter than boiling Water; ſo that this Experiment correſponds exactly with the Theory I have laid down in Regard to the Heat of boiling Liquors.

Hitherto we have conſidered only the Effects of ſuch Degrees of Heat as are great enough to expand Liquors into

large Bubbles and make them boil, or to raiſe a viſible Steam from their Surface, but I find it neceſſary (for a Reaſon I ſhall mention preſently) to conſider alſo the Effects of the leſſer Degrees of Heat, down to that which is juſt ſufficient to keep Liquors in a State of Fluidity.

It is generally allowed that Heat keeps Bodies fluid, by cauſing their Particles in ſome Meaſure to repel each other, and thereby preventing them from coming into ſuch cloſe Contact as would render them hard. Now I ſhall ſhew from Experiments that all Degrees of Heat above what is neceſſary to keep Liquors fluid, will raiſe from their Surface (provided they are not viſcid) ſome kind of Steam, which, for Diſtinction's ſake, I ſhall call an *Effluvium*. Under a large Glaſs ſet a Cup of Water, not hot enough to emit any viſible Steam, and let the Glaſs be expoſed to the cold Air, a Dew will ſoon appear on its Inſide. Here an Effluvium is raiſed from the Water, but it riſes too ſlowly and in too ſmall a Quantity to become

come visible till it is condensed on the Glass. As Steam rises from Hot Liquors more abundantly when the Pressure of the Atmosphere is taken away, it may be supposed that this Effluvium will also rise more copiously from colder Liquors in the same Case, as we shall see it really does by what follows. From a great Number of Experiments made with Spirit of Wine, of different Degrees of Strength, I found that, at a Medium, the Quantities lost in the same Time in a close Receiver full of Air, in one only half full of Air, in Air rarefied two and forty Times, and in the open Air, were nearly in the Proportion of 1, $1\frac{5}{7}$, 6, and 48. The same Kind of Spirit was used in each Experiment, the Time was 24 Hours, and the Spirit was contained in equal Cups, so that their Quantities and their Surfaces were as nearly equal as might be. That all the Spirit used in each Experiment might be in the same Circumstances, before I put it into the Cups I drew from it all the Air I could by the Air-pump, which could not rarefy the Air in the Receiver more than two and

forty Times; it was neceſſary to do this, *becauſe the Spirit loſt five or ſix Grains* in a few Minutes while the Air was drawing from it by the firſt Exhauſtion of the Receiver, and a Quantity leſs and leſs during the ſecond and third Exhauſtions. A Cup of Water, when in a warm Room, loſt one Grain on the firſt Exhauſtion, and when it had afterwards ſtood in the exhauſted Receiver for 24 Hours, it loſt two Grains and a Half, while the ſame Quantity of Water loſt 35 Grains in the open Air; but Ice that was thawing, or Water with Ice in it, did *not loſe any Thing in the exhauſted Receiver, or in a cloſe Receiver full of Air.* Theſe Experiments were made in a large Room without a Fire, and the Fluids, whoſe Loſſes I compared together, had the ſame Degree of Heat.

The Spirit of Wine, which is ſo eaſily rarefied by Heat, and which has always more Heat than is ſufficient to keep it fluid, loſt in every Experiment conſiderably more than Water did in the ſame Circum-

Circumſtances; and as Water did not loſe any of its Weight, when it had not more Heat than was neceſſary to keep it fluid, I think the riſing of an Effluvium from theſe Liquors may juſtly be aſcribed to the repelling Force given to their Particles by certain Degrees of Heat. The Air in the Receiver did not contribute to this Effect, but on the Contrary prevented it, in a great Meaſure, by its Preſſure, for the more Air was drawn from the Receiver, the greater Quantity of this Effluvium aroſe. I obſerved, that when the Air was rarefied two and forty Times, the Effluvium that roſe from the Spirit, which was ſometimes near forty Grains in twenty-four Hours, not being ſupported by a ſufficient Quantity of Air, and loſing its firſt Elaſticity by being very much expanded, fell by its Weight to the Bottom, and covered it and the lower Parts of the Receiver with Moiſture. But none, or very little, of this Moiſture appeared when only one Half of the Air was drawn out of the Receiver, for the Effluvium which then aſcended (amounting general-

ly to eight or nine Grains) was supported by the remaining Air; but when I rarefied this Air suddenly, as in an Experiment before mentioned, (Page 37.) the Effluvium was immediately gathered into a vast Number of visible Drops, and fell to the Bottom. This plainly shews that the Effluvia which are raised from Liquors, by these very small Degrees of Heat, cannot continue suspended, unless they are supported by a sufficient Quantity of Air.

I thought it necessary to make these Experiments and Observations, in Order to obviate an Objection which might be made to the Principle I have endeavoured to establish. For, as it is found that Fluids lose of their Weight both in an exhausted Receiver, and in the open Air, it might be said that this Loss proceeded from the same Cause in both Cases, and therefore that common Evaporation did not depend on the dissolving Power of the Air. But from these Experiments, I think, we might give a sufficient Answer to such an Objection. For it appears,

first;

firſt; that Ice, or Water that has no more Heat than is neceſſary to keep it fluid, loſe nothing of their Weight in an exhauſted Receiver, tho' they loſe very conſiderably in the open Air. Secondly; The Quantity which the Spirit of Wine loſt by Evaporation in the open Air, was eight Times greater than what it loſt in the ſame Time by an Effluvium, when the Air in the Receiver was rarefied two and forty Times; therefore the Cauſe of Evaporation muſt be a much more powerful one than that which raiſed the Effluvium. And further, the Quantity loſt by Evaporation was forty-eight Times greater than what was loſt, in the ſame Time, by an Effluvium, when the Receiver was full of Air; therefore, ſuppoſing the ſame Effluvium to riſe from it in the open Air, we muſt allow that of the whole Quantity which the Spirit of Wine loſt in the open Air, one Part only in forty-eight could be owing to that Effluvium which is occaſioned merely by its Heat, conſequently forty-ſeven Parts muſt have been carried off by ſome very

powerful Action of the Air; which must alſo be the ſole Cauſe of the Evaporation of Ice or very cold Water, which are found not to emit any Effluvia in an exhauſted Receiver. And this Action of the Air I have ſhewn to be its diſſolving Power.

Before we conclude, it may not be amiſs to take a general View of the important Purpoſes which Air is contrived to anſwer, and of the Means by which it is adapted to theſe ſeveral Purpoſes. By its Subtilty and Elaſticity it is capable of being eaſily taken into the Lungs of Animals; and by its attracting and diſſolving Power it carries on that Perſpiration, both internal and external, which we find is neceſſary to the Preſervation of Life. By the ſame Power it takes away the ſuperfluous Moiſture from Trees and Plants, and thereby promotes Vegetation. By the ſame Power it raiſes and ſuſtains aqueous Vapours, and its Heat or Denſity being diminiſhed, it returns them again in Rain and Dew, and thus keeps up a continual Circu-

Circulation of Moiſture. By the ſame Power it contributes to the Support of Fire, by carrying off from burning Bodies all ſuch Fumes and Vapours as would otherwiſe extinguiſh them.

By its Weight and Preſſure on the Surface of Fluids it keeps their Particles together, and enables them to bear (without being diſperſed in Steam) ſuch Degrees of Heat as are neceſſary for all thoſe Uſes to which boiling Liquors are applied. By the ſame Preſſure it raiſes Water in Pumps and other Hydraulic Engines.

And laſtly; we may add to theſe, all the various Purpoſes to which the Winds are ſubſervient; which are too many to be enumerated, and too well known to require being particularly mentioned.

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# Obſervations *and* Conjectures

On the Nature of the

# AURORA BOREALIS

AND THE

# TAILS of COMETS.

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# OBSERVATIONS

## AND

## CONJECTURES, &c.

HAVING obſerved that ſome late Writers, who endeavour to revive the exploded Hypotheſis of an univerſal *Plenum*, bring Arguments in Favour of their Opinion from what Sir *Iſaac Newton* ſays of the Aſcent of Comet's Tails in a Direction oppoſite to the Sun; I was induced to reconſider his Account of that Matter, which, I own, never appeared ſatisfactory to me; tho' I agree intirely with him that this

Phænomenon

Phænomenon affords a ſufficient Proof of a *Vacuum* in the Celeſtial Regions. As this is a Subject of ſome Importance in Phyſics, I ſhall, in the following Eſſay, firſt, mention ſuch Objections as occur to me againſt Sir *Iſaac*'s Opinion as to the Cauſe of the Aſcent of Comet's Tails; and then offer ſome Conjectures that may poſſibly lead to a further Knowledge of this Subject, leaving them to be confirmed or overthrown as future Obſervations and Experiments ſhall determine. For I think that Conjectures, or Hypotheſes, when rendered probable by ſome Experiments, and propoſed with Caution, may be of great Uſe by directing our Enquiries into ſome certain Channel.

That I may proceed methodically, I ſhall begin by relating the Phænomena of Comets as obſerved by *Newton*, and other accurate Aſtronomers, for I ſhall have Occaſion to refer frequently to them.

It appears that a Comet is a Kind of Planet which revolves round the Sun in a very

a very excentric Orbit, and recedes much farther from the Sun in its *Aphelion* than any of the Planets; it is not visible until it comes down into the Planetary Regions, and then appears surrounded with a dense Atmosphere, and from the Side opposite to the Sun, it emits a shining Train, which we call its Tail. It is at its first Appearance very short, and encreases as the Comet approaches towards the Sun, and immediately after its *Perihelion*, the Tail is longest and most luminous, and then is generally observed to be somewhat bent, and to be convex towards those Parts to which the Comet moves; the Convex Side being rather brighter and better defined than the Concave Side. When the Tail arrives at its greatest Length, which in some Comets has been computed to be 60 or 70 Millions of Miles, it quickly decreases and soon vanishes entirely, about the same Time that the Comet itself ceases to be seen. The Matter of which the Tail is formed is exceedingly rare, and so very pellucid that the Light of the smallest Stars suffers

no

no Diminution in paſſing thro' it, for Sir *Iſaac Newton* obſerves: 'The extraordinary Rarity of Comet's Tails may be collected from the Stars ſhining thro' them; for the ſmalleſt Stars are obſerved to ſhine without any Loſs of Splendor thro' the Tails which are of an immenſe Thickneſs, and are alſo illuminated by the Light of the Sun.*

Theſe are the principal Phænomena of Comets, and it is from hence we muſt deduce whatever we can know of the Subſtance of which the Tails conſiſt, or of the Reaſon why they are always thrown off from the Head of the Comet, in a Direction nearly oppoſite to the Sun. And with theſe Phænomena I propoſe to compare the Opinions which are commonly received concerning this Matter.

* Caudarum inſignis raritas colligitur ex Aſtris per eas Tranſlucentibus.—Per Immenſam vero Caudarum Craſſitudinem, Luce pariter Solis illuſtratam, Aſtra minima abſque Claritatis Detrimento tranſlucere noſcuntur. *Principia*, Page 513. Edit. 2da.

Sir

Sir *Isaac* tells us, that there were three different Opinions about Comet's Tails, *viz.* that they were only Rays of the Sun propagated thro' the transparent Head of the Comet. Or that they arose from the Refraction of the Light in its Passage from the Head of the Comet to the Earth. Or, lastly, that they consisted of Clouds and Vapours continually rising from the Head of the Comet, and going off in a Direction opposite to the Sun. The first and second of these Opinions he refutes, and adopts the third, and proves by several Arguments, that the Tail must consist of some Kind of Vapour arising continually from the Head of the Comet. The Cause of its ascending always from the Sun, he assigns in another Paragraph, which I shall now quote at Length, translating it as faithfully as I can; it is as follows:

'The Ascent of Tails from the Atmo-
'sphere of Comets, and their Progress
'towards the Parts opposite to the Sun,
'*Kepler* ascribes to the Action of the Rays
'of

'of Light, carrying with them the Mat-
'ter of which the Tails consist. And
'that so very thin an Air or Vapour
'should yield to the Action of the Rays,
'in Spaces void of Resistance, is not al-
'together against Reason; altho' in our
'Regions, clogged with resisting Matter,
'the solar Rays cannot sensibly impel
'dense Bodies. Others think that there
'may be some Particles of Matter in
'their own Nature light, as well as some
'that are heavy, and that the Matter of
'the Tails is of the former Sort, and by
'its Levity ascends from the Sun. But
'since the Gravity of all terrestrial Bodies
'is proportional to their Quantity of
'Matter, and cannot in the same Body
'be increased or diminished, I suspect
'that this Ascent of the Tails arises ra-
'ther from the Rarefaction of their Mat-
'ter. Smoke ascends in a Chimney by
'the Impulse of the Air in which it
'floats; that Air, being rarefied by Heat
'and its specific Gravity thereby dimi-
'nished, ascends and carries the Smoke
'with it. Why then should not the
'Tail

'Tail of a Comet aſcend in the ſame
'Manner from the Sun? for the ſolar
'Rays do not agitate any Medium thro'
'which they paſs, but in Reflection or
'Refraction, the reflecting Particles by
'that Action grow warm, and heat
'the ætherial Air *(auram Ætheream)*
'with which they are mixed, which be-
'ing rarefied by this Heat, and the ſpeci-
'fic Gravity by which it tended to the
'Sun being thereby diminiſhed, it will
'aſcend and carry with it the reflecting
'Particles of which the Tail is formed:
'it conduces alſo to the Aſcent of theſe
'Vapours that they revolve round the
'Sun, and therefore endeavour to recede
'from it; while the Atmoſphere of the
'Sun either is at Reſt, or revolves more
'ſlowly with ſuch Motion as it can ac-
'quire from the Rotation of the Sun
'round its Axis. Theſe are the Cauſes
'of the Aſcent of the Tails in the Neigh-
'bourhood of the Sun, where the Orbit
'has a greater Curvature, and the Co-
'met moves in a denſer, and therefore
'heavier Atmoſphere of the Sun, and

'then

'then emits a Tail of a greater Length. 'For the Tails, which then arise, by pre-'serving their own Motion, and at the 'same Time gravitating towards the Sun, 'will revolve about the Sun in *Ellipses* 'just as their Heads do; and by that 'Motion will always accompany their 'Heads and adhere to them most freely. 'For the Gravity of those Vapours to-'wards the Sun will no more cause the 'Tails to fall from the Heads to the Sun, 'than it will cause the Heads to fall from 'the Tails, but they must both, by their 'common Gravity, fall together to the 'Sun, or both together be retarded in 'their Ascent from it: and consequently 'their Gravity will not hinder the Heads 'and Tails of Comets easily to receive '(from the abovementioned or other 'Causes) any Position whatever in respect 'to each other, or to keep this Position 'afterwards most freely.'*

We find in this Account that Sir *Isaac*

**Principia*, Page 514.

ascribes

aſcribes the Aſcent of Comet's Tails to their being rarer and lighter, and moving round the Sun more ſwiftly, than the ſolar Atmoſphere, with which he ſuppoſes them to be ſurrounded, whilſt in the Neighbourhood of the Sun; he ſays alſo, that whatever Poſition (in Reſpect to each other) the Head and Tail of a Comet then receive, they will keep the ſame afterwards moſt freely, and in another Place he obſerves, 'That the celeſtial Spaces muſt be entirely void of any Power of reſiſting, ſince not only the ſolid Bodies of the Planets and Comets, but even the exceeding thin Vapours, of which Comet's Tails are formed, move thro' thoſe Spaces with immenſe Velocity, and yet with the greateſt Freedom.'* — I cannot help thinking that this Account is liable to many Difficulties and Objections, and that it ſeems not very conſiſtent with itſelf, or with the Phænomena.

I do not know that we have any Proof

* *Principia*, Page 514.

of

of the Exiſtence of a ſolar Atmoſphere of any conſiderable Extent, nor are we any where taught how to gueſs at the Limits of it. It is evident that the Exiſtence of ſuch an Atmoſphere cannot be proved merely by the Aſcent of Comet's Tails from the Sun, as that Phænomenon may poſſibly ariſe from ſome other Cauſe. However let us ſuppoſe, for the preſent, that the Aſcent of Comet's Tails is owing to an Atmoſphere ſurrounding the Sun, and ſee how the Effects ariſing from thence will agree with the Phænomena. When a Comet comes into the ſolar Atmoſphere, and is then deſcending almoſt directly to the Sun, if the Vapours which compoſe the Tail are raiſed up from it by the ſuperior Denſity and Weight of that Atmoſphere, they muſt riſe into thoſe Parts that the Comet has left, and therefore at that Time they may appear in a Direction oppoſite to the Sun. But as ſoon as the Comet comes near the Sun, and moves in a Direction nearly at right Angles with the Direction of its Tail, the Vapours

which then arise, partaking of the great Velocity of the Comet, and being specifically lighter than the *Medium* in which they move, and being vastly expanded thro' it, must necessarily suffer a Resistance immensely greater than what the small and dense Body of the Comet meets with, and consequently cannot possibly keep up with it, but must be left behind, or, as it were, driven backwards by the Resistance of that Medium into a Line directed towards the Parts which the Comet has left, and therefore can no longer appear in a Direction opposite to the Sun. And in like Manner, when a Comet passes its *Perihelion*, and begins to ascend from the Sun, it certainly ought to appear ever after with its Tail behind it, or in a Direction pointed towards the Sun; for if the Tail of the Comet be specifically lighter than the Medium in which it moves with so great Velocity, it must be just as impossible it should move foremost, as it is that a Torch *moved swiftly thro' the Air should* project its Flame and Smoke before it.

Since

Since therefore we find that the Tail of a Comet, even when it is aſcending from the Sun, moves foremoſt and appears in a Direction nearly oppoſite to the Sun, I think we muſt conclude that the Comet and its Tail do not move in a Medium heavier and denſer than the Matter of which the Tail conſiſts, and conſequently that the conſtant Aſcent of the Tail from the Sun muſt be owing to ſome other Cauſe. For that the ſolar Atmoſphere ſhould have Denſity and Weight ſufficient to raiſe up the Vapours of a Comet from the Sun, and yet not be able to give any ſenſible Reſiſtance to theſe Vapours in their rapid Progreſs thro' it, are two Things inconſiſtent with each other. And therefore, ſince the Tail of a Comet is found to move as freely as the Body does, we ought rather to conclude that the celeſtial Spaces are void of all reſiſting Matter, than that they are filled with a ſolar Atmoſphere, be it ever ſo rare.

But there is, I think, a further Conſideration

ſideration which will ſhew that the received Opinion, as to the Aſcent of Comet's Tails, is not agreeable to the Phænomena, and may at the ſame Time lead us to ſome Knowledge of the Matter of which theſe Tails conſiſt; which I ſuſpect is of a very different Nature from what it has been hitherto ſuppoſed to be. Sir *Iſaac* ſays, the Vapours, of which the Tail of a Comet conſiſts, grow hot by reflecting the Rays of the Sun, and thereby warm and rarefy the Medium which ſurrounds them; which muſt therefore aſcend from the Sun, and carry with it the reflecting Particles of which the Tail is formed; for he always ſpeaks of the Tail as ſhining by reflected Light. But one would rather imagine, from the Phænomena, that the Matter which forms a Comet's Tail has not the leaſt ſenſible Power of reflecting the Rays of Light. For it appears from Sir *Iſaac*'s Obſervation, which I have quoted already, that the Light of the ſmalleſt Stars, coming to us through the immenſe Thickneſs of a Comet's Tail, does not ſuffer the leaſt

Diminution. And yet, if the Tail can reflect the Light of the Sun so copiously, as it must do if its great Splendor be owing to such Reflection, it must undoubtedly have the same Effect on the Light of the Stars; that is, it must reflect back the Light, which comes from the Stars behind it, and by so doing must intercept them from our Sight, considering its vast Thickness, and how exceedingly slender a Ray is that comes from a small Star; or if it did not intercept their whole Light, it must, at least, increase their Twinkling. But we do not find that it has even this small Effect, for those Stars that appear thro' the Tail are not observed to twinkle more than others in their Neighbourhood. Since therefore this Fact is supported by Observations, what can be a plainer Proof that the Matter of a Comet's Tail has no Power of reflecting the Rays of Light? and consequently that it must be a self-shining Substance. But the same Thing will further appear, from considering that Bodies reflect and refract Light by one and the same

ſame Power; and therefore if Comet's Tails want the Power of refracting the Rays of Light, they muſt alſo want the Power of reflecting them. Now, that they want this refracting Power appears from hence, if that great Column of tranſparent Matter which forms a Comet's Tail, and moves either in a *Vacuum*, or in ſome Medium of a different Denſity from its own, had any Power of refracting a Ray of Light, coming thro' it from a Star to us, that Ray muſt be turned far out of its Way in paſſing over the great Diſtance between the Comet and the Earth; and, therefore, we ſhould very ſenſibly perceive the ſmalleſt Refraction that the Light of the Stars might ſuffer in paſſing through a Comet's Tail. The Conſequence of ſuch a Refraction muſt be very remarkable, the Stars that lie near the Tail would, in ſome Caſes, appear double, for they would appear in their proper Places by their direct Rays, and we ſhould ſee their Images behind the Tail, by Means of their Rays which it might refract to our Eyes; and thoſe

Stars that were really behind the Tail would diſappear in ſome Situations, their Rays being turned aſide from us by Refraction. In ſhort, it is eaſy to imagine what ſtrange Alterations would be made in the apparent Places of the fixed Stars by the Tails of Comets, if they had a Power of refracting their Light, which could not fail to be taken Notice of, if any ſuch ever happened. But ſince Aſtronomers have not mentioned any ſuch apparent Changes of Place among the Stars, I take it for granted that the Stars ſeen thro' all Parts of a Comet's Tail appear in their proper Places, and with their uſual Colours, and conſequently I infer that the Rays of Light ſuffer no Refraction in paſſing thro' a Comet's Tail. And thence I conclude (as before) that the Matter of a Comet's Tail has not the Power of refracting or reflecting the Rays of Light, and muſt therefore be a lucid or ſelf-ſhining Subſtance.

And thus if I have argued rightly from the Phænomena, it muſt appear, that the Tail

Tail of a Comet does not consist of aqueous or other Vapours, that shine by reflecting the Light of the Sun, but is a very rare, transparent and lucid Substance, which has no Sort of Effect on the Rays of Light that pass thro' it, and that it is thrown off from the dark Hemisphere of the Comet in a Direction opposite to the Sun, not by the superior Weight and Density of any circumambient Medium, but by some other Cause that has not yet been discovered.

This seems to me to be all the Knowledge we can acquire of the Nature and Properties of that Matter which forms the Tails of Comets, by attending merely to the Phænomenon itself. But perhaps we may be able to extend this Knowledge somewhat further, if we could find any other Phænomenon in Nature which resembles this of Comet's Tails, and can become acquainted with any Kind of Matter that has the same Properties with that of which they are formed. Now I have often observed a Phænomenon that, I think,

very ſtrongly reſembles the Tail of a Comet, both in its Appearance, and in the Nature of its Subſtance. We frequently ſee a very rare, tranſparent, and lucid Subſtance thrown off, in a Direction nearly oppoſite to the Sun, from the dark Hemiſphere of the Earth, and principally from the more Northern and colder Regions of our Atmoſphere. This Appearance is ſo luminous that it has been from thence called the *Aurora Borealis*; it is now ſo common and well known that I ſhall not deſcribe it particularly, and will only take Notice of thoſe Circumſtances in which it chiefly reſembles a Comet's Tail. Thoſe Northern Lights never appear, at leaſt in any remarkable Degree, ſoon after Sun-ſet or before Sun-riſe, tho' it may be then dark enough to make them viſible, but generally from about ten o'Clock at Night till one in the Morning; and the very long Streams of Light, which iſſue frequently from the Northern Parts of our Atmoſphere, ſeem ſtill to tend towards the Zenith of that Place where the Spectator is, and ſometimes

get

get beyond the Zenith, and appear to the Southward of it; which ſhews that theſe Streams of Light tend towards the Vertex of the Earth's Shadow, that is, towards the Part of the Heavens which is oppoſite to the Sun. From the great Length of theſe Streams of Light, which ſeem always moving upwards, we may conclude that they extend to a great Height in the Atmoſphere, and probably riſe far above it. For by the Accounts we have of an *Aurora Borealis*, obſerved in *England* on the Sixth of *March*, 1716, it was viſible from the Weſt Side of *Ireland*, to the Confines of *Ruſſia* and *Poland*, and probably farther to the Eaſt; ſo that it extended at leaſt over thirty Degrees of Longitude, and from about the fiftieth Degree of Latitude over almoſt all the North of *Europe*, and at all Places it exhibited the ſame Appearances, nearly at the ſame Time.

Now this great Body of luminous Mat-

ter which appears in an *Aurora Borealis*, being ſo very extenſive, and ſometimes ſo very bright, muſt be viſible to a Spectator placed at a conſiderable Diſtance from the Earth, and ſhaded from the Sun's Light; and ſuch a Spectator would then ſee the Earth attended by a Train of Light in the Form of a Tail. It would probably appear ſmall in Proportion to the Earth's Diameter, it would ſeem unſteady, changeable in its Shape, and of a ſhort Continuance; but whilſt it laſted, it muſt, both in its Direction, and in the Nature and Appearance of its Light, very much reſemble the Tail of a Comet. And if ſuch a Spectator was to obſerve the Earth for a Year, he might perceive a further Reſemblance in this Reſpect between the Earth and a Comet; for as the Tail of a Comet appears only a ſhort Time before and after its *Perihelion*, ſo he would ſee this luminous Matter riſe from the Earth frequently whilſt it was moving from the Autumnal to the Vernal Equinox, thro' the Half of its Orbit that is neareſt to the Sun, and very

ſeldom

ſeldom during the other Part of the Year, for we rarely ſee an *Aurora Borealis* in the Summer Months. Thus we find that the Matter of an *Aurora Borealis* and that of a Comet's Tail are very like each other in their Appearance, and in their Situation, with Reſpect to the Sun and the Bodies from which they flow. And if we examine further, we ſhall find that they have exactly the ſame Properties; for the Matter of which the *Aurora Borealis* conſiſts is not only very rare, tranſparent and lucid, but is alſo found to have no Sort of Effect on the Rays of Light which paſs thro' it. This I have often obſerved, and particularly at one Time when there appeared here an *Aurora Borealis*,* which for its Extent, for the Quantity, Brightneſs and Steadineſs of its Lights, was the moſt remarkable one I ever ſaw; ſome Parts of it appeared like very denſe white Clouds, illuminated by a full Moon, but with a more vivid Brightneſs; and yet thro' one of the denſeſt and whiteſt of

*October* 16th or 17th, 1763.

these Clouds, I could plainly see the smallest Star in the *Pleiades*, and could not perceive that its Splendor was at all diminished, or that it even twinkled more than it did before this lucid Matter was interposed, which, as it moved with a quick tremulous Motion, must have at least increased the Twinkling of the Stars, if it had any Sort of Effect on the Rays which passed thro' it. Since then the Matter of a Comet's Tail, and that of the *Aurora Borealis* are alike in their Appearance, and agree also in their Properties, we have some Reason to suppose that they are Substances of the same Kind.

Having gained this Step, we may go on in our Enquiries, and try if any other Substance, that we are better acquainted with, has the same Properties with the Substance of which Comet's Tails and the *Aurora Borealis* are formed. It is now well known that our Atmosphere abounds with electric Matter, which is more or less contained in all Bodies; this Matter

is

is never visible but whilst it is passing from one Body to another, thro' the Air or a *Vacuum*, it then appears to be a very rare, subtile, shining Substance. We often see it flashing from one Cloud to another, or into the Earth, with great Velocity and Brightness, and then we give it the Name of Lightning; and in the same Manner when we bring our Finger near a Bar of Iron strongly electrified, we see very bright Sparks issue from it to our Finger. It seems that Air, in its common State of Condensation, resists the Egress of the electric Matter from Bodies in which it is accumulated, especially if they are round and smooth, and when it forces its Way it seems to come out, as it were, all at once, and in a very condensed State, and therefore it appears very bright. But if the Air be considerably rarefied, its Resistance is thereby greatly lessened, and the electric Matter cannot be accumulated in a Body surrounded by such Air, for in that Case, as fast as it is communicated to the Body it will issue out from various Parts of it in small Streams of a

faint Light, as will appear from ſome Experiments I ſhall have Occaſion to mention preſently.

Now ſince a ſolid Body and a Cloud, when electrified in denſe Air, will both diſcharge their Fire in the ſame Manner, that is, ſuddenly and in bright Sparks or large bright Flaſhes, we muſt conclude, from Analogy, that when they are both electrified in Air much rarefied, they will then likewiſe diſcharge their Fire in the ſame Manner, and conſequently, that an electrified Cloud, raiſed into the higher and rarer Parts of the Atmoſphere, will diſcharge its Fire in continued Streams of faint Light. And as we ſometimes ſee faint Flaſhes of Lightning in a Summer Evening after Sun-ſet, tho' no Clouds appear; ſo if the Vapours which riſe into the higher Part of the Atmoſphere, tho' not formed into Clouds, carry up with them the electric Matter, they muſt diſcharge it in continued Streams of faint Light, juſt as a Cloud would do; and thoſe Streams of Light in the higher

Parts,

Parts of the Atmosphere must exactly represent to us the Appearance of an *Aurora Borealis*. Any one will readily perceive a strong Resemblance between the *Aurora Borealis* and the electric Fire discharged from a Body in rarefied Air, who will make the following Experiments.

Let the Air be almost exhausted out of a Glass Globe or Cylinder, and let it be turned by a Machine and rubbed as usual; the electric Fire will then appear in the Inside of the Globe, shooting out in various Branches of faint Light, crossing each other in all Directions, and this Light will sometimes appear tinged with different Colours; when the Air is very much rarefied, the Light appears white, and grows more of a purple Colour as more Air is admitted into the Globe. [A] I

[A] This Experiment was first made by Mr. *Hawksbee*, and has since been often repeated; and I find that the *Aurora Borealis* has of late been generally supposed to be an electrical Phænomenon, *though I have not met with any Attempt to* prove that it is so.

found

found this Experiment ſucceed beſt when I held in my Hand the Cuſhion with which the Globe was rubbed, and preſſed it ſometimes cloſely and ſometimes ſlightly to the Globe. I found that a like Appearance might alſo be exhibited by the following Experiment. A Cylinder 20 Inches high, and about five in Diameter, having a pretty thick Braſs Wire put thro' the Top, was almoſt exhauſted, then being myſelf electrified, I moved my Finger towards the Top of the Wire, and immediately I ſaw every Spark that came from my Finger divided into a Multitude of ſmall Streams of Light iſſuing from the Wire at right Angles to it, and in different Directions. When I took hold of the Wire I could ſee but little Light in the Cylinder, ſo found it was neceſſary to keep my Finger at a ſmall Diſtance, and let the electric Matter come to the Wire in ſucceſſive Sparks. I thought the Lights that iſſued from the Wire were brighteſt when it was oiled, and when the Air was about 30 Times rarer than the outward Air. Several Per-
ſons

ſons almoſt as ſoon as they ſaw the electric Lights compared them to the Appearance of the *Aurora Borealis*; and certainly theſe two Phænomena reſemble each other entirely, both in the Colours of their Light, and in the Quickneſs of their Motions. For when the Air in the Glaſs-Globe was very much rarefied, the electric Lights appeared very white, and became more of a purple Colour as more Air was admitted into the Globe; juſt ſo the long Streams of Light in the *Aurora Borealis* are very white on their upper Parts, where the Air about them is much rarefied, and are often of a purple Colour on their lower Parts, which are in denſer Air. And as in the Globe the electric Lights appear in greater Abundance when the Air has a particular Degree of Denſity than in other Caſes; ſo the quick Appearing and Diſappearing of the Streams of Light in the *Aurora Borealis* may poſſibly ariſe from a Charge of Denſity in the higher Parts of the Atmoſphere. For where the Air is ſo very thin it may be ſubject to very ſudden

Condenſations and Rarefactions, occaſioned by the Motion of the Winds, and I have obſerved thoſe Lights to appear and diſappear more quickly in a windy Night than when it was calm; though their Courſe or Direction was no ways influenced by the Wind.

But the electric Matter appears to be of the ſame kind of Subſtance which forms the *Aurora Borealis*, and the Tails of Comets, by its having alſo that remarkable Property of letting the Rays of Light paſs thro' it, without having any Sort of Effect upon them. And this I found by ſeveral Experiments, for I obſerved that ſmall Rays of Light, paſſing over ſharp Points, and by the Edges of Knives, from whence the electric Matter iſſued abundantly, were affected in the very ſame Manner as when theſe Points and Edges were not electrified. Having provided a large Pane of Glaſs properly coated on both Sides with thin ſheet Lead, I made two ſmall Holes in the Lead, oppoſite to each other, for a Ray

of

of Light to paſs thro'; and I found this Ray was no more refracted in its Paſſage thro' the Holes, when one Side of the Glaſs was electrified *plus*, and the other *minus*, than it was before the Glaſs was electrified at all, or after the electric Matter was diſcharged, which ſhews that the Accumulation, or the Abſence of this Matter no way contributed to encreaſe or diminiſh the refractive Power of the Glaſs. I found that when Water was electrified, no Change was made either in its Power of refracting or reflecting the Rays of Light.

I made many other Experiments of the ſame Kind, too tedious to deſcribe, and they all led me to conclude that the electric Matter had no Sort of Effect on the Rays of Light that paſſed thro' it. Since then the electric Matter ſeems to be of the ſame Nature with that which forms the *Aurora Borealis*, and abounds much in the Atmoſphere, and, when it gets into the rarer Parts of it, will, by its known Properties, exhibit to us an Appearance like that

that of the *Aurora Borealis*, we muſt acknowledge it to be a Cauſe really exiſting, and ſufficient to explain this Phænomenon, and therefore we may aſcribe the Appearance of an *Aurora Borealis* to the Riſing of the electric Matter into the upper Regions of the Atmoſphere. The following Obſervation will ſerve further to confirm this Opinion. In our Summer Months, when the electric Matter is frequently diſcharged from the lower Clouds in Lightning, and ſo returns to the Earth, we ſcarce ever ſee an *Aurora Borealis*; but at other Times, when it is not uſually diſcharged in Lightning, it may riſe higher into the Atmoſphere, and will occaſion more frequent Appearances of this Kind. And this probably is the Reaſon why theſe Appearances are more frequent in cold than in warm Climates, the former being leſs ſubject to Storms of Thunder and Lightning than the latter. In Countries that lie far to the North, the *Aurora Borealis* is ſaid to ſhine much brighter than with us, and to appear almoſt every Night.

As

As the preceding Considerations seem to make it probable that the Tails of Comets consist of the same Kind of Substance which forms the *Aurora Borealis*, and that this is no other than the electric Matter; I shall assume this as a Principle, and try if I can from thence account, in some Measure, for the Phænomenon of Comet's Tails, and in doing this I shall have an Opportunity of making some Observations which may serve to shew a further Resemblance between those three Substances that I have compared together. The Earth, and all Bodies near it, contain more or less of the electric Matter, and tho' it may be accumulated in some Bodies, and diminished in others, we cannot be sure that any Body may be totally deprived of it, but on the contrary have great Reason to think it can neither be increased nor diminished in any Body beyond a certain Degree; we must therefore suppose that it is contained in all Bodies in our solar System. Some Bodies, such as Glass, Amber and others, that are called *Electrics*, attract and retain this Matter more

more ſtrongly than thoſe do which are called *Non-Electrics*, for an electric Body will draw this Matter from one that is not electric, againſt which it is rubbed, and it will alſo ſtop the electric Matter in its Progreſs from one Body to another, and therefore an electric Body is called a *Non-conductor*, in Oppoſition to other Bodies thro' which the electric Matter readily paſſes. But we find that any Body, even the moſt electric, if ſufficiently heated, will become a *Conductor*, or will let the electric Matter paſs from it very eaſily, and therefore we conclude that Heat diſpoſes all Bodies readily to part with the electric Matter they contain, and we have an Inſtance in the *Tourmalin* Stone that ſome Bodies will always throw off an electric Matter merely by being heated. Now when a Comet comes down towards the Sun, from Regions of extreme Cold, and begins to acquire ſome Degree of Heat, it will, like other Bodies, be diſpoſed to part with the electric Matter, which it may poſſibly contain in great Abundance, and this Matter, when thrown off, will exhibit

to

to us the Appearance of a ſhining Train as it does in the *Aurora Borealis*; and as the Comet comes to its *Perihelion*, and the Heat increaſes, this Matter will iſſue more abundantly, and the Train or Tail will increaſe in Length, till upon the Comet's receding from the Sun the Heat will decreaſe, and this Matter being pretty much exhauſted, the Tail will be contracted in its Dimenſions, and at length will be too far removed, and grow too faint to be obſerved.

As a Comet is expoſed to vaſt Extremes of Heat and Cold, Light and Darkneſs, we may well ſuppoſe it to be uninhabited, and if ſo, it is not neceſſary that it ſhould turn different Sides to the Sun, but may always keep the ſame Face towards it, as the Moon keeps the ſame Face towards the Earth, and indeed it muſt do ſo if its Figure be that of an oblong Spheroid. Now the electric Matter which riſes from the Earth goes off into the colder Regions of the Atmoſphere, and in a Direction nearly oppoſite to the Sun, and I believe

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we have no Inſtance of what we call the *Aurora Borealis* appearing between the Tropicks. Why then ſhould not this Matter take the ſame Courſe in its Progreſs from the Head of the Comet, and fly off from its dark Hemiſphere, where its Atmoſphere is colder and clearer, and where the Vapours are thin, and, riſing more gradually, will give it an Opportunity of riſing along with them; whilſt on the other Hemiſphere, which is expoſed to the Sun, the Vapours muſt riſe very thick, and form Clouds which may intercept the electric Matter in its Progreſs, and collecting it together may return it back to the Head of the Comet in Lightning, as our Clouds in hot Countries return their electric Matter into the Earth. Beſides as we find that the electric Matter paſſes off from a Body where it is rough or pointed, much more readily than where it is round and ſmooth, ſo it is poſſible that the Hemiſphere of the Comet, which is turned from the Sun, may be ſo formed as to part with the electric Matter more readily than the other, which is turned towards

wards the Sun, and in whatever Direction the electric Matter is thrown off from any Body, we find it continues to move with immenſe Velocity, as I obſerved in the Streams of electric Matter which iſſued from the Wire in the exhauſted Receiver. I obſerved alſo that theſe Streams did not grow much thicker as they advanced in their Courſe, either in the exhauſted Globe or cylindrical Receiver; nor did they ſeem diſpoſed to expand themſelves into the Space that ſurrounded them, but went ſtraight forward, juſt as a Ray of ſolar Light would do. And thus the Matter which iſſues from a Comet proceeds in the ſame Direction in which it is thrown off, and forms that large Column, which we call the Tail; and we ſee that the Matter of which the Tail conſiſts has very little or no Diſpoſition to expand itſelf into the ſurrounding Spaces; for the Tail is not much broader towards the End than near the Head of the Comet. This I think is a moſt extraordinary Property, both of the electric Matter and of that which forms a Comet's Tail, and which

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is a further Argument for concluding them to be of the ſame Nature, for they both fly off from the Body, in which they are, with great Velocity, which ſeems to argue a repulſive and expanſive Force, and yet they proceed as the Rays of Light do without expanding themſelves laterally into the Spaces thro' which they paſs.

And this remarkable Property ſeems well worth attending to, in all our Enquiries concerning the electric Matter. At preſent we are ſo little acquainted with the true Nature of it, and ſo ignorant of the Subſtance which forms the Body of the Comet, that it is not to be expected, we ſhould be able to ſay how it can furniſh ſuch a vaſt Quantity of this electric Matter, or to aſſign with Certainty the Reaſon why the Tail of a Comet is thrown off from its dark Hemiſphere, in a Direction oppoſite to the Sun, rather than in any other Direction. Future Experiments and Obſervations will either confirm theſe Conjectures of mine, or ſuggeſt others more probable; but now

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we can only argue by Analogy from the rising of the electric Matter thro' the colder Regions of our Atmosphere in the *Aurora Borealis*, that the same Effect will take Place in the Atmosphere of a Comet, and from the same Cause, whatever that may be.

Sir *Isaac Newton* observes that the Tail of the Comet which came to its *Perihelion* on the eighth of *December*, 1680, appeared about the Middle of *January* following to be bent into a Curve. Now as the Tail was convex towards those Parts which the Comet moved, this Bending might seem to arise from its meeting with some resisting Matter; but this Curvature was much less than what would arise from a resisting Matter denser than the Tail, and whose superior Gravity would be able to raise it up from the Sun; for he tells us that on the 5th of *January*, when the Tail was 40 Degrees long, its Chord, or a Line drawn from the Head of the Comet to the Extremity of its Tail, made an Angle of

only 8 Degrees with a great Circle passing thro' the Sun and Comet. But that this Curvature was not owing to any resisting Matter appears from hence, that the Tail must be bent into a Curve tho' it met with no Resistance; for it could not be a right Line, unless all its Particles were projected in parallel Directions, and with the same Velocity, and unless the Comet moved uniformly in a right Line. But the Comet moves in a Curve, and each Part of the Tail is projected in a Direction opposite to the Sun, and at the same Time partakes of the Motion of the Comet; so that the different Parts of the Tail must move on in Lines which diverge from each other; and a Line drawn from the Head of a Comet to the Extremity of the Tail will be parallel to a Line drawn from the Sun to the Place where the Comet was, when that Part of the Tail began to ascend, as Sir *Isaac* observes; and so all the Chords, or Lines drawn from the Head of the Comet to the intermediate Parts of the Tail, will be respectively parallel to Lines drawn from

from the Sun to the Places where the Comet was when these Parts of the Tail began to ascend. And therefore, since these Chords of the Tail will be of different Lengths, and parallel to different Lines, they must make different Angles, with a great Circle passing thro' the Sun and Comet, and consequently a Line passing thro' their Extremities will be a Curve.

It is observed that the convex Side of the Tail which is turned from the Sun is better defined, and shines a little brighter than the concave Side. Sir *Isaac* accounts for this by saying, that the Vapour on the convex Side is fresher (that is, has ascended later) than that on the concave Side, and yet I cannot see how the Particles on the convex Side can be thought to have ascended later than those on the concave Side which may be nearer to the Head of the Comet. I think it rather looks as if the Tail, in its rapid Motion, met with some slight Resistance just sufficient to cause a small Condensation in

that Side of it which moves foremoſt, and which would occaſion it to appear a little brighter and better defined than the other Side; which ſlight Reſiſtance may ariſe from that ſubtile Æther which is ſuppoſed to be diſperſed thro' the celeſtial Regions, or from this very electric Matter diſperſed in the ſame Manner, if it be different from the Æther. Here I muſt obſerve that the convex Side of the Tail, which is turned from the Sun, being brighter than the other Side, affords an additional Argument in Favour of what I have aſſerted, that the Tail does not ſhine by reflecting the Sun's Light. And this leads me to ſay ſomething of that luminous Quality which we obſerve in the electric Matter, and by which I ſuppoſe the Tails of Comets to ſhine.

The Writers on Electricity tell us that the electric Matter carries off from Bodies certain ſubtile Particles of a ſulphurous inflammable Nature, which it kindles as ſoon as they are diſengaged from the Body, and thence it ſhines. And this Account

Account is proved from its inflaming other Bodies, ſuch as warm Spirits, and from that ſulphurous Smell which always attends the electric Matter, and which any one will perceive from his Hand, if he receives the electric Sparks on it for ſome Time, and the ſame Smell is more ſtrongly perceived in Places that have been ſtruck by Lightning. Now theſe inflammable Vapours which often abound in the Air, being carried up by the electric Matter, and kindled in the higher Parts of the Atmoſphere, will cauſe it to ſhine and appear to us in the *Aurora Borealis.* That the electric Matter can kindle the inflammable Particles that it carries off from Bodies, in Air highly rareſied, or even in *vacuo*, appears from its ſhining in the upper Part of the Barometer, in which is the moſt perfect *Vacuum* we can make.

But perhaps it may be ſaid, that without having Recourſe to the electric Matter, we might ſuppoſe the Comet, or a great Part of it, to conſiſt of ſome very

combuſtible Matter which may take fire by a ſmall Degree of Heat, and blaze out in ſuch Abundance as to occaſion the luminous Appearance we call the Tail. And this Hypotheſis may appear at firſt Sight more natural and probable than the one I have ſuggeſted; yet I imagine it will not be found ſo, if we examine it attentively. For if the Comet were to take fire and blaze out as burning Bodies do with us, the Elaſticity of the Flame might indeed raiſe it to ſome Diſtance from the Body of the Comet, but then it would riſe equally on all Sides, or rather to a greater Height on the Side next the Sun, where the Heat is greateſt. And a Flame of this kind could not be carried up in a Direction oppoſite to the Sun, unleſs it were by the ſuperior Denſity and Weight of ſome ſurrounding Medium which gravitates towards the Sun; juſt as we find the Flame of burning Bodies is raiſed upwards by the Preſſure of the ſurrounding Air. But I have ſhewn, in the former Part of this Eſſay, that a Medium denſer

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and heavier than the Tail muſt reſiſt and retard its Motion much more than that of the Comet, and therefore could never permit the Tail to move foremoſt as it ſometimes does, but muſt cauſe it always to fall behind, and conſequently to appear as directed towards the Sun when the Comet has paſſed its *Perihelion*, and is retiring from the Sun. So that in order to account for the conſtant Aſcent of this luminous Matter in a Direction oppoſite to the Sun, we muſt have Recourſe to ſome Medium that has no ſenſible Gravity, and that is apt to move in ſome particular Direction from the Body in which it is, and with ſuch Velocity as to carry the burning Matter to a vaſt Diſtance from the Comet before it is entirely conſumed. Now I believe we do not know of any Medium that has theſe Properties except that which we call the electric Matter. For it ſeems no more affected by the Force of Gravity than the Rays of Light are, and when it moves freely it is apt to go on in the Direction, in which it ſet out, as I obſerved before,

and then it moves with ſuch a Velocity as we cannot meaſure, for it has been found to paſs thro' a Wire two Miles and a half in Length, as it were, inſtantaneouſly. This Medium therefore ſeems not only capable of kindling ſuch ſubtile inflammable Particles as it meets with in the Comet, but alſo of carrying them off, before they are conſumed, to the vaſt Diſtance to which the Tail ſometimes extends.

Where the inflammable Particles are quite conſumed, the Tail of the Comet muſt end; and the electric Matter will afterwards be inviſibly diſperſed thro' the planetary Regions, where it may be gathered up by the Planets in their Courſes round the Sun. For ſince we find this kind of Matter placed in all Bodies by the Wiſdom of Providence, we muſt conclude it is neceſſary for carrying on the ſeveral Operations of Nature; and we know it is very apt to eſcape from Bodies by its great Subtilty and repelling Force. We ſee it riſes from the Earth

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into the Atmosphere, and is probably going off from thence when it appears in the *Aurora Borealis*. In like Manner it may fly off from the other Planets, and be continually expanding itself from the Center of our System beyond the Orbit of *Saturn*. So that it may be necessary it should be brought back again and dispersed among us by the Comets. And it seems to me more probable that Comets were intended for this Use, than for that of supplying the Planets with Moisture, as Sir *Isaac Newton* thought. His Opinion was founded on a Supposition that all Vegetables have their Growth and Increase entirely from Water, and that since they do not turn again into Water but into Earth, there must be a continual Decay of Moisture, and therefore a fresh Supply of it must be necessary from time to time.* But this Supposition does not seem

* Nam Vegetabilia omnia ex Liquoribus *omnino* crescunt, dein magna ex parte in Terram aridam per Putrefactionem abeunt, et Limus ex Liquoribus putrefactis perpetuo decidit. Hinc moles

seem to have been sufficiently grounded on Experience. For, since Sir *Isaac* wrote, Dr. *Woodward*, an ingenious Physician, made several Experiments on Water and Vegetables growing from it. He shews that all Water contains an earthy Matter, and concludes: 'It is evident, 'that Water is not the Matter that com-'poses vegetable Bodies; but is the A-'gent that conveys that Matter to them, 'that introduces and distributes it to the 'several Parts for their Nourishment. 'Where the proper terrestrial Matter is 'wanting, the Plant is not augmented, 'tho' never so much Water ascends into 'it.'* This is also the Opinion of Dr. *Boerhaave*, and he affirms from his own Experience, that pure elementary Water cannot, by repeated Distillations, or otherwise, be converted into Earth.† So that

Terræ aridæ indies augetur, & Liquores, nisi aliunde augmentum sumerent, perpetuo decrescere deberent, ac tandem deficere.

*Principia*, Pag. 515. Edit. 2da.

* *Philos. Transactions*, No. 253.

† *Elements of Chymistry*, Part 2d.

there

there ſeems to be no Neceſſity for ſuppoſing a gradual Decay of Moiſture in any of the Planets. Beſides, if the Comets were intended to ſupply the Planets with Moiſture, none of them could ſerve for this Purpoſe more than once, but muſt afterwards become uſeleſs, tho' they return regularly in their Orbits, which is not agreeable to the Œconomy of Nature. For when the Heat of the Sun had driven all the Moiſture it could from a Comet in its *Perihelion*, where ſhould it afterwards get a freſh Supply? We can ſcarce ſuppoſe the Planets to loſe any Moiſture by Evaporation, as no Vapours can riſe above their Atmoſpheres. Or even if any very thin Vapours, Steams or Effluvia of a moiſt Nature ſhould ariſe from them, they could not have Heat and Elaſticity enough to expand themſelves very far. But the electric Matter, from its vaſt Subtilty and Velocity, ſeems capable of making great Excurſions from the planetary Syſtem; and therefore the ſeveral Comets in their long Excurſions from the Sun, in all Directions, may overtake

this Matter; and attracting it to themselves may come back replete with it, and being again heated by the Sun, may disperse it among the Planets, and so keep up a Circulation of this Matter, which we have Reason to think is necessary in our System.

Sir *Isaac*, after giving his Opinion that the aqueous Particles thrown off from Comets are taken up by the Planets as a Supply of Moisture, adds: 'I suspect 'moreover, That that Spirit which is the 'least, but the most subtile and the best 'Part of our Air, and is necessary for 'supporting the Life of all Things, 'comes chiefly from the Comets:'* which shews that he thought the Tails of Comets might consist of something more than watery Clouds and Vapours. What he meant by these Words I cannot say, but I think they are extremely applicable to that kind of Matter which I have sup-

* Porro suspicor Spiritum illum qui Aeris nostri pars minima est, sed subtilissima & optima, & ad rerum omnium vitam requiritur ex Cometis præcipue venire. *Principia*, Pag. 515.

posed

poſed comes to us from the Comets; and with which our Air generally abounds.

I ſhall now recapitulate, in a few Words, the Subſtance of what has been ſaid. As the Tail of a Comet, tho' exceedingly rare, yet meets with no Reſiſtance in its rapid Motion round the Sun, (except ſo ſlight a one as can only cauſe a very ſmall Condenſation on that Side of it which moves foremoſt, and thereby may make it a little brighter than the other Side) it cannot poſſibly move in a *Medium* denſer and heavier than itſelf, and therefore cannot be raiſed up from the Sun by the ſuperior Gravity of ſuch a *Medium*. And ſince the Tail is not capable of reflecting or refracting the Light of the Stars, it cannot ſhine by reflecting the Sun's Light; and conſequently does not conſiſt of Clouds or aqueous Vapours, but is itſelf a ſhining Subſtance, the Nature of which it is the Buſineſs of Philoſophers to diſcover. And from what Aſtronomers ſay of the Splendor of Comet's Tails, I am perſuaded they do not ſhine

ſhine with ſuch a dull Light, as would be reflected to us by the Clouds or Vapours at ſo great a Diſtance, but with a briſker, tho' a glimmering Light, ſuch as would ariſe from a very thin volatile burning Matter. And here I muſt not omit an Obſervation of Dr. *Halley*'s, which ſeems very much to my Purpoſe. In his Deſcription of the remarkable *Aurora Borealis* ſeen in *England* in the Year 1716, (which I mentioned before) ſpeaking of the great Streams of Light, he ſays: *They ſo much reſembled the long Tails of Comets, that at firſt Sight they might well be taken for ſuch.* And afterwards, *This Light ſeems to have a great Affinity to that which the Effluvia of electric Bodies emit in the Dark.** From whence we find that this accurate Obſerver perceived a Reſemblance between thoſe Subſtances that I have been comparing together. Now I have ſhewn that they agree remarkably, not only in their Appearance, but alſo in ſuch Properties as we can ob-

* *Philoſ. Tranſactions*, No. 347.

ſerve in each of them, and therefore I have ſuppoſed them to be Subſtances of the ſame Nature. I have alſo endeavoured to ſhew that the electric Matter, from its known Properties, is capable of exhibiting to us all the Phænomena of Comet's Tails, and that we may from thence aſſign the Uſe of Comets with more Probability than has hitherto been done.

I have been leſs ſcrupulous of propoſing ſuch Conjectures as occurred to me concerning the Subſtance that forms the Tail of a Comet, as I conſidered that though they ſhould hereafter appear groundleſs, as very poſſibly they may, yet others by examining them, and comparing them with future Experiments and Obſervations, may probably be led to the Diſcovery of ſomething on this Subject that will be more ſatisfactory. And I think every Hypotheſis relating to the Effects of the electric Matter, if at all plauſible, may have its Uſe, by inducing us to make further Enquiries into the Nature and Properties of that Kind of

Matter,

Matter, from a Knowledge of which I suspect our future Improvements in Natural Philosophy will chiefly arise; especially in that Part of it which relates to Fire and Heat, the Nature of which is at present but little known.

# AN

# ESSAY

## ON THE

## PRINCIPLES OF MECHANICKS.

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# AN

# ESSAY

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IN this Essay I mean to offer some Remarks on the Methods that have been* commonly used in treating of those Engines that are called the Mechanick Powers; and to give an Account of the Principles on

* This Essay was read at a Meeting of the Royal Society on the 21st and 23d of *April* 1765, communicated in a Letter, dated 13 *July* 1762, to

on which, I think, we may beſt explain their Nature and Manner of Acting.

The many uſeful Inſtruments that have been ſo ingeniouſly invented, and ſo ſucceſsfully executed, and the great Perfection to which the Mechanick Arts are now arrived, would naturally incline one to think that the true Principles on which the Efficacy and Operations of the ſeveral Machines depend, muſt long ſince have been accurately explained. But this is by no Means a neceſſary Inference; for, however Men may differ in their Opinions about the true Method of accounting for the Effects of the ſeveral Machines, yet the practical Principles of Mechanicks are ſo perfectly known by Experience and Obſervation, that the Artiſt is thereby enabled to contrive and adjuſt the Movements of his Engines with as

to *Matthew Raper*, Eſq; F. R. S. of *Thorley*, in *Hertfordſhire*. *Vide* Phil. Tranſactions. Vol. LIII. —[In which ſome Improvements have been ſince made by the Author.]

as much Certainty and Succeſs as he could do, were he thoroughly acquainted with the Laws of Motion, from which theſe Principles may be ultimately derived. However, though an Inquiry into the true Method of deducing the practical Principles of Mechanicks from the Laws of Motion, ſhould perhaps not contribute much to promote the Progreſs of the Mechanick Arts, yet it is an Enquiry in itſelf uſeful, and in ſome Meaſure neceſſary; for, ſince late Authors have uſed very different Methods of treating this Subject, it may be ſuppoſed that no one Method has been looked upon as ſatisfactory and unexceptionable. I ſhould therefore wiſh to contribute towards having this Subject treated with more Accuracy than has been hitherto done.

The moſt noted Theorem in Mechanicks is this, "When two heavy Bodies counterpoiſe each other by Means of any Machine, and are then made to move together, the Quantities of

"Motion

"Motion with which one deſcends and "the other aſcends perpendicularly will "be equal." An *Æquilibrium* always accompanying this Equality of Motions, bears ſuch a Reſemblance to the Caſe wherein two moving Bodies ſtop each other when they meet together with equal Quantities of Motion, that many Writers have thought that the Cauſe of an *Æquilibrium* in the ſeveral Machines might be immediately aſſigned by ſaying, that ſince one Body always loſes as much Motion as it communicates to another, two heavy Bodies counteracting each other muſt continue at Reſt, when they are ſo circumſtanced that one cannot deſcend without cauſing the other to aſcend at the ſame Time, and with the ſame Quantity of Motion; for then ſhould one of them begin to deſcend, it muſt inſtantly loſe its whole Motion by communicating it to the other. This Argument, however plauſible it may ſeem, I think is by no Means ſatisfactory; for when we ſay that one Body commu-

nicates

nicates its Motion to another, we must necessarily suppose the Motion to exist first in the one and then in the other; but in the present Case, where the two Bodies are so connected that one cannot possibly begin to move before the other, the descending Body cannot be said to communicate its Motion to the other, and thereby make it ascend: But whatever we should suppose causes one Body to descend, must be also the immediate Cause of the other's ascending, since, from the Connexion of the Bodies, it must act upon them both together, as if they were really but one. And therefore, without contradicting the Laws of Motion, I might suppose the superior Weight of the heavier Body, which is in itself more than able to sustain the lighter, would overcome the lighter, and cause it to ascend with the same Quantity of Motion with which the heavier descends; especially as both their Motions, taken together, may be less than what the Difference of the Weights, which is here

supposed

ſuppoſed to be the moving Force, would be able to produce in a Body falling freely.

However, as the Theorem abovementioned is a very elegant one, it ought certainly to be taken Notice of in every Treatiſe of Mechanicks, and may ſerve as a very good *Index* of an *Æquilibrium* in all Machines; but I do not think that we can from thence, or from any one general Principle, explain the Nature and Effects of all the Mechanick Powers in a ſatisfactory Manner, becauſe ſome of theſe Machines differ very much from others in their Structures, and the true Reaſon of the Efficacy of each of them, is beſt derived from its particular Structure.

The ſimple Mechanick Powers are uſually reckoned ſix; the Lever, Axle and Wheel, Pulley, Wedge, inclined Plane, and Screw. I ſhall conſider theſe Machines ſeparately, and ſhall explain the

Nature

Nature and Property of each of them, by ſhewing from its Structure what Weight it will enable any given Force to ſuſtain.

The Lever is conſidered as an inflexible Line, void of Weight, and moveable about a fixed Point called its *Fulcrum* or Prop. The Property of the Lever, expreſſed in the moſt general Terms, is this; "When two Weights, "or any two Forces, act againſt each "other on the Arms of a Lever, and are "in *Æquilibrio*, they will be to each "other inverſly as the perpendicular or "ſhorteſt Diſtances of their Lines of Di-"rection from the *Fulcrum*."

This Propoſition contains two Caſes, for the Directions of the Forces may either meet in a Point or be parallel to each other. Moſt Writers begin their Demonſtration of this Propoſition with the ſecond Caſe, which ſeems to be the ſimpleſt, and from which the other may

be deduced by the Resolution of Forces. *Archimedes*, in his Demonstration, sets out with a Supposition, the Truth of which may reasonably be doubted: For he supposes, that if a Number of equal Weights be suspended from the Arm of a Lever, and at Points equidistant from each other, whether all these Points be at the same Side of the *Fulcrum*, or some of them on the opposite Side, these Weights will have the same Force to turn the Lever as they would have were they all united and suspended from a Point which lies in the Middle between all the Points of Suspension, and may be considered as the common Center of Gravity of all the separate Weights. Mr. *Huygens*, in his *Miscellaneous Observations on Mechanicks*, says that some Mathematicians have endeavoured, by altering the Form of this Demonstration, to render its Defects less sensible, though without Success. He therefore proposed another Proof, which is extremely tedious and prolix, and also depends on a *Postulatum* that,

that, I think, ought not to be granted on this Occaſion; it is this: "When "two equal Bodies are placed on the "Arms of a Lever, that which is fur-"theſt from the *Fulcrum* will prevail and "raiſe the other up." Now this is taking it for granted, in other Words, that a ſmall Weight placed further from the *Fulcrum* will ſuſtain or raiſe a greater one. The Cauſe and Reaſon of which Fact muſt be derived from the Demonſtration that follows, and therefore this Demonſtration ought not to be founded on the ſuppoſed Self-evidence of what is partly the Thing to be proved.

Sir *Iſaac Newton*'s Demonſtration of this Propoſition is indeed very conciſe, but it depends on this Suppoſition. That when from the *Fulcrum* of a Lever ſeveral Arms or *Radii* iſſue out in different Directions, all lying in the ſame vertical Plane, a given Weight will have the ſame Power to turn the Lever from which-ever Arm it hangs, provided the

Diſtance of its Line of Direction from the *Fulcrum* remains the ſame. Now it muſt appear difficult to admit this Suppoſition, when we conſider that the Weight can exert its whole Force to turn the Lever only on that Arm which is the ſhorteſt, and is parallel to the Horizon, and on which it acts perpendicularly, and that the Forces which it exerts, or with which it acts perpendicularly, on any one of the oblique Arms, muſt be inverſly as the Length of that Arm, which is evident from the Reſolution of Forces.

Mr. *Maclaurin*, in his *View of Newton's Philoſophy*, after giving us the Methods by which *Archimedes* and *Newton* prove the Property of the Lever, propoſes one of his own, which, he ſays, appears to be the moſt natural one for this Purpoſe. From equal Bodies, ſuſtaining each other at equal Diſtances from the *Fulcrum*, he ſhews us how to infer that a Body of one Pound (for Inſtance) will ſuſtain another

of

of two Pounds at Half its Diſtance from the *Fulcrum*, and from thence that it will ſuſtain one of three Pounds at a third Part of its Diſtance from the *Fulcrum*; and going on thus, he deduces, by a Kind of Induction, what the Proportion is in general between two Bodies that ſuſtain each other on the Arms of a Lever. But this Argument, were it otherwiſe ſatisfactory, yet as it cannot be applied, when the Arms of the Lever are incommenſurable, it cannot conclude generally, and therefore is imperfect.

There are ſome Writers on Mechanicks who, from the Compoſition of Forces, demonſtrate that Caſe of the general Propoſition, relating to the Lever, in which the Directions of the Forces are oblique to each other, and meet in a Point: But I do not find that they have had any other Way of proving the ſecond Caſe, in which the Directions of the Forces are parallel, but by conſidering theſe Directions as making an Angle

with each other, tho' an infinitely ſmall one, or as meeting at an infinite Diſtance; which Way of Reaſoning is not to be admitted in Subjects of this Kind, where the Proof ſhould always ſhew us, directly from the Laws of Motion, why the Concluſion muſt be true, in ſuch manner that we might ſee clearly the Force of every Step from the firſt Principles down to the Concluſion, which we are prevented from doing when any ſuch arbitrary and inconſiſtent Suppoſition is introduced.

From thus conſidering the various Proofs that have been given of this fundamental Propoſition in Mechanicks, we may ſee the Reaſon why many ſubſequent Writers have appeared diſſatisfied with the former Demonſtrations, and have looked for new ones; I ſhall now propoſe two Methods of demonſtrating it, merely from the Compoſition and Reſolution of Forces. The Propoſition may be expreſſed as follows,

"When

"When three Forces act upon an in-
"flexible Line, whether straight or crook-
"ed, and keep it in *Æquilibrio*, any
"two of them will be to each other in-
"versly as the perpendicular Distances
"of their Lines of Direction from that
"Point to which the third Force is ap-
"plied."

Let the three Forces E, G, F, (Fig. 2.) act upon three Points A, B, D, in an inflexible Line; and first let the Directions of the Forces E and F (which act on the same Side of the Line) meet in the Point C. Then it is evident that the Force, which is compounded of these two, must act upon the Line A B D in the Direction of a right Line that passeth through the Point C, consequently the Force G, which sustains this compounded Force, must be equal thereunto, and must act in a contrary Direction; therefore the Force G must act in the Direction of the Line C B. From the Point B draw B H and B K perpendicular to the Directions

of the Forces E and F, and draw B M and B N parallel to these Directions forming the Parallelogram B M C N; then, since these three Forces are in *Æquilibrio*, they must be to each other respectively as the Sides and Diagonal of this Parallelogram to which their Directions are parallel, therefore E is to F as C M, to C N, or M B, that is (because the Sides of a Triangle are as the Sines of the opposite Angles) as the Sine of the Angle, M B C or its alternate one, B C N to the Sine of the Angle B C M; but, making C B the *Radius*, B K is the Sine of the former Angle, and B H of the latter, therefore E is to F as B K to B H, so that the Forces E and F are to each other inversly as the perpendicular Distances of their Lines of Direction from the Point B, on which the third Force G acts. Now to compare the Forces F and G together; from the Point A, on which the third Force acts, draw A B and A L perpendicular to the Directions of the Forces G and F, then, as

was

was ſaid before, F is to G as M B is to C B, but M B is to C B as A B to A L; becauſe, making C A the *Radius*, A B is the Sine of the Angle M C B, and A L is the Sine of the Angle M C N, or C M B its Supplement to two right ones; therefore the Forces F and G are to each other inverſly as the perpendicular Diſtances of their Lines of Direction from the Point A, on which the third Force E acts; and thus the firſt Caſe of the Propoſition is proved, in which the Forces act againſt each other in oblique Directions.

We muſt now conſider what Parts of the Forces E and F act againſt the Force G in Directions parallel to G C, for it is ſuch Parts only that really oppoſe the Force G, and keep it in *Æquilibrio*, and from thence we ſhall ſee what Proportion two Forces muſt have to each other when they are in *Æquilibrio*, and act in parallel Directions. Let the three Forces act upon the Points A, B and D, (Fig. 3.)

let them be in *Æquilibrio*, and their Lines of Direction meet in the Point C, as in the preceding Case; then if the Points A, B and D, are not in a right Line, draw the Line A D meeting B C in P, and from P draw P N and P M parallel to the Directions of the Forces E and F; through the Points A and D draw Lines parallel to B C, and thro' B draw a Perpendicular to these Lines meeting them in H and K, from the Point M draw M O parallel to A D, and meeting B C in O. Now the three Forces E, G and F, that are in *Æquilibrio*, will be to each other respectively as the Sides of the Triangle C M P, as in the preceding Case; but the Force E, which is denoted by the Line M C, may be resolved into two Forces acting in the Directions M O and O C, the former of these only urges the Point A towards D, and the latter acts in direct Opposition to the Force G; in like Manner the Force F, which is denoted by the Line P M, may be resolved into two Forces acting in

in the Directions O M and P O, the former of which only urges the Point D towards A, and the latter acts in direct Opposition to the Force G; now it is evident that the Force G, which is denoted by the Line P C, is sustained only by those Parts of the Forces E and F, which act against it, in Directions parallel to B C, and are denoted by the Lines O C and P O, which, taken together, are equal to P C, for the other Parts of the Forces E and F which are denoted by M O, are lost, being equal and contrary to each other; if, therefore, instead of the Forces F and E, we suppose two other Forces R and L, to act on the Points D and A, in Directions parallel to B C, and to keep the Force G in *Æquilibrio*, it follows, from what has been proved, that R and L, taken together, will be equal to G, and that these three Forces will be to each other respectively as the Lines P O, O C and P C; therefore R will be to L as (P O to O C, that is, as A M to M C, or as A P to P D,

or) H B to B K, consequently the Forces R and L are to each other inversly as the perpendicular Distances of their Lines of Direction from the Point B, to which the third Force is applied. Now to compare the Forces R and G together; since the Forces R and L may be denoted by B H and B K, and are both together equal to G, that Force will be denoted by the whole Line K H, and therefore R will be to G as B H to K H; so that these Forces are also to each other inversly as the perpendicular Distances of their Lines of Direction from the Line of Direction of the third Force L; and thus the second Case of the Proposition is proved, in which the Forces act against each other in parallel Directions. If the Point in the inflexible Line, to which one of the Forces is applied, should become a fixed Point, or *Fulcrum*, round which the Line may turn, it is evident that the other two Forces will continue in *Æquilibrio*, as they were before, and therefore the Property of the Lever, in all Cases,

Caſes, is manifeſtly proved by this Propoſition.

The Center of Gravity of a Body is ſaid to be that Point which being ſuſtained, or prevented from deſcending, the Body will continue at reſt. From hence it follows, that when a Body hangs freely from a ſingle Point, and continues at Reſt, its Center of Gravity will lie perpendicularly under the Point of Suſpenſion; for in that Situation only it will be ſuſtained, and can deſcend no lower.

From this Property, which agrees likewiſe to the common Center of Gravity of two Bodies, joined together by an inflexible right Line, and which may then be conſidered as one, I ſhall ſhew that their Center of Gravity is a Point in the Line that joins them together, ſo ſituated that the Diſtances of the two Bodies from it are to each other inverſly as their Weights. This Theorem concerning the Poſition of the common Center of Gravity

Gravity of two Bodies, which is a very noted one in Mechanicks, I have never ſeen demonſtrated otherwiſe than by inferring it from the general Property of the Lever: But I think the Method I ſhall now propoſe of deducing it directly from the Definition of the Center of Gravity, is the moſt conciſe, as well as the moſt natural, and, beſides, it will afford us a very eaſy Way of demonſtrating the Property of the Lever.

Let the two Bodies A and B (Fig. 4.) be joined by an inflexible right Line paſſing through their Centers of Gravity, and let them be ſuſpended from the fixed Point or Pin at P, by the Threads A P and B P, ſo that they may hang freely in ſuch a Poſition as their joint Gravity will give them. When theſe Bodies continue at Reſt, their common Center of Gravity muſt lye directly under the Point of Suſpenſion, or in the perpendicular Line P L, conſequently it muſt be at the Point C, the Interſection of the Lines

P L and A B; the *Position* of which Point, in the Line A B, will be determined by finding out the Proportion between the Segments C A and C B. If the inflexible Line was not interposed between these Bodies, they would move till their Threads coincided with the perpendicular Line P L; since therefore they are kept asunder by this Line they must urge it with certain Forces in opposite Directions, and these urging Forces must be equal, since the Line on which they act continues at Rest; and therefore the Force with which each Body urges the other in the Direction of this Line, may be denoted by the same Letter U, and we may denote the Weights of the two Bodies respectively by the Letters A and B. Now the Body A is acted upon by three Forces, *viz.* by its Weight A in the Direction P C, by the Force U, with which the other Body urges it, in the Direction C A, and by the Reaction of the Pin in the Direction A P, and since these three Forces are in *Æquilibrio*, and keep the Body at Rest,

Reſt, they are to each other reſpectively as the Sides of the Triangle P C A; therefore A is to U, as P C to C A. In like Manner the Body B is urged by three Forces, *viz.* its Weight B in the Direction P C, the urging Force U in the Direction C B, and the Reaction of the Pin in the Direction B P, which Forces are to each other as the Sides of the Triangle P C B, therefore U is to B, as C B to P C, and therefore *(ex æquo perturbate)* A is to B, as C B to C A, conſequently the Weights of the Bodies A and B are to each other inverſly as their Diſtances from the Point C, which lies directly under the Point of Suſpenſion, and is therefore their common Center of Gravity.

When two Bodies are connected by an inflexible Line, and this Line is ſupported by a Prop, ſo that their Center of Gravity cannot deſcend, the Bodies muſt continue at Reſt, and will be in *Æquilibrio.* Therefore it is eaſy to ſee how, from the

Theorem now demonſtrated, we may prove the Property of the Lever in that Caſe where the Directions of the Forces are parallel; and from thence the other Caſe, in which the Directions are oblique to each other, may be deduced by the Reſolution of Forces, as is uſually done. And this is the ſecond Method by which I ſaid the general Property of the Lever might be ſtrictly demonſtrated.

The Lever is the moſt ſimple of all the Mechanick Powers, and to it may be reduced the Balance and the *Axis in Peritrochio*, or Axle and Wheel. Though I do not conſider the Balance as a diſtinct Mechanick Power, becauſe it is evidently no other than a Lever fitted for the particular Purpoſe of comparing the Weights of Bodies, and does not ſerve for raiſing great Weights or overcoming Reſiſtances as the other Machines do.

When a Weight is to be raiſed by Means of an Axle and Wheel, it is faſtened

tened to a Cord that goes round the Axle, and the Power, which is to raiſe it, is hung to a Cord that goes round the Wheel. If then the Power be to the Weight as the *Radius* of the Axle to the *Radius* of the Wheel, it will juſt ſupport that Weight; as will eaſily appear from what was proved of the Lever. For the Axle and Wheel may be conſidered as a Lever, whoſe *Fulcrum* is a Line paſſing through the Center of the Wheel and Middle of the Axle, and whoſe long and ſhort Arms are the *Radii* of the Wheel and Axle which are parallel to the Horizon, and from whoſe Extremities the Cords hang perpendicularly. And thus an Axle and Wheel may be looked upon as a Kind of perpetual Lever, on whoſe Arms the Power and Weight always act perpendicularly, tho' the Lever turns round its *Fulcrum*. And in like Manner, when Wheels and Axles move each other by Means of Teeth on their *Peripheries*, ſuch a Machine is really, a perpetual

petual compound Lever: and, by considering it as such, we may compute the Proportion of any Power to the Weight it is able to sustain by the Help of such an Engine. And since the *Radii* of two contiguous Wheels, whose Teeth are applied to each other, are as the Number of Teeth in each, or inversly as the Number of Revolutions, which they make in the same Time; we may, in the Computation, instead of the *Ratio* of these *Radii*, put the *Ratio* of the Number of the Teeth on each Wheel; or the inverse *Ratio* of the Number of Revolutions they make in the same Time.

Some Writers have thought the Nature and Effects of the Pulley might be best explained by considering a fixed Pulley as a Lever of the first, and a moveable Pulley as one of the second Kind. But the Pulley cannot properly be considered as a Lever of any Kind, for when any Power sustains a Weight by Means of a System of Pullies, that

Power

Power will ſuſtain the ſame Weight if the Pullies be removed, and the Ropes be brought over the Axles on which the Pullies turned. And in this Caſe I believe no one would ſay, that theſe Axles could be conſidered as Levers. If the Weight was to be raiſed up, there would, in this Caſe, be a very great Reſiſtance from the Friction of the Ropes on the Axles; and it is merely to avoid this Reſiſtance that Pullies are uſed, which move round the Axles with but little Friction. I think the beſt and moſt natural Method of explaining the Effects of the Pulley (that is, of computing the Proportion of any Power to the Weight it can ſuſtain by Means of any Syſtem of Pullies) is by conſidering that every moveable Pulley hangs by two Ropes equally ſtretched, which muſt bear equal Parts of the Weight; and therefore when one and the ſame Rope goes round ſeveral fixed and moveable Pullies, ſince all its Parts on each Side of the Pullies are equally ſtretched, the

the whole Weight muſt be divided equally amongſt all the Ropes by which the moveable Pullies hang. And conſequently if the Power which acts on one Rope be equal to the Weight divided by the Number of Ropes, that Power muſt ſuſtain the Weight.

Upon this Principle, the Proportion of the Power to the Weight it ſuſtains by Means of any Syſtem of Pullies, may be computed in a Manner ſo eaſy and natural, as muſt be obvious to every common Capacity.

The Proportion which any Power bears to the reſiſting Force it is able to ſuſtain by Means of a Wedge, has been laid down differently by different Authors, as they happened to conſider it in particular Caſes. Without examining their ſeveral Opinions, I ſhall endeavour to expreſs this Proportion in one general Propoſition, which may extend

to

to the ſeveral Caſes in which the Wedge is applied.

Let the *Æquicrural* Triangle A B C (Fig. 5) repreſent a Wedge, whoſe Baſe or Back is A C, and Sides are the Lines A B and C B, and whoſe Height is the Line B P, which biſects the vertical Angle A B C, and alſo, the Baſe perpendicularly in P. When a Power is applied to the Wedge, in order to overcome or remove any reſiſting Forces, it acts perpendicularly on the Back of the Wedge, and the reſiſting Forces act on its Sides, and they are always ſuppoſed to act in Directions that make equal Angles with the Sides. When the reſiſting Forces and the Power, that acts on the Wedge, are in *Æquilibrio*, the former will be to the latter, as the Height of the Wedge to a Line drawn from the Middle of the Baſe to one Side, and parallel to the Direction in which the reſiſting Force acts on that Side.

Let

Let E and F represent two Bodies or two resisting Forces acting on the Sides of the Wedge perpendicularly, and whose Lines of Direction E P and F P meet at the Middle Point of the Base, on which the Power P acts perpendicularly, then will E P and F P be equal, let the Parallelogram E N F P be compleated, its Diagonals P N and E F will bisect each other perpendicularly in H. Now when these Forces (which act perpendicularly on the Sides and Base of the Wedge) are in *Æquilibrio*, they will be to each other as the Sides and Diagonal of this Parallelogram, that is, the Sum of the resisting Forces will be to the Power P, as the Sides E P and F P to the Diagonal P N, or as one Side E P to half the Diagonal P H, that is (from the Similarity of the right-angled Triangles B E P, E H P) as B P, the Height of the Wedge, to E P the Line which is drawn from the Middle of the Base to the Side A B, and is the Direction in which the resisting Force acts on that Side.

From

From the Demonſtration of this Caſe, in which the reſiſting Forces act perpendicularly on the Sides of the Wedge, it appears that the Reſiſtance is to the Power which ſuſtains it, as one Side of the Wedge A B is to the Half of its Breadth A P; becauſe A B is to A P as B P is to E P.

It appears alſo from hence, that if P N be made to denote the Force with which the Power P acts on the Wedge, the Lines P E and P F which are perpendicular to the Sides, will denote the Force with which the Power P protrudes the reſiſting Bodies in Directions perpendicular to the Sides of the Wedge.

Let us now ſuppoſe, in the ſecond Caſe, that the reſiſting Bodies E and F act upon the Wedge in Directions parallel to the Lines D P and O P, that are equally inclined to its Sides, and meet in the Point P. Draw the Lines E G and F K perpendicular to D P and O P; then

then making P N denote the Force with which the Power P acts on the Wedge, P E and P F will denote the Forces with which it protrudes the resisting Bodies in Directions perpendicular to the Sides of the Wedge, as I observed before; now each of these Forces may be resolved into Two, denoted respectively by the Lines P G and G E, P K and K F, of which G E and K F will be lost, as they act in Directions perpendicular to those of the resisting Bodies, and P G and P K will denote the Forces by which the Power P opposes the resisting Bodies, by protruding them in Directions contrary to those in which they act on the Wedge; therefore when the resisting Forces are in *Æquilibrio* with the Power P, the former must be to the latter, as the Sum of the Lines P G and P K is to P N, or as P G is to P H, that is, as P B, the Height of the Wedge, is to P D * the Line drawn

* [*P G is to P H as P B to P D.*] The right-angled

drawn from the Middle of the Base to one Side of the Wedge and parallel to the Direction in which the resisting Force acts on that Side.

From what has been demonstrated, we may deduce the Proportion of the Power to the Resistance it is able to sustain in all the Cases in which the Wedge is applied. First, when in cleaving Timber the Wedge fills the Cleft, then the Resistance of the Timber acts perpendicularly on the Sides of the Wedge, therefore in this Case, when the Power which drives the Wedge,

angled Triangles P G E and P E D are similar, having the Angle at P common to both; therefore P G is to P E as P E to P D; so likewise the rightangled Triangles P H E and P E B are similar, and therefore P H is to P E as P E to P B; therefore the Rectangles P G into P D and P H into P B are equal, each of them being equal to the Square of P E, consequently their Sides are reciprocally proportional, that is, P G is to P H as P B to P D.

is

is to the cohesive Force of the Timber, as Half the Base, to one Side of the Wedge, the Power and Resistance will be in *Æquilibrio*.

Secondly, when the Wedge does not exactly fill the Cleft, which generally happens, because the Wood splits to some Distance before the Wedge. Let E L F represent a Cleft into which the Wedge A B C is partly driven; as the resisting Force of the Timber must act on the Wedge in Directions perpendicular to the Sides of the Cleft, draw the Line P D in a Direction perpendicular to E L the Side of the Cleft, and meeting the Side of the Wedge in D; then the Power driving the Wedge and the Resistance of the Timber, when they balance, will be to each other as the Line P D to P B the Height of the Wedge.

Thirdly, when a Wedge is employed to separate two Bodies that lie together

on an horizontal Plane, for Inſtance two Blocks of Stone; as theſe Bodies muſt recede from each other in horizontal Directions, their Reſiſtance muſt act on the Wedge in Lines parallel to its Baſe C A; therefore the Power which drives the Wedge will balance the Reſiſtance when they are to each other as P A, Half the Breadth of the Wedge to P B its Height; and then any additional Force ſufficient to overcome the Reſiſtance ariſing from the Friction of the Bodies on the horizontal Plane will ſeparate them from each other.

The inclined Plane is reckoned by ſome Writers among the mechanick Powers; and I think with Reaſon, as it may be uſed with Advantage in raiſing Weights.

Let the Line A B (Fig. 6.) repreſent the Length of an inclined Plane, A D its Height, and the Line B D we may

may call its Base. Let the circular Body G E F be supposed to rest on the inclined Plane, and to be kept from falling down it by a String C S tied to its Center C. Then the Force with which this Body stretches the String will be to its whole Weight, as the Sine of A B D the Angle of Elevation, to the Sine of the Angle which the String contains with a Line perpendicular to A B the Length of the Plane. For let the *Radius* C E be drawn perpendicular to the Horizon, and C F perpendicular to A B, and from E draw E O parallel to the String and meeting C F in O. Then, as the Body continues at Rest and is urged by three Forces, to wit, by its Weight in the Direction C E, by the Reaction of the Plane in the Direction F C, and by the Reaction of the String in the Direction E O; the Reaction of the String, or the Force by which it is stretched, is to the Weight of the Body, as E O to C E: That is, as the Sine of (the

Angle E C O, which is equal to) A B D the Angle of Elevation, to the Sine of the Angle E O C, equal to S C O, the Angle which the String contains with the Line C F perpendicular to A B, the Length of the Plane.

When therefore the String is parallel to the Length of the Plane, the Force with which it is ſtretched, or with which the Body tends down the inclined Plane, is to its whole Weight, as the Sine of the Angle of Elevation, to the *Radius*, or as the Height of the Plane to the Length. And in the ſame Manner it may be ſhewn, that when the String is parallel to B D, the Baſe of the Plane, the Force with which it is ſtretched is to the Weight of the Body, as A D to B D, that is, as the Height of the Plane to its Baſe. If we ſuppoſe the String, which ſupports the Body G E F, to be faſtened at S, and that a Force, by acting on the Line A D, the Height of the Plane, in a Direction parallel

parallel to the Base B D, drives the inclined Plane under the Body, and by that Means makes it rise in a Direction parallel to A D. Then, from what was proved in the third Case of the Wedge, it will appear, that this Force must be to the Weight of the Body, as A D to B D, or rather in a Proportion somewhat greater: If it makes the Plane move on and the Body rise.

From this last Observation we may clearly shew the Nature and Force of the Screw; a Machine of great Efficacy in raising Weights, or in pressing Bodies closely together. For if the Triangle A B D be turned round a Cylinder whose Periphery is equal to B D, then the Length of the inclined Plane B A will rise round the Cylinder in a spiral Manner; and form what is called the Thread of the Screw, and we may suppose it continued in the same Manner round the Cylinder from one End to the other; and

A D the Height of the inclined Plane will be every where the Diſtance between two contiguous Threads of this Screw, which is called a Convex Screw. And a Concave Screw may be formed to fit this exactly, if an inclined Plane every Way like the former be turned round the Inſide of a hollow Cylinder, whoſe Periphery is ſomewhat larger than that of the other. Let us now ſuppoſe the Concave Screw to be fixed, and the Convex one to be fitted into it, and a Weight to be laid on the Top of the Convex Screw: Then, if a Power be applied to the Periphery of this Convex Screw to turn it round, at every Revolution the Weight will be raiſed up through a Space equal, to the Diſtance between the two contiguous Threads, that is, to the Line A D the Height of the inclined Plane B A; therefore ſince this Power applied to the Periphery, acts in a Direction parallel to B D, it muſt be to the Weight it raiſes as A D to B D, or as the Diſtance between two

contig-

contiguous Threads, to the Periphery of the Convex Screw; which Diſtance between two contiguous Threads is to be meaſured by a Line parallel to the Length of the Screw. If we now ſuppoſe that a Hand-ſpike or Handle is inſerted into the Bottom of the Convex Screw, and that the Power which turns the Screw is applied to the Extremity of this Handle, which is generally the Caſe; then as the Power is removed farther from the Axis of Motion, its Force will be ſo much encreaſed, and therefore ſo much may the Power itſelf be diminiſhed. So that the Power, which, acting on the End of a Handle, ſuſtains a Weight by Means of a Screw, will be to that Weight, as the Diſtance between two contiguous Threads of the Screw, to the Periphery deſcribed by the End of the Handle. In this Caſe we may conſider the Machine as compoſed of a Screw and a Lever, or as Sir *Iſaac Newton* expreſſes it, *Cuneus a vecte impulſus.*

Of

Of any two or more of these simple Machines combined together, all other Machines, however complicated, are composed. And their Powers and Manner of acting may therefore be explained from the Principles here laid down.

FINIS.

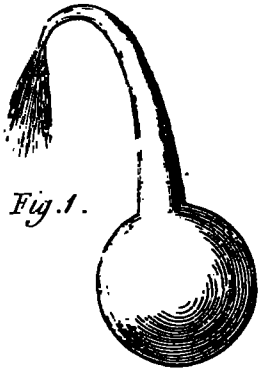


Fig. 1.

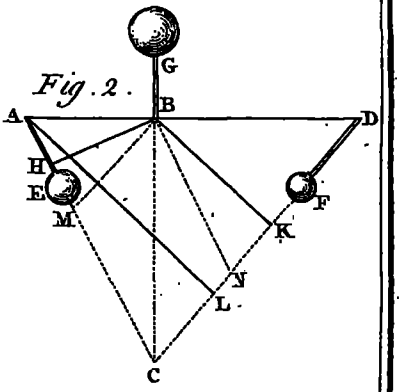



Fig. 2.

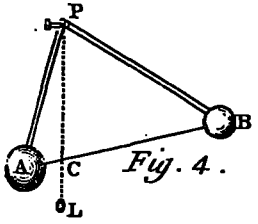
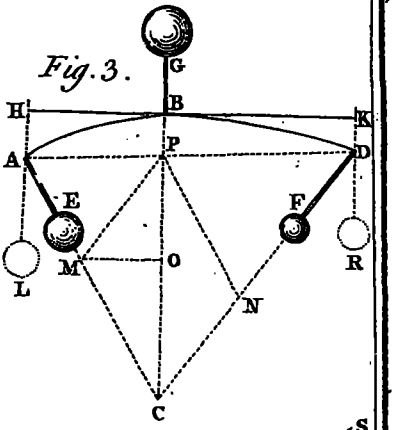



Fig. 4.

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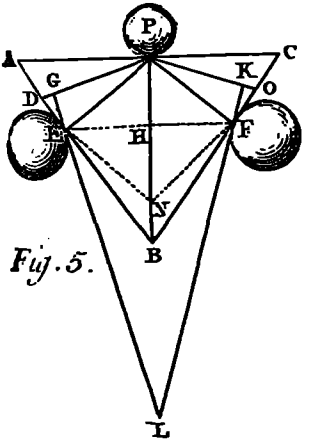


Fig. 5.

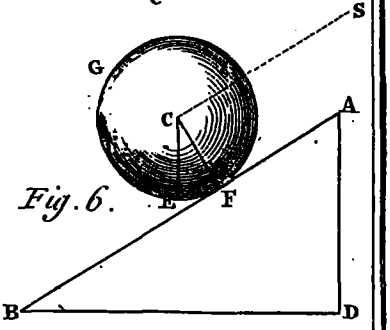


Fig. 6.

# FOUR INTRODUCTORY LECTURES IN Natural Philoſophy.

# FOUR INTRODUCTORY LECTURES IN Natural Philosophy.

I.

Of the Rules of philosophising, the essential Properties of Matter, and Laws of Motion.

II.

Of the several Kinds of Attraction, and particularly of Cohesion,

III.

Of Gravity, or the Attraction of Gravitation.

IV.

The Laws of Motion explained, and confirmed by Experiments.

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# LECTURE I.

OF THE

## Rules of Philosophising,

THE

## Essential Properties of Matter,

## And Laws of Motion.

AS a knowledge of the operations of Nature, and their causes, is not only entertaining to the mind, but capable of being usefully applied to practice, in providing for the ease and convenience of life; it must seem surprising that Natural Philoso-

phy ſhould have made ſo very inconſiderable a progreſs in the world, as we find it had done about a Century ago. This muſt have been owing chiefly to the wrong methods by which it had been cultivated before that time. For, till then, philoſophers did not pay a proper attention to experiments, but employed their ſagacity in inventing ſyſtems and contriving Hypotheſes, by which they might explain the operations of Nature. They of latter times have more wiſely choſen to build their philoſophy on the ſolid foundation of facts and experience. The method, which they happily purſued, conſiſts in making a number of accurate experiments and obſervations, and from thence collecting what thoſe powers and principles of motion are which really obtain in Nature; and in explaining the phænomena, or natural appearances, from thoſe manifeſt principles aſſumed as cauſes; and in proving their explanations to be true by ſhewing, from mathematical reaſoning, that the cauſes aſſigned are adequate to the effects aſcribed to them. Theſe different

ferent methods of philosophising, as one might reasonably expect, were attended with very different success. The former only amused the world with conjectures and philosophical romances, the latter enlightened it by valuable discoveries.

The first who insisted on the necessity of using this method for promoting natural knowledge was Sir *Francis Bacon*, who flourished about the beginning of the last century, and may justly be reckoned the founder of experimental philosophy. This great man, having taken an accurate and comprehensive view of the state of learning as it then stood, soon perceived the emptiness of the philosophy that had so long prevailed, which he says had been produced merely by the confidence of a few men, and received and admired only through the indolence and inattention of the rest. And therefore, in his admirable *Treatise on the Advancement of Learning*, he proposes, that men should lay aside all former Hypotheses, and endeavour to raise a new structure of philosophy, not

founded on uncertain opinions and ſpecious conjectures, but on truth and experience. The advantages, that might be expected by purſuing this method, he ſet forth in ſo ſtrong a light, that his plan was immediately approved of and adopted by the Learned in all parts of *Europe*, and ſince that time ſeveral men of great abilities, and particularly the famous Sir *Iſaac Newton*, have cultivated natural philoſophy according to his ſcheme, and enriched it with more important diſcoveries, than all the foregoing ages can boaſt of. To give ſome account of theſe diſcoveries, and to exhibit the experiments by which they are confirmed, is to be the buſineſs of the following lectures. But before I can proceed to this it is neceſſary to lay down certain rules, which will be of uſe in directing us how to deduce general concluſions from a number of experiments, and to inveſtigate cauſes from their effects. The rules delivered for this purpoſe by Sir *Iſaac Newton*, and which he himſelf ſo ſucceſsfully applied, are as follow:

RULE

## RULE I.

*More causes of Natural Things, are not to be admitted, than are true and sufficient for explaining their Phænomena.*

THAT is, we are not to admit any thing as a cause whose existence we cannot manifestly prove by experiments. And then we must not admit various causes of any effects when one is sufficient. For all philosophers agree that Nature does nothing in vain, and that is certainly done in vain by more causes which may be done by fewer. From hence follows a second rule:

## RULE. II.

*Of Natural Effects of the same Kind, the same Causes are to be assigned, as far as can be done.*

As, for instance, the same cause must be assigned, of respiration in a man and in other animals, of the descent of heavy bodies in different parts of the earth, of light in a culinary fire and in the sun, of

the reflection of light in the earth and in the planets.

## RULE III.

*The Qualities of Bodies which cannot be increased or diminished, and that agree to all Bodies on which Experiments can be made, are to be reckoned as Qualities of all Bodies whatsoever,*

THUS if it be evident, from experiments and astronomical observations, that all bodies near the earth gravitate towards it in proportion to their quantity of matter, that the moon also gravitates towards the earth, and the waters of our sea towards the moon, that the planets and the sun gravitate towards each other mutually, that comets, in like manner gravitate towards the sun; and if the gravity of bodies on which we can make experiments, can neither be increased nor diminished; we must by this rule pronounce that gravity, or a mutual tendency towards each other, is a quality of all bodies whatsoever.

RULE

## RULE IV.

*In Experimental Philosophy, Propositions collected from the Phænomena by induction are to be deemed, notwithstanding contrary Hypotheses, either accurately true, or very nearly so; until other Phænomena occur, by which they may be rendered either more accurate, or liable to Exceptions.*

THE meaning of this rule is, that against propositions founded on facts and experience, we are not to admit any exceptions that are taken merely from Hypotheses, or metaphysical considerations, which we know have often misled philosophers in their inquiries, and seldom have been of any use to them.

THESE rules of philosophising, and indeed all our attempts to enquire into the causes of natural things, depend entirely on this supposition; that the Universe hath been produced by the Will of an infinitely powerful and wise Agent, and that therefore all events, not depending on the will of man, are the effects of certain established causes, made to act according

cording to regular laws, the very beſt that could be deviſed, for preſerving the whole frame of Nature in the ſtate we now obſerve it to be. For in this caſe only can we hope to arrive at ſome knowledge of thoſe general cauſes, and their manner of acting, by carefully attending to the phænomena. Could we once ſuppoſe the Univerſe to have been the effect of chance, any endeavour to find out the cauſes of the common operations of Nature, or the laws by which they are regulated, would be a vain attempt, and quite inconſiſtent with ſuch an Hypotheſis.

But experience fully evinces the truth of our firſt ſuppoſition. For philoſophers, directing their reſearches by the foregoing rules, have diſcovered, and plainly proved that the phænomena, or natural appearances, are effected by the moſt ſimple and general cauſes, made to act with all the conſtancy, regularity and uſefulneſs, that could be expected in the works of perfect Power, Wiſdom and Goodneſs. They have alſo proved that theſe are but ſecondary cauſes, and ſuch as never could have produced

duced the Universe, out of Nothing; or could even have given its parts their first motions, or reduced them to the order they are now in.

Such discoveries therefore must amount to a strict demonstration; that all things were at first produced, and are still governed, by the Will of an ever-living, powerful, wise and good Being; whose Influence cannot suffer any diminution through the greatest distance of space, or length of time. So that the great truths of Natural Religion are the most evident conclusions, as well as the happiest fruits of Natural Knowledge.

Having given some account of the methods of philosophising and the rules we are to observe, I proceed to consider the Properties of Matter, and first such as are essential to it.

As the intimate Nature, or real Essence of Matter, is unknown to us, we can define it only by such properties as we take to be essential to it, and without which we cannot conceive it to exist. I shall, therefore say, that Matter or Body is a

Substance

Subſtance extended, ſolid and perfectly inactive, or incapable of producing any change in its ſtate, whether of reſt or motion.

THE idea of Extenſion is ſo very ſimple and clear, that any attempt to explain it would probably render it more obſcure.

SOLIDITY is that property by which a Body is enabled to reſiſt, and abſolutely prevent all others from coming into its place, till it has left it. By this property it is that Body is ſaid to fill Space, and upon this is founded the common Axiom, that it is impoſſible for two Bodies to be in the ſame place at the ſame time. Though ſome Bodies, as Fluids for inſtance, ſeem to give very little reſiſtance to others, yet this does not ariſe from any defect of ſolidity; but from their parts yielding to the leaſt impreſſion, and therefore being eaſily put out of their places. For if the moſt fluid Body be preſſed equally on all ſides, its reſiſtance will then be as ſenſible as that of the hardeſt. So likewiſe, though ſoft ſpongy Bodies may be compreſſed into a ſmaller

ſpace

ſpace than they uſually take up, yet they are nevertheleſs ſolid; for there is always a certain degree beyond which no force can compreſs them.

THAT Matter is capable of being put into Motion, our experience fully teſtifies. We have a power of moving our limbs according to the determination of our will, and we frequently ſee Bodies communicate Motion to each other by Impulſe. In what manner Motion is communicated, in the firſt caſe, we ſhall probably never be able to comprehend. In the ſecond caſe, we can eaſily conceive the power of communicating Motion to ariſe merely from Solidity. For when a Body in Motion ſtrikes another at reſt, which is not retained in its place by ſome force; ſince theſe Bodies, on account of their Solidity, cannot penetrate each others dimenſions, the ſtriking Body muſt protrude the other, and move it out of its place. So that the communication of Motion, in this caſe, ariſes as neceſſarily from the Solidity of Bodies, as their having

having Figure or being divisible, does from their extension.

Every Body must be terminated by one or more surfaces, and therefore all Bodies must have some sort of Figure; hence Figurability is reckoned an inseparable property of Matter.

Extension necessarily implies Divisibility, for whatever is extended must have Parts, and consequently must be divisible into those Parts. Divisibility is therefore an inseparable property of every particle of Matter, however small. Hence we are necessarily led to affirm that Matter is divisible *in infinitum*: the meaning of which is, that any particle of Matter is capable of being divided into parts, the number of which may be greater than any given number. As Lines and Surfaces are extended, they also must be capable of an endless division, as mathematicians have demonstrated *(a)*.

Although Matter is capable of be-

(a) Tacquet's *Euclid, Lib.* iii. *Prop.* 17. Cor. 4.

ing

ing diminiſhed without end by a continued diviſion of its Parts, yet we muſt ſuppoſe that the ultimate and elementary Particles of which Bodies conſiſt, are ſuch as never were, nor probably can be divided by any ordinary force. Sir *Iſaac Newton* judges (with great appearance of reaſon) that Matter in the beginning was formed in ſolid, maſſy, impenetrable, moveable Particles; which are incomparably harder than any porous Body compounded of them, even ſo hard as never to wear or break in pieces. For while the Particles (ſays this great Philoſopher) continue entire, they may compoſe Bodies of the ſame nature and texture in all ages. But ſhould they wear away or break in pieces, the nature of things depending on them would be changed. Water and earth compoſed of old worn particles and fragments of particles would not be of the ſame nature and texture now with Water and Earth, compoſed of entire Particles in the beginning. And therefore he concludes, in order that the nature of Bodies may be

laſting,

*lasting*, that the changes of corporeal things must consist only in the various separations and new associations and motions of these permanent Particles; compound Bodies being apt to break, not in the midst of solid Particles, but where those Particles are laid together and only touch in a few Points.

The third Property, which I included in the definition of Matter, was its inactivity, by which it not only perseveres in its state of Rest or Motion, but must in some measure oppose every force that endeavours to make any change in its state. For though a Body be in its own nature quite indifferent as to Rest or Motion, yet when it is in either of those states it is not without some sort of difficulty compelled to change it; and therefore must exert, as it were, some Force to preserve itself in the state it happens to be in. Hence this property of Matter is called its *vis insita*, or, more expressively, its *vis inertiæ*. And this Force a Body never exercises but against some other which endeavours to cause a change in its state.

On

On which occasion this Force may be considered either as a Resistance or an Impulse: as a resistance, so far as, by endeavouring to persevere in its state, it yields with some difficulty to the Force impressed; and as an impulse so far as, by yielding with some difficulty, it must make also some change in the state of that Body which impresses the Force upon it. Resistance is generally attributed to quiescent Bodies, and Impulse to those that are in Motion. As we cannot conceive the *vis inertiæ* of the same solid Particle of Matter to be increased or diminished, we must suppose that it is always the same in equal Quantities of Matter, and therefore that the *vis inertiæ* of any Body is proportional to its Quantity of Matter.

On these essential Properties of Matter is founded the Doctrine of Motion, which is justly called the Key of Nature, as without a true knowledge of that we can scarce account for any of her operations. Nothing therefore could so much have obstructed Philosophers in their pursuit of Natural Knowledge as their forming wrong

notions

notions concerning the nature of Motion, *Des Cartes* held that all Space was equally full of Matter, and that there was always the ſame Quantity of Motion in the world; both which opinions have ſince been proved to be erroneous. Even the ſagacious *Kepler*, on whoſe Aſtronomical Obſervations and Diſcoveries the *Newtonian* Philoſophy is built, muſt have been inevitably hindered from ſucceeding in his various attempts to find out the phyſical cauſes of the Planetary Motions, by his having imagined that, from the Inertneſs of Matter, a Body put in Motion by any ſingle Impulſe would ſoon after ſtop of itſelf, and that therefore it required to have a Force continually impreſſed upon it to keep up its Motion, which is not at all neceſſary.

The Laws of Motion, or Laws of Nature as they are ſometimes called, which are immediately deduced from the eſſential Properties of Matter, are as follow:

## LAW I.

*Every Body must persevere in its State of Rest, or of uniform Rectilineal Motion, till by some Force it be compelled to change its State.*

Every one will readily allow that a Body at rest must for ever continue so, unless some Force puts it in Motion. Now a Body, when put in Motion by a single Impulse, is not less passive in persevering to move than it is in continuing to rest; for if it be granted that a Body is unable of itself to make any change in its state, it must be just as unable to destroy its own Motion, or to cause any change in its Velocity, or in the Direction of its Motion, as it is to change its shape, or to begin of itself to move from a state of rest. Some Philosophers indeed seem to have thought that Bodies were naturally more disposed to Rest than to Motion; and probably they were induced to think so, by observing that all the Motions produced here on earth gradually decay, and at length cease. But Bodies never cease to move without

our

our being as well able to aſſign the cauſe of their ſtopping, as the reaſon of their beginning to move. For when a Body is put in Motion, we find it does not ſtop, till its Motion is deſtroyed by the Reſiſtance of ſome other Body, that it ſtrikes or rubs againſt.

## LAW II.

*Every Motion, or Change of Motion, in any Body muſt be proportional to, and in the Direction of, the Force impreſſed.*

For ſince a Body, by reaſon of its Inactivity, cannot produce its own Motion, or cauſe any change therein, it is evident that whatever Motion or change of Motion is generated in any Body, muſt proceed entirely from the Force impreſſed, and conſequently muſt be proportional thereto, and muſt likewiſe be directed towards the ſame Part with the Force impreſſed.

## LAW III.

*Reaction is always equal to Action, and contrary thereto; or in other Words, the Actions*

*Actions of two Bodies on each other are always equal, and are exerted in oppoſite Directions.*

WHATEVER preſſes or draws any thing, is itſelf as much preſſed or drawn in an oppoſite direction. If I preſs a ſtone with my finger directly downwards, I find my finger as much preſſed by the ſtone, and that directly upwards. If a horſe draws a load by means of a rope, ſince that rope is equally ſtretched in oppoſite directions, by endeavouring to relax itſelf, it muſt urge the horſe towards the load as much as it urges the load towards the horſe, and muſt as much retard the progreſs of one as it promotes that of the other: for the force which the horſe exerts would carry him to a greater diſtance in the ſame time, were he freed from the incumbrance of the load, and therefore as much as his progreſs falls ſhort of that diſtance, ſo much is he in effect drawn back by the reaction of the load.

As the Laws of Motion cannot be properly confirmed by Experiments, until I have treated of thoſe Powers or Qualities

of Bodies, which we consider as the immediate causes of their several Motions, I shall employ the remaining part of this Lecture in explaining some terms which will frequently occur hereafter; and in laying down the method of computing the Proportions which the Velocities of Bodies, and also their Forces and Quantities of Motion bear to each other.

VELOCITY is that affection of Motion by which a Body describes a certain Space in a certain Time. For if I am asked, what the Velocity of a Body is in any particular case? I must answer by telling the Space which that Body will describe in a certain Time. And the Velocity, in that case, is always supposed to be uniform.

THE Velocity of a Body is said to be equable or uniform, when it continues the same for the whole time during which the Body moves. And here it must be observed, that whenever I speak of the Velocity of a moving Body, that Velocity is always supposed to be uniform, unless it is expresly said to be otherwise.

IN computations relating to Forces,

Motions, Times, Velocities, or Spaces described, we generally have occasion to consider the Proportions of these Quantities to each other, and not the absolute Quantities themselves. Therefore in such computations, when any two of these quantities are compared together, we may substitute in their places any other two Quantities which have the same Proportion to each other, and which may be of a more convenient kind, such as Numbers, Lines, or Rectangles; and then those Quantities are said to be denoted or expressed by the others that are substituted for them. And therefore when one of those Quantities is said to be multiplied or divided by another, the meaning is that the Quantities by which they are respectively expressed, are multiplied or divided one by the other: as when the Velocity of a Body is said to be multiplied into the Time of its Motion, it is meant that the Numbers or Lines, that express these Quantities, are multiplied by each other.

When one Quantity so depends on another that it always encreases or dimi-

niſhes in the ſame Proportion in which that other is increaſed or diminiſhed, one of theſe Quantities is ſaid to be directly as the other, or directly proportional to the other. This manner of expreſſion is uſed for the ſake of brevity, for though but two Quantities are expreſſed, yet four at leaſt are always underſtood, and the expreſſion implies, that if each of the two Quantities be compared with another of its own kind, each of them will have the ſame Proportion to the one with which it is compared. For inſtance, when a Body moves for any given or determined Time, ſuppoſe a minute, it is evident that the Space it deſcribes in that Time, will be greater or leſs in Proportion as its Velocity is greater or leſs, and therefore the Space deſcribed in that Time is ſaid to be directly as its Velocity; and this implies, that if two Spaces deſcribed in equal Times be compared, they will have the ſame Proportion to each other as the two Velocities have, wherewith they were deſcribed.

When one Quantity depends on two others

others jointly, so that it increases or diminishes in the same Proportion in which either of them is increased or diminished, while the other remains unvaried; then, if they are both varied, it will increase or diminish in the same Proportion in which the product of these Quantities is increased or diminished: for it is evident that the product of these two Quantities depends on them jointly, in the same manner that the first Quantity was said to do, because it increases or diminishes in the same Proportion in which either of them is increased or diminished, while the other remains unvaried: and therefore, when any Quantity depends on two others jointly, in the manner above-mentioned, it will be directly proportional to their product. To illustrate this by an example, the Space which a moving Body describes depends on its Velocity and the Time of its Motion jointly: for it is evident that the Space it describes will be proportional to its Velocity, when the Time of its Motion remains the same, and to the Time of its Motion, when its Velocity

remains the ſame. Therefore in all caſes the Space which a Body deſcribes will be directly as the product which ariſes from multiplying its Velocity into the Time of its Motion. Or, to expreſs this more fully, if the Spaces deſcribed by two Bodies be compared together, they will have the ſame proportion to each other which the two Products have, that ariſe from multiplying the Velocity of each Body into the Time of its Motion. And theſe Products will be denoted either by two Numbers, or two Rectangles, according as the Velocities and Times were denoted by Numbers or Lines. Now as the proportion of any two Products in Numbers, or of two Rectangles, is compounded of the proportions of their reſpective Factors, or of their reſpective Sides; ſo the Spaces deſcribed by uniform Velocities are commonly ſaid to be to each other in a proportion compounded of the proportions of the Velocities and of the Times of the Motion.

When one Quantity ſo depends on

another, that it increaſes in the ſame proportion in which that other is diminiſhed, and diminiſhes in the ſame proportion in which that other is increaſed; one of theſe Quantities is ſaid to be inverſely or reciprocally proportional to the other. For inſtance, when a Body deſcribes any given or determined Space, it is evident that the time, in which it deſcribes this ſpace, will increaſe or diminiſh in the ſame proportion in which its velocity is diminiſhed or increaſed. Therefore in this caſe, the time of the Body's Motion is ſaid to be inverſely as its Velocity, and its Velocity is ſaid to be inverſely as the Time of its Motion. Or, to expreſs the ſame thing more fully, when two Bodies deſcribe equal Spaces, the Times of their Motions, when compared together, are to each other in the inverſe proportion of their Velocities; that is, the Time of the ſlower Body's Motion is to the Time of the ſwifter Body's Motion, as the Velocity of the ſwifter Body to the Velocity of the ſlower.

When one Quantity depends on two

others jointly in such manner that it is directly proportional to the first, when the second is unvaried, and inversely proportional to the second when the first is unvaried; then, if they are both varied, this Quantity will be directly as the quotient, which arises from dividing the first of these two Quantities by the second. For it is evident that the quotient of these two Quantities depends on them both, in the same manner that the first-mentioned Quantity was said to do. Because the quotient of any two Quantities is directly proportional to the dividend when the divisor is unvaried, and inversely proportional to the divisor when the dividend is unvaried. For instance, the Velocity with which a Body moves is directly as the Space it describes, when the Time of its Motion is unvaried, and inversely as the Time of its Motion, when the Space it describes is unvaried; therefore when the Space which a Body describes, and the Time of its Motion, are both varied, its Velocity will be directly as the Quotient which

which arises from dividing the Space it describes by the Time of its Motion. Or, to express this more fully, the Velocities of two moving Bodies, when compared together, will be to each other directly as the Spaces they describe divided by the respective Times of their Motion. Now as the Proportion of any two Quotients is compounded of the direct Proportions of the Dividends and the inverse Proportion of the Divisors; so the Velocities of two Bodies are commonly said to be to each other in a Proportion compounded of the direct Proportion of the Spaces described, and the inverse Proportion of the Times of their Motion.

I HAVE chosen to illustrate these several methods of expressing the Proportions of Physical Quantities, by applying them to the Quantities of Velocities, Times, and Spaces, because our ideas of them are most clear and simple, and they are such Quantities as occur most frequently in philosophical and astronomical computations.

I SHALL now, from what has been ſaid, ſhew how we are to compute the Proportions which the Quantities of Motion or Forces of moving Bodies have to each other.

THE Quantity of Motion, or *momentum*, of a Body is that Force with which it moves. And this muſt always be proportional to the Force of that Impulſe which is able either to produce or deſtroy its Motion; for a Body cannot of itſelf produce its own Motion, or make any alteration therein, and therefore whatever Motion it has muſt be proportional to the Force that produces it. Now if a certain Impulſe or Force impreſſed on a Body, be able to give it a certain Velocity, then an Impulſe of a double or triple Force muſt produce a double or triple effect, that is, muſt give the Body a double or triple Velocity, and therefore in general the Velocity with which one and the ſame Body moves is proportional to the Force impreſſed; but the Force with which that Body moves is alſo proportional to the Force impreſ-

ſed,

ſed, and therefore muſt be proportional to its Velocity. But further, as the Force of a Body in Motion is compoſed of the Forces of all its Parts, which move with the ſame Velocity that the whole does, it is evident that the Force of a moving Body muſt be proportional to the number of its Parts, that is, to its Quantity of Matter, while its Velocity is the ſame. Since therefore the Forces of moving Bodies are directly as their Velocities when their Quantities of Matter are equal, and directly as their Quantities of Matter when their Velocities are equal, it follows, from what was ſaid before, that their Forces will, in all caſes, be to each other as the Products which ariſe from multiplying their Quantities of Matter into their reſpective Velocities.

Hence it follows, that if the Forces of two Bodies be divided by their reſpective Velocities, the Quotients will expreſs their Quantities of Matter, or if their Forces be divided by their reſpective Quantities of Matter, the Quotients will expreſs their Velocities. This muſt

appear evident, when we consider that the Force or Quantity of Motion in each Body is expressed by the Product of its Velocity multiplied into its Quantity of Matter, and that when the Product of any two Quantities is divided by one of them, the other will be the Quotient.

It follows, from what has been proved, that two Bodies will move with the same Force if their Velocities be to each other inversely as their Quantities of Matter. For in that Case the Products will be equal, which arise from multiplying the Velocity of each body into its Quantity of Matter. If therefore two Bodies be given, however unequal in their Quantities of Matter, they may be made to move with equal Forces; by making the Velocity of the lesser Body exceed that of the greater, in the same Proportion in which the Quantity of Matter of the greater exceeds that of the lesser.

# LECTURE II.

OF THE

## Several Kinds of Attraction, And particularly of Cohesion.

AS the essential Inertness of Matter precludes all inanimate Bodies from having any Activity of their own or Propensity to change their State, whether of Rest or Motion; the various Motions of such Bodies, in the several Operations of Nature, must arise from certain Forces im-

preſſed upon them by their Creator, either immediately, or by means of ſecondary Cauſes, which ultimately muſt be actuated by Him.

THE Nature of theſe Forces muſt now be conſidered; and we ſhall find that the whole buſineſs of Philoſophy conſiſts, *Firſt*, in proving the Exiſtence of theſe Forces from ſuch ſimple and obvious Effects as cannot well be aſcribed to any other immediate Cauſe.

SECONDLY; in diſcovering the laws according to which theſe Forces are made to act, by carefully attending to the Nature of their Effects.

THIRDLY; in aſſuming theſe Forces as Principles or Cauſes, and from thence explaining the ſeveral Phænomena; always proving our Explanations by mathematical Reaſoning, or other juſt methods of arguing, founded on the eſſential Properties of Matter and Laws of Motion.

FOURTHLY; in endeavouring to inveſtigate the Cauſes, from whence theſe Forces immediately ariſe, and in deducing

cing Causes from Effects, till we come to the very first Cause, which certainly is not mechanical, that is, cannot consist in any Properties of Matter or Motion. And though every true step in this Philosophy does not bring us immediately to the knowledge of the first Cause, yet it brings us nearer to it, and on that account is highly to be valued.

I SHALL now briefly enumerate the principal Forces by which Bodies are acted upon, and afterwards treat of each of them in their order, and the several Phænomena that arise from them.

FIRST; The Particles of Bodies, especially of such as are hard, must be made to cohere or stick together by some certain Force, since a considerable Force is necessary to separate them from each other. For if the parts of a Body continued together merely from their *vis inertiæ*, and because they are at rest among themselves, (as some have imagined) it could not then require a greater Force to separate them from each other, than it does to move the whole Body from its place.

So

So that the *vis inertiæ* of Matter can never cauſe the parts of Bodies to ſtick together, and conſequently ſome Force muſt be impreſſed upon them to produce this effect, which Force is called the *Attraction of Coheſion.*

SECONDLY; If I let a Body go from my hand, tho' I do not give it any Impulſe, yet it will immediately move towards the center of the Earth; and if it be projected in any direction oblique to the Horizon, it will not move on uniformly, and in a right line, as it ought to do by the firſt Law of Motion, but will be made to move in a curve till it reaches the Earth; which plainly ſhews that ſome Force continually acts upon it, to turn it from the rectilineal Courſe, which it would otherwiſe purſue. This Force is called *Gravity, or the Attraction of Gravitation.*

THIRDLY; if a load-ſtone and a piece of iron be ſuſpended near each other, or made to float on water, they will approach towards each other, and ſtick together, when they come into contact.

Two

Two pieces of iron, properly rubbed on a load-ſtone, will alſo come together in the ſame manner, and in ſome Caſes they will recede or fly from each other and from the Magnet; which ſhews that a Force then takes place, that is of a contrary nature to the former One. Theſe two Forces are called *Magnetic Attraction and Repulſion.*

FOURTHLY; if amber, glaſs, or wax be rubbed briſkly with a piece of dry leather, any light Bodies near them will be firſt drawn towards them, and then repelled from them. The Forces which act in this Caſe are called *Electric Attraction and Repulſion.*

THOUGH the beſt Philoſophers have agreed in calling theſe Forces by the names of Attraction and Repulſion, yet they intend thereby only to denote certain Cauſes or Powers, whatever they are, that produce well known Effects, and not to expreſs the Nature of theſe Cauſes or the Manner in which they operate. And as there is a manifeſt convenience in having names for theſe general

Causes which must be so often mentioned, to object to the use of these words, as some have lately done, is but disputing merely about names, and could arise only from not knowing the proper sense in which these words are to be taken. We may also consider these Forces, till their Causes are found out, as Powers or Qualities with which Bodies have been endued for carrying on the Operations of Nature.

The Attraction of Cohesion, tho' it has but very little effect, even at small distances, yet is sufficient to make the Parts of Bodies, when brought into close contact, unite firmly together. Thus if two plates, made of any Matter that takes a fine polish, be pressed together, they will cohere with a sensible Force, and much more strongly if they be moistened by any liquid which excludes the air, and fills up their small scratches and inequalities.

This kind of Attraction appears remarkably in those Bodies that are tenacious or viscid, such as wax, pitch, or bird-lime, which, being soft, are easily brought

brought into close contact with other Bodies, and adhere strongly to almost every thing they touch: and when a Body is very soft and viscid, if it be stretched out, it will run back again and contract itself into a narrower compass, which plainly shews a tendency of the parts to each other.

The particles of Fluids, tho' so easily separated, are not entirely void of this kind of Attraction, for the drops of all Fluids affect a round figure, which must arise from their particles running together so as to be all contained within the smallest dimensions, as they are when the drop has a spherical shape; in like manner two drops of water or clean Quicksilver, when brought into contact, run immediately into one drop. When a small quantity of Quicksilver is poured on Paper, its drops still retain their spherical shape, which shews that the Attraction of its Particles to each other is so great that their weight is not able to separate them, and make them spread over the Paper as a drop of Water would

would do: but if the Quickſilver be laid on any clean metalline Body (except Iron) it will ſpread upon its Surface, its Particles being more attracted by the Metal than by each other.

THE Attraction between Fluids and hard Bodies will further appear from the following obſervations.

WATER always riſes ſomewhat about the ſides of the veſſel in which it is contained, and if the veſſel be very narrow the ſurface of the Water will be viſibly concave towards the middle. The ſame thing will happen when Mercury is contained in a veſſel made of any metal that attracts its particles more ſtrongly than they do each other; but in other veſſels the Mercury will be depreſſed round the edges, and convex in the middle, its particles being more attracted by each other than by the ſides of the veſſel. Water riſes in the like manner round a Glaſs Bubble that floats on its ſurface, and when the veſſel is narrow, as the Water is concave towards the middle, it muſt riſe higheſt between the Bubble

Bubble and the ſide of the veſſel neareſt to it; therefore the Attraction of the Water, being ſtrongeſt on that part of the Bubble, will make it move towards the ſide of the veſſel, which it will do with an accelerated Motion. I know this has been aſcribed to an Attraction between the Bubble and the ſide of the veſſel, but that cannot be the caſe, for the Bubble, when it floats freely on the Water, will not be in the leaſt affected by the Attraction of a Glaſs Tube, or any other Body, tho' held almoſt in contact with it; but if the Glaſs Tube be dipped in the Water, the Bubble will immediately run to it; which ſhews that it is affected only by the Attraction of the Water, which then riſes between it and the Tube. Beſides, if the veſſel be filled till the Water riſes a little above the edge, the Bubble will quit the edge and move towards the middle, where the Water is then higheſt. And if two clean Glaſs-bubbles float near each other, they will come together, becauſe the Water riſes higher between them than it does on their

oppoſite

oppoſite ſides: but if the Bubbles be greaſed, ſo that the Water may not riſe about them, they will not approach each other; for the Attraction of the Bubbles themſelves is too weak even at ſmall diſtances to bring them together, and overcome the reſiſtance they meet with in moving through the Water: indeed when the floating Bodies are very large, their Attraction may be able to overcome this reſiſtance; and accordingly we find that large ſhips floating near each other in a calm, are with difficulty kept from coming together.

All theſe Phænomena, which are of the moſt ſimple kind, clearly point out a certain tendency in the minute particles of Matter to each other, and conſequently prove the exiſtence of ſome Force which muſt be the cauſe of this tendency; and tho' we do not diſcover the nature of this Force, or its manner of acting, yet, having proved its exiſtence, we may aſſume it as a natural principle of Motion, and proceed from thence to explain other Phænomena of a more complicated nature

ture than those before mentioned. Thus we may on this Principle account for the rising of Fluids in Capillary Tubes, and for other effects of the like kind.

When the orifice of a small Glass Tube, open at both ends, is dipped in Water, the little Ring or small annular Surface of Glass that lies on the inside of the Tube, and just over the Orifice, will still draw up the Water that lies immediately under it, and make it ascend into the Tube, and every Plate of Water, as it is drawn in, will raise up that which lies above it, until the weight of the Water raised is able to counterbalance the Force by which the Attracting Annulus endeavours to draw in more Water: if the Orifice of the Tube be $\frac{3}{25}$ of an inch in diameter, the Water will rise to the height of about $\frac{1}{4}$ of an inch, and then remain suspended. The thin Plate of Water that lies just over the lowest Annulus, and every other Plate of the elevated Water, must be drawn both upwards and downwards with equal Forces, because it has equal attracting Surfaces above and below it,

it, and therefore the whole Column of elevated Water, which lies above the lowest Annulus, being drawn equally in opposite directions, may be considered as not at all affected by the Attraction of the Glass, and must press with its whole weight on the Water which is retained at the Orifice of the Tube, by the Force of that lowest Annulus that has no other Surface below it to counteract its Attraction.

From this way of reasoning, it seems evident, that the ascent and suspension of Water in these Tubes are entirely owing to the Action of the very lowest Glass Annulus that lies just over the Orifice, and not to that of the Annulus which lies over the elevated Water, or of any other part of the internal Surface of the Tube, as hitherto has been imagined. However, as what I have advanced is contrary to the received opinion, it may be necessary to confirm it by the following Experiment.

When the Water has ascended into a small Glass Tube, take it up, wipe off the Drop that hangs at the end of it, and invert the Tube; the small Column of included

cluded Water, being then drawn equally by the Glaſs in oppoſite directions, will deſcend by its own weight, and not ſtop till it arrives at the other Orifice; which ſhews that the Force which keeps it ſuſpended lies there. And if, while the included column is deſcending, the loweſt end of the Tube be dipped in Water and taken up, a ſmall Plate of Water will be retained at its Orifice, and the included Column will remain ſuſpended; now this Column of Water muſt, by means of the intermediate Air, preſs with its whole weight on the ſmall Plate of Water at the Orifice, and this Plate can be retained there by no other Force than the Attraction of the Glaſs Annulus that lies juſt within the Orifice of the Tube: and therefore it appears that this Attraction alone is ſufficient to ſuſtain, and, conſequently, to raiſe all the Water that ſeems ſpontaneouſly to aſcend into a Glaſs Tube.

THIS attracting annular ſurface on the inſide of the tube, is of a very ſmall breadth, becauſe the action of the glaſs extends

extends to but a very ſmall diſtance, and as it is of the ſame breadth in different tubes, its quantity, or the number of attracting particles, muſt be proportional to the diameter of the tube; conſequently, in cylindrical tubes, the quantities of Water raiſed muſt be as their diameters; and therefore the altitudes of the cylindrical columns of Water raiſed will be inverſely as their diameters; becauſe when cylinders are to each other as their diameters, they muſt have their heights inverſely proportional to their diameters; and this is the reaſon why Waters riſe higher in narrow tubes than in wide ones. But having meaſured, as accurately as I could, the diameters of ſeveral tubes and the heights to which the ſame fluid roſe in each, I found in a great many trials that theſe heights were not exactly in the inverſe proportion of the diameters, for in the narrow tubes the Fluid always roſe higher than it ſhould do according to that proportion.

And indeed there ſeems to be a plain reaſon for this, for in narrow tubes the oppoſite

oppoſite attracting particles, being cloſer together, act more in conjunction in drawing up the Fluid, and being alſo nearer to the middle Parts of the Fluid, they muſt on that account act more forcibly in raiſing and ſuſtaining it.

When a drop of Water or any thin oil, is included in a ſmall conical glaſs tube, open at both ends, it will run with an accelerated Motion to the narroweſt end, although that end be raiſed ſomewhat higher than the other; the reaſon of which may be thus ſhewn. Let the * lines A B and C D repreſent the ſides of a ſmall conical tube, and let P be a particle in the included drop, from which draw P E and P F perpendicular to the oppoſite ſides of the tube; theſe ſides muſt exert their attractions on the particle P in the directions of the lines P E and P F; and therefore theſe Forces (as ſhall be ſhewn when I come to treat of the compoſition of Motion) will, by their joint action, make the particle P move in the direction of a line P G, drawn thro'

* See *Fig.* 1.

the angle E P F and pointing towards the ſmalleſt end of the tube, and conſequently the whole drop muſt move towards that end.

For the ſame reaſon that Water riſes in ſmall cylindrical tubes, it will riſe between two glaſs planes ſet parallel to each other, and kept at a ſmall diſtance aſunder. And ſince the quantity of attracting glaſs ſurfaces will in this caſe be ſtill the ſame, whatever be the diſtance between the planes, the quantity of elevated Water muſt ſtill be the ſame. Therefore, in whatever proportion the diſtance between the planes is diminiſhed, the height of the elevated Water muſt be increaſed. And therefore, if the edges of the Planes are made to meet on one ſide, and the oppoſite edges are kept at a ſmall diſtance from each other, the elevated Water will have different heights at different diſtances from the concourſe of the Planes; ſo that the ſurface of the elevated Water will form a regular curve, riſing from the ſurface of the Water in the veſſel towards the concourſe of the

Planes

Planes. Let the * line A B represent the concourse of two glass Planes, whose opposite edges at C O are kept at a small distance from each other, and let A C be the surface of the Water in which the lower edges of the Planes are immersed; the curve line K L M N will represent the surface of the Water elevated between the Planes by their attraction. Now if any two columns of this elevated Water, as D L and F M be taken of very small but equal breadths as D E and F G, these columns will contain equal quantities of Water, being sustained by equal portions of the attracting Planes; therefore the heights of these columns must be inversely as their thickness, that is D L must be to F M as the interval between the Planes at F is to their interval at D; but these intervals are to each other as A F and A D, their distances from the concourse of the Planes; therefore the heights of any two columns of the elevated Water are to each other

* See *Fig.* 2.

inverſely as their diſtances from the concourſe of the Planes.

Let two well poliſhed Planes of Glaſs be laid together, ſo that the loweſt may be parallel to the Horizon, and the other may make with it a ſmall Angle of about a quarter of a Degree; the inward ſides of the Planes being well moiſtened with any thin Oil, let a Drop of the ſame Oil be put in with a Feather, ſo that it may touch both Planes, it will begin to move towards their concourſe, for the ſame reaſon that it would move towards the narroweſt end of a ſmall conical Tube; and, notwithſtanding the ſide where the Planes meet be ſomewhat elevated, the Drop will continue to aſcend, until the elevation of the Planes becomes ſo great that the weight of the Drop, which is always proportional to that elevation, will be ſufficient to counteract the Force by which the Drop is drawn towards the concourſe of the Planes.

Now by obſerving the elevations of the Planes that are neceſſary to ſtop the motion

tion of the Drop when at different diſtances from the concourſe of the Planes, it has been found that equal quantities of the Glaſs Surfaces, taken at ſeveral diſtances from the concourſe of the Planes, exert attractive Forces on the included Drop, that are to each other in the inverſe proportion of thoſe diſtances; that is, the Force with which the Drop is attracted by the Planes, when placed at the diſtance of ſix inches from their concourſe, is but one half of the Force with which it would be attracted at three inches, and but a ſixth part of the force with which it would be attracted at the diſtance of one inch from the concourſe; ſuppoſing the Drop not to ſpread, but to be ſtill touched by equal ſurfaces of the Glaſs: *(b)* and therefore the Attraction of the Glaſs

*(b)* It is evident that the Quantity of Surface over which the Drop ſpreads muſt increaſe as the thickneſs of the Drop diminiſhes, that is, as its diſtance from the concourſe of the Planes diminiſhes; therefore the ſame Drop, at three inches from the concourſe, will ſpread over double

Glaſs Surfaces grows greater in the ſame proportion as their diſtance from each other grows leſs; conſequently, where the diſtance between them is exceeding ſmall, their Attraction muſt be exceeding great.

SIR *Iſaac Newton*, who mentions this Experiment, in the Queries at the end of his Opticks, computes, that where the thickneſs of the Oil between the Planes is about the two millioneth part of an inch, the Attraction will be ſo great as to be able to ſuſtain, within a circle of an inch in diameter, the weight of a Column of Water, two or three furlongs in length, and where it is of a leſs thickneſs the Attraction will be proportionally greater,

the Quantity of Surface that it does at ſix inches from the concourſe. Now experiments ſhew that the elevations of the Planes neceſſary to ſtop the Motion of the Drop at theſe diſtances are to each other as four and one, and therefore the Attraction of the double Surface, at three inches from the concourſe, is four times greater than the Attraction of the ſingle Surface at ſix inches from the concourſe; conſequently the Attractions of equal Surfaces at thoſe diſtances are to each other as two and one.

and

and will continue to increaſe until the thickneſs does not exceed that of a ſingle particle of Oil. There are therefore agents in nature able to make the particles of Bodies ſtick together with very ſtrong attractions.

In all the experiments already mentioned, the Phænomena happen exactly in the ſame manner *in vacuo*, that they do in the open air; and therefore they cannot be owing to the preſſure of the Atmoſphere, but muſt neceſſarily be aſcribed to ſome power which cauſes the particles of the Fluid to tend more to the Glaſs than to each other. And if any Fluid be employed in theſe Experiments whoſe particles tend more to each other than to the Glaſs, the effects will then be the reverſe of the former ones. Now Mercury is ſuch a Fluid, for tho' its particles are attracted by Glaſs (as appears from their ſticking to the back of a looking-glaſs) yet they are more ſtrongly attracted by each other; and therefore, when a ſmall Glaſs Tube is immerſed in Mercury, it does not riſe ſo high within

the Tube as it is in the veſſel: and when two Glaſs Planes, that make a ſmall angle with each other, and ſtand perpendicular to the Horizon, are immerſed to ſome depth in a veſſel of Mercury, it will be higheſt between the Planes where they are fartheſt aſunder, and loweſt towards their concourſe; which is the reverſe of what happens when Water is included between thoſe Planes.

If clean Mercury, well purged of air, be carefully poured into a clean Glaſs Tube, of about 70 inches long, ſo that its parts may be every where contiguous to each other and to the Glaſs, it has been found, upon inverting the Tube, that the whole Mercury would remain ſuſpended. Now the preſſure of the Atmoſphere could only ſupport about 29 or 30 inches of Mercury, and therefore ſome other agent muſt have ſuſtained the reſt, not by preſſing the Mercury into the Glaſs, but by making its parts adhere to the Glaſs, and to one another; for upon any diſcontinuation of parts, made either by bubbles intervening, or by

ſhaking

ſhaking the Glaſs, the whole Mercury falls down to the height of 29 or 30 inches.

It ſeems to be by the ſame attractive Force, with which ſmall pipes and capillary tubes are endued, that ſponges and other dry porous Bodies draw in Water, and the glands in the Bodies of Animals, according to their ſeveral natures and diſpoſitions, take in various juices from the Blood, and Plants receive nouriſhment from the Earth; the ſmall Tubes whereof their roots are compoſed taking in different juices, according to their different conſtitutions: juſt as the ſame capillary Tube of Glaſs acts differently on different liquors, which therefore will not all aſcend in it to the ſame height; for Water, though heavier than Spirit of Wine, will aſcend near twice as high in the ſame Tube, which ſhews it is twice as ſtrongly attracted by the Glaſs. It has been alſo obſerved, that Tubes made of different Kinds of Glaſs, will attract the ſame Liquor with

different Forces, and cauſe it to aſcend to different heights.

MANY other Operations of Nature ſeem to be carried on merely by means of this Attraction that obtains among the minute particles of Bodies; particularly moſt of the Operations in Chymiſtry ſeem ſcarce explicable on any other principle. But, as that ſubject is not within my province, I ſhall enter into it no further than to give ſome account of that common Operation, the Solution of Bodies in Fluids, which I ſhall have occaſion to make uſe of hereafter in explaining certain Phænomena.

WHEN the Particles of a Body, ſurrounded by a Fluid, are leſs ſtrongly attracted by each other than by the Fluid, they muſt ſeparate from each other and join themſelves to the Particles of the Fluid, and remain ſuſpended therein. Thus various Salts are diſſolved in Water, and Metals and other Bodies in the liquors that are reſpectively adapted to their Solution.

Upon the various degrees of Attraction between different Substances depend almost all the Phænomena which Chymistry exhibits, and therefore it has been found of great use to have Tables composed, wherein those mutual Attractions are set down according to the different degrees in which they are found to obtain between several Bodies. These are called tables of *Affinities* or *Elective Attractions*; and as this is a curious subject, I shall illustrate it by the following instance.

When Silver is dissolved in Aqua-fortis, which is the acid Spirit of Nitre, if Filings of Copper be thrown into the Solution, the Aqua-fortis will dissolve the Copper and quit the Silver, which will be precipitated to the Bottom in the Form of a white Powder: if then Filings of Iron be thrown in, they will in like manner be dissolved, and the Copper will fall to the Bottom. And lastly, if Salt of Tartar, or any other alkaline Salt be thrown in, the Aqua-fortis will unite with it and dismiss the

Iron. This acid Spirit has therefore a greater affinity, or a ſtronger Attraction to the alkaline Salt, than to any of the Metals, and it attracts the Iron, the Copper and the Silver with different degrees of Strength; and very ſtrong muſt theſe Attractions be, ſince they are able to ſeparate from each other the Particles of ſuch hard Metals.

FROM hence we may ſee the nature of that Operation of turning Iron into Copper (as it is called) by laying bars of Iron in Water that ſprings from a Copper-mine, and which is impregnated with Particles of Copper diſſolved in a mineral acid. *This is by no means a tranſmutation of one metal into another*, but the acid, having a greater affinity with the Iron than it has with Copper, corrodes and diſſolves the Iron, and leaves the Particles of Copper in its place, which adhere together in ſmall ſcales; ſo that after ſome time the Bar is found incruſted with Copper, and moſt part of the Iron is carried off by the Water.

THESE

These different degrees of Attraction between the minute Particles of Matter seem to be the immediate cause of all the several degrees of hardness and softness that we find in different Bodies; for the stronger the Attraction, the more firmly must the Particles cohere, and the harder must the Body be which they compose. But how far hardness and softness may depend also on the size and shape of the ultimate and constituent Particles of Bodies, we shall probably never be able to determine, because they are too minute to fall under the cognizance of our senses.

In many cases, when the Particles are placed without the sphere of each other's Attraction, a repelling Force prevails among them; for two polished Plates of Marble, which by immediate contact cohere together, are with difficulty brought into contact: and the object-glasses of long Telescopes lie upon one another without touching, as appears by the colours which the air between

tween them exhibits. From the ſame repelling power it ſeems to be that Flies walk upon the Water without wetting their feet, and that the Particles of dry Powders are with difficulty made to touch one another ſo as to ſtick together. The Particles of Fluids, when ſeparated by heat, are turned into an elaſtic ſteam, which, if confined and ſufficiently heated, will burſt the ſtrongeſt veſſel. This repulſive Force ſeems alſo to be the cauſe of the emiſſion and reflection of the rays of light, and of ſeveral other Phænomena that ſhall be taken notice of in their proper places.

# LECTURE III.

## OF GRAVITY, OR THE Attraction of GRAVITATION.

THE ſecond kind of Attraction I propoſed to treat of was Gravity, or that Force which cauſes all Bodies near the earth, to tend towards its centre; and which prevents the earth's rapid Motion round the axis from throwing off the Bodies that lie on its ſurface, as it

it certainly would do, were they not retained there by ſome very potent principle.

As the drops of all Fluids affect a round Figure by the mutual tendency of their Parts to each other; ſo the ſurface of our ſea muſt be ſpherical, ſince the waters every where tend to the centre; and the prominences, of the land above the ocean, are ſo very ſmall with reſpect to the earth's magnitude, that the whole may be conſidered as a ſphere. And ſuch it muſt appear to a ſpectator placed at a proper diſtance, juſt as the moon appears ſpherical to us, though a good teleſcope diſcovers greater inequalities on her Surface, than are to be met with on the Surface of the earth.

The Attractions of Coheſion and Gravity ſeem to be general Forces affecting all Bodies, for their particles cohere together when brought into cloſe contact, and the Bodies themſelves are all equally affected by the Force of Gravity. There is however this difference between them, the

the cohesion of Bodies may be diminished or destroyed, and when their particles are separated there is some natural Force that makes them repel each other: whereas there is not any Body whose absolute Gravity can be in the least diminished. This Force by which a Body tends to the centre of the earth, is commonly called its Weight; and the Weights of Bodies, at equal distances from the centre, are always proportional to the quantities of solid Matter which they contain: For all Bodies whatever, being let fall from the same height, descend with equal velocities, provided they meet with no resistance from the air; as will appear from the following experiment. If a piece of gold and a feather be let fall from the top of a tall exhausted Receiver at the same instant, they will both come to the bottom at the same time.

SINCE therefore the attractive Force of the earth causes all Bodies, that fall freely, to descend with the same velocity; it follows that this Force must act

act equally on the particles of all Bodies whatever; and therefore it must act on every Body in proportion to its number of Particles, that is, in proportion to its quantity of Matter or its *vis inertiæ*; for otherwise it could not cause all Bodies to move downwards with the same velocity. Consequently, the weights of different Bodies, at equal distances from the centre of the earth, or the Forces with which they descend freely, or endeavour to descend, are to each other as their quantities of Matter. The same thing may be proved thus; when Bodies begin together to descend freely from a state of rest, their quantities of Motion, acquired in the same time, must be proportional to the moving Forces, that is to their weights; but since they descend with equal velocities, their quantities of Motion are also proportional to their quantities of Matter; therefore their weights are likewise proportional to their quantities of Matter. Hence it is that the quantity of Matter in any Body may be justly estimated by its weight, or the

the Force with which it endeavours to descend.

THE attractive Force of the earth is found not to act equally on Bodies at all distances from its centre. Sir *Isaac Newton* has demonstrated, that this Force above the surface of the earth decreases in the same proportion that the square of the distance from the centre increases; that is, the Forces with which the earth acts on Bodies to put them in Motion, at different distances above the surface, are reciprocally as the squares of their distances from the centre. So that if a Body, at the surface of the earth, (whose distance from the centre is about 4,000 miles) weighs four pounds, and by the Force of Gravity falls thro' 16 feet in a second of time; it will at double that distance weigh but one pound, and will fall thro' but four feet in a second of time. He has likewise proved that the Gravity of a Body, at any place below the surface of the earth, is directly proportional to its distance from the centre; that is, a Body, which at the

the ſurface weighs one pound, will, within the earth, at the diſtance of two thouſand miles from the centre, weigh but half a pound, and at the diſtance of one thouſand miles but a quarter of a pound, and ſo on till at the centre it loſes all its weight. The attractive force of the earth, when conſidered as acting differently on Bodies at different diſtances from the centre, is called its accelerating Force, and is meaſured by the velocity it is able to generate in the Bodies in a given time.

Tho' ſtrictly ſpeaking the accelerating Force of Gravity decreaſes in the manner above-mentioned, yet where the diſtances from the Surface are inconſiderable with reſpect to the Earth's Radius, (as are all the diſtances to which we can project Bodies) the Force of Gravity may be looked upon as equal at all thoſe diſtances. And on this ſuppoſition are founded the reaſonings of *Gallileo*, *Torricellius*, *Huygens*, and other Naturaliſts, concerning the deſcent of heavy Bodies, and the ſeveral Theorems

rems are formed which relate to the acceleration of falling Bodies, the ſpaces deſcribed by them, the times of the fall, and the velocities thereby acquired.

If the Force of Gravity remains unvaried, the Motion of a Body, falling freely from a ſtate of reſt, will be uniformly accelerated; that is, the increments of the velocity will be equal in equal times. For let us ſuppoſe the time of the deſcent to be divided into a number of equal parts indefinitely ſmall; in each of theſe the Force of Gravity muſt make equal impreſſions on the Body to carry it downwards, and conſequently muſt by each impulſe generate an equal velocity in the falling Body; and ſince all the velocities are in the ſame direction, the laſt acquired muſt be ſtill added to the former, and therefore the velocity of the falling Body will be uniformly accelerated.

It follows alſo that, at the end of any time, the whole velocity generated muſt be as the number of Impulſes received

ceived from Gravity, that is, as the number of the indefinitely ſmall parts of time taken from the beginning of the fall; and therefore the velocity acquired at the end of any time by a Body, falling freely from a ſtate of reſt, will be as the time of its deſcent from the beginning of the fall.

THE ſpace which a Body falling freely from a ſtate of reſt deſcribes in any time, taken from the beginning of the fall, may be expreſſed by a right angled triangle * A B C, whoſe Baſe A B denotes the time of the fall, and the perpendicular B C the velocity acquired at the end of that time.

FOR, let there be drawn in the triangle the lines H I, F G and D E, parallel to B C, then ſince theſe lines H I, F G, D E and B C are to each other as A H, A F, A D and A B, and ſince B C denotes the velocity acquired in the time A B, the lines H I, F G and D E muſt denote the velocities reſpectively acquired in the times A H, A F

* See *Fig.* 3.

and

and A D, becauſe the velocities are as the times of the Motion. Now if we ſuppoſe the whole time of the Motion to be divided into a number of very ſmall and equal parts, as A H, H F and F D, we may then conſider the velocity of the Body as uniform during each of theſe parts of time; and ſince the ſpace deſcribed by any uniform velocity is expreſſed by a rectangle contained under lines proportional to the time of the Motion and the Velocity, the ſpaces deſcribed in the ſeveral ſmall parts of time A H, H F and F D will be expreſſed by the little rectangles A H I K, H F G L and F D E P, and thus the Space deſcribed in the whole time A B will be expreſſed by the ſum of all the little rectangles that are formed in this manner, by multiplying each ſmall part of the time into the velocity with which the Body then moves. But when we ſuppoſe thoſe equal parts, into which the whole time A B is divided, to be indefinitely ſmall, and their number indefinitely great, (as we ought to do if we

we conſider the velocity as uniform in each of thoſe parts of time) then the ſum of all the rectangles will differ from the triangle A B C by a quantity leſs than any given one, and conſequently the Space deſcribed in the whole time of the Motion will be expreſſed by the triangle A B C.

From hence we may eaſily deduce, as corollaries, all the other properties of an uniformly accelerated Motion. Firſt, the Space which a Body falling freely deſcribes in any time, taken from the beginning of the fall, is one half of the Space it would deſcribe in the ſame time, if it moved uniformly with the velocity acquired at the end of the fall. For when, in the right angled triangle A B C, the ſide A B denotes the time of the fall, and B C, the laſt acquired velocity, the ſpace deſcribed in the time of the fall will be expreſſed by the triangle A B C; but the Space deſcribed in the ſame time by a Body moving uniformly with the velocity B C will be expreſſed by

by the rectangle A B C O, of which the triangle is one half.

SECONDLY; The Spaces, described by a Body falling freely from a state of rest, are to each other as the Squares of the times from the beginning of the fall, or as the Squares of the velocities acquired in those times. For it appears from what has been said, that the Spaces described by a falling Body in the times denoted by A B and A D will be in the same proportion with the triangles, A B C and A D E; but these triangles being similar, their areas are to each other as the Squares of their homologous sides; that is, as the Squares of the lines A B and A D, which express the times of the fall, or as the Squares of the lines B C and D E, which express the velocities acquired in those times: Wherefore the Spaces described in different times by a falling Body are to each other as the Squares of the times from the beginning of the fall; or as the Squares of the velocities acquired at the ends of those times.

To confirm this by an Experiment!

Let a weight of eleven hundred grains fall from the height of three inches, ſo as to ſtrike one end of a balance, its Force will be juſt ſufficient to raiſe a pound weight, hung at the other end of the balance, to a ſmall height; but in order to raiſe weights of two or three pounds, the ſame body muſt fall reſpectively from the heights of twelve and twenty-ſeven inches, for leſs heights will not be ſufficient.

The forces wherewith the deſcending Body ſtrikes the end of the balance are proportional to the weights they are able to raiſe; but the Forces with which the ſame Body ſtrikes are alſo proportional to its velocities; wherefore the velocities acquired by the falling Body are, in this caſe, as the weights raiſed, that is, as one, two, and three; and therefore the Squares of the velocities are as the Squares of theſe numbers, that is, as one, four, and nine; but the Spaces three, twelve, and twenty-ſeven are alſo in the ſame proportion as one, four, and nine, and therefore the Spaces deſcribed are as

the Squares of the velocities acquired by a Body in falling thro' them.

HENCE it follows, that the Spaces described by a falling Body in the several moments of time taken separately, and in their order, from the beginning of the fall, are to each other as the odd numbers, one, three, five, seven, and so on, taken in their natural order; for, where the times of the fall are one, two, three, and four moments, the Spaces described will be as the Squares of those times respectively, that is, as one, four, nine, and sixteen; therefore the Spaces described in the second, third, and fourth moments, taken separately, will be as the differences between the numbers one, four, nine, and sixteen respectively, which are three, five, seven, nine, and so on.

As the Motion of a Body falling from a state of rest is uniformly accelerated, so likewise the Motion of a Body thrown directly upwards is uniformly retarded. For the same Force of Gravity, which conspires with the Motion of a falling Body, acts in direct opposition to the

motion of ſuch as aſcend; and therefore, in whatever manner it accelerates one, it muſt retard the other. Whence it follows, that a Body thrown directly upwards will continue to aſcend for a time equal to that, in which, by falling from a ſtate of reſt, it would acquire the ſame velocity with which it is thrown up. For ſince the action of gravity is conſtant and uniform, in whatever time it generates any velocity in a falling Body, in the very ſame time it muſt deſtroy that velocity in a riſing Body, and therefore the time of the aſcent muſt be equal to that of the fall. Hence if a Body be thrown directly upwards with a velocity equal to that which it has acquired by falling from any height, it will aſcend to the ſame height before it loſes all its velocity. For ſince, of theſe equal velocities, one is generated and the other deſtroyed in the ſame manner, by the uniform action of the ſame Force, and in the ſame time, it is manifeſt that the ſum of the velocities wherewith the body moves, during its deſcent and its aſcent,

aſcent, muſt be equal, and conſequently the Spaces deſcribed in its deſcent and in its aſcent muſt alſo be equal.

In order to determine the abſolute Force of Gravity at the ſurface of the Earth, it is neceſſary to know thro' what Space a Body will fall in a given time. And by very accurate experiments made with Pendulums, which will be mentioned hereafter, it has been found, that a Body, near the ſurface of the Earth, falling from a ſtate of reſt, will deſcend through the Space of about ſixteen feet and one inch in a ſecond of time, that is, in the ſixtieth part of a minute: from whence it appears that the Force of Gravity, by acting on any Body only for one ſecond of time, will generate in it ſuch a velocity as, being continued uniform, would carry it thro' two and thirty feet and two inches in one ſecond, or thro' very near twenty-two *Engliſh* miles in an hour.

I must obſerve here, that Bodies do not deſcend in all climates at the rate of ſixteen feet and an inch in a ſecond

of time, but in ſuch places only as are in, or near, the Latitude of forty-nine degrees. In places more diſtant from the Æquator, the deſcent is quicker, and ſlower in thoſe that are nearer to it. For it has appeared, from a great number of obſervations, that the Force of Gravity is leaſt under the Æquator, and that it increaſes continually as we approach towards the Poles, where it is greateſt of all.

The chief cauſe of this difference is, the rotation of the Earth round its Axis, by which all Bodies on the Surface acquire a centrifugal Force; and, as I obſerved before, would actually fly off, if they were not retained by their Gravity. *(c)* Now as all theſe Bodies revolve uniformly round the Earth's Axis in four and twenty hours, either in the Æquator

*(c)* By the centrifugal Force, is meant that force which we ſee makes Bodies, lying looſely on a wheel or a globe, fly off when it revolves ſwiftly round its Axle; and this ariſes from their tendency to move on in a right line according to the firſt law of motion.

or

or in circles parallel to it, their velocities, and consequently their centrifugal Forces, must be as the Peripheries of the Circles they describe; and therefore as the Æquator is the greatest of all those Circles, and the others grow less and less as they are more and more distant from the Æquator, the centrifugal force of Bodies must be greatest in the Æquator, and be continually diminished towards the Poles, till at last it vanishes at the Polar points. As this force acts in opposition to Gravity, it must of course diminish it, and this diminution must be greatest in the Æquator, and grow less and less in the approach towards the Poles.

There is also another reason why the Force of Gravity should be more diminished by the centrifugal force at the Æquator than in any other place, which is this. The centrifugal Force always causes a Body to tend from the centre of the Circle in which it moves; and therefore it must act in direct opposition to the Force of Gravity at the

Æquator, whose center is the same with that of the Earth; but as the centers of all the Circles parallel to the Æquator, are at several distances from the center of the Earth, in every such Circle the centrifugal Force acts obliquely against the Force of Gravity, and the more so as the Circle is nearer to the Pole, and therefore cannot diminish it so much as it does at the Æquator.

SIR *Isaac Newton* has proved, by a most ingenious method of computing, that Bodies at the Æquator lose $\frac{1}{289}$ part of the weight which they would have if they were placed at the Poles; and has shewn that the Æquatorial diameter of the Earth exceeds the Polar diameter, or the Axis round which the Earth turns, by about seventeen *English* miles and $\frac{1}{10}$; for if the Æquatorial parts of the Earth, where the Waters are lightest, were not so much higher than the Polar parts, where they are heaviest, the Seas about the Poles would subside, and rising at the Æquator, would overflow the Lands thereabouts.

FROM

FROM an experiment made at the beginning of this Lecture, it was concluded that the Gravity of every Body is proportional to its Quantity of Matter; and as this is a propoſition of great importance in Natural Philoſophy, it may be proper to explain it a little more fully, and to obviate ſome objections that, to common obſervers, may ſeem to ariſe againſt it. Bodies of different kinds ſeem, at firſt ſight, to be endued with different degrees of weight; thus Lead is ſaid to be heavier than Cork, and Gold to be the heavieſt of all Bodies. Now the reaſon why ſome Bodies are heavier than others of an equal ſize is, that ſome Bodies contain in the ſame bulk, a greater Quantity of Matter than others do. Thus a ball of Lead contains much more Matter than one of Cork of the ſame ſize, for Lead is a much more compact Body than Cork, which abounds with large empty Pores and Interſtices; and therefore, ſince the particles of Lead lie cloſer together, it muſt contain more Matter in the ſame

bulk than Cork does, and consequently it ought to be proportionably heavier.

Bodies differ very much in regard to the proportion which their Pores bear to their solid Parts, and accordingly are said to be of different Densities; that being called the densest which contains the greatest Quantity of matter in proportion to its bulk. Now as every species of Matter has a degree of Density peculiar to itself, if we suppose many Bodies of different kinds to have the same magnitude; each Body will contain a Quantity of Matter proportional to its Density, and consequently each Body will have a different weight, and that in proportion to its Density, which weight is therefore called its *specific Gravity*. From hence we see how Bodies of the same size may have different weights, and yet the Gravity of each be still in proportion to its Quantity of Matter.

That Air is heavy like other Bodies, is now well known, and the weight of the Atmosphere is accurately measured by

by the weight of the Quickſilver that is ſuſtained in the Tube of the Barometer. It is alſo well known, that Smoke aſcends in the open Air for the ſame reaſon that every Body will aſcend in a Fluid that is heavier than itſelf; ſo that we have really no inſtance of any Body abſolutely light or void of weight, but find, on the contrary, that all Bodies whatſoever, on or near the ſurface of the Earth, gravitate towards it, and that in proportion to the Quantity of Matter in each of them.

THIS property of Gravitation is not confined to the Matter of which our Earth is formed, but is found to be a general property of all Bodies that come any way under our obſervation. Sir *Iſaac Newton* has demonſtrated, that the Moon gravitates towards the Earth, and is retained in her Orbit merely by that Force. And ſince the revolution of the Moons round Jupiter and Saturn, and of the primary Planets round the Sun, are Phænomena, or effects of the ſame

kind with the revolution of our Moon round the earth, he concludes, by the second Rule of Philosophising, that all these Effects must proceed from like Causes, and therefore that the Moons of Jupiter and Saturn gravitate towards their Primaries, and that all the Primary Planets gravitate towards the Sun. He has also shewed, that if one Body attracts another with any Force, with the same Force does that other Body attract it; so that the Earth must gravitate towards the Moon, the Sun towards the Planets, and they all towards each other. He has proved likewise, that the attractive forces of these great Bodies act according to one universal and invariable Law, which is, that every two of them attract each other with Forces that are directly as their Quantities of Matter, and inversely as the Square of the distance between their Centers. And since the Attractions of these Bodies are made up of the Attractions of all their Particles, it follows, that every

every two Particles of Matter must attract each other with Forces that are as their Quantities of Matter directly and inversely as the Square of their Distance. The reason why we do not perceive the Attraction of any two Bodies towards each other, when they fall freely together near the surface of the Earth, is, that this Attraction bears the same proportion to the weight of the Bodies that the Bodies themselves do to the whole earth, and therefore it must be altogether imperceptible.

SIR *Isaac Newton*'s great discovery therefore consists in his having proved that the well-known power which we call Gravity, acting throughout the Solar System, according to the law above mentioned, is the immediate cause which preserves the Planets and Comets in their Motions round the Sun; and that this Force alone is fully sufficient to account for all the irregularities of the Lunar Motions, for the Retrogression of the Æquinoctial Points, and for the Tides

in

in our ſeas, whoſe waters gravitate towards the Moon.

All this he has done by ſhewing, from mathematical calculations, that this Force acting on thoſe Bodies muſt neceſſarily produce ſuch effects and appearances, as exactly correſpond with thoſe which, the beſt obſervations aſſure us, do really take place in Nature; ſo that there can remain no doubt of his having aſſigned the true cauſe of all thoſe great Phænomena. Thus has he entirely overthrown all the ſpecious Hypotheſes by which his Predeceſſors endeavoured to explain thoſe matters, and has at length laid open to us the true ſyſtem of Nature; in which the wiſe diſpoſition of the great Bodies in the Univerſe, the ſurpriſing regularity of their Motions, and the great ſimplicity and uniformity of the means by which they are effected, appear every way worthy of the infinitely wiſe and Almighty Author of all things.

It ſtill remains to be determined, whether theſe Forces of Gravity and Co-

heſion

hesion arise immediately from the Will of the Supreme Being, or are the effects of some secondary or mechanical cause, which He is pleased to employ in carrying on the operations of Nature; and which, as an immediate instrument in his hand, must derive its whole efficacy from his Will only. Sir *Isaac*, from some Phænomena, was induced to suspect that the immediate cause of Gravity was mechanical; and that there existed throughout the Universe a most subtile ætherial fluid, whose particles are so small as to pass freely thro' the pores of all Bodies; and that these particles are endued with an exceeding strong repelling Force, which makes this fluid vastly more rare and more elastic than our air, and of consequence vastly less able to resist the Motion of Bodies, and much more able to press upon gross Bodies by endeavouring to expand itself. This Æther he supposes must, from its repelling force, be much rarer within the dense Bodies of the Sun, Planets, and Comets, than in the empty

spaces

ſpaces between them; and that in paſſing from them to greater diſtances it grows denſer and denſer perpetually, and thereby cauſes the Gravity of theſe great Bodies towards each other, and of their parts towards the Bodies, every Body endeavouring to go from the denſer parts of this Æther towards the rarer *(d)*. All this however he propoſes only as a conjecture, and leaves the truth of it to be determined by future Experiments; and I have mentioned it here only becauſe it is the conjecture of ſo great a Philoſopher. For tho' the late Experiments in Electricity prove the Exiſtence of ſome ſuch ſubtile fluid, which eaſily pervades the denſeſt Bodies, yet I have not heard of any Experiments that prove it to be the cauſe either of Gravity or Coheſion.

WHATEVER may be the cauſe of Gravity, it cannot be improper, in our philoſophic reaſonings about its effects, to conſider it as a quality or property belonging to all Bodies that fall in any-

*(d) Newton's* Optics. Query 1.

wiſe under our obſervation, as our experience ſufficiently warrants us in ſo doing; and ſince this quality cannot in any Body be increaſed or diminiſhed, it muſt be looked upon (by the third Rule of Philoſophiſing) as a quality of all Bodies whatever. This being the caſe, we have from hence an unanſwerable argument for the exiſtence of a *Vacuum*. For if the region of our Air, for inſtance, was filled with any Matter that had no empty pores, let this matter be ever ſo ſubtile or ever ſo fluid, it muſt ſtill have a greater Denſity, and conſequently a greater ſpecific Gravity than Quickſilver or Gold; ſo that it would be as impoſſible for even the heavieſt Bodies to deſcend in this Fluid, as it is for Cork to deſcend in Water, or Wood in Quickſilver. And ſince Bodies, which in the open Air are reſiſted in very different degrees, fall together in an exhauſted Receiver without any ſenſible reſiſtance; we muſt conclude that ſuch a Receiver doth not contain in it any Matter that hath either a ſenſible Gravity, power

of

of resisting, or *vis inertiæ*, or in other words, that it doth not contain any sensible Matter at all. It is therefore incumbent on those, who assert that all Space is equally full of Matter, to tell us what kind of Matter it is that adequately fills a Receiver exhausted of air, and to shew us its properties; since it is evidently divested of those properties that are common to all the Bodies we know of.

# LECTURE IV.

## THE Laws of Motion explained AND Confirmed by Experiments.

HAVING given an account of the Properties that are eſſential to Matter, and of the Forces called Attraction and Repulſion; I come now to ſhew how the Motions of Bodies, ariſing from theſe Forces, are regulated according to the Laws laid down in the firſt Lecture, and to confirm theſe Laws by Experiments.

As

As by the firſt Law of Motion every Body muſt, in proportion to its Quantity of Matter, endeavour to continue in the ſtate it is put into, whether it be of Reſt or uniform rectilineal Motion; and as a Body put in Motion by any Impulſe muſt begin to move with ſome certain Velocity, and its Motion muſt be directed towards ſome certain point; it follows, that the Body muſt go on in the ſame right line, deſcribing equal ſpaces in equal times, until ſome Force be impreſſed upon it to produce a change. Therefore, when a Body moves in a Curve line, that Curvature muſt neceſſarily proceed from ſome Force which continually acts upon it, and turns it from its natural rectilineal Courſe; and whenever that Force ceaſes to act, the Body will move forward in a right line touching the Curve in that point where the Body was when the Force ceaſed to act. The truth of this is ſufficiently teſtified by frequent experience; for if a Stone be moved round in a Sling, by its tendency to move in a right line it will ſtretch the ſtring with ſome Force, and when

when it is ſet at liberty it will not continue its circular Motion, but will go on in a right line touching the circle made by the revolution of the Sling, until its Gravity draws it from this line towards the Earth.

By the ſecond Law of Motion it appears, that any Motion, or change of Motion, produced in a Body muſt be proportional to, and in the direction of the Force impreſſed. Therefore if a moving Body receives an impulſe in the direction of its Motion, its velocity will be thereby increaſed; if in the contrary direction, its velocity will be diminiſhed, tho' its direction will not be changed; but if the Force be impreſſed in a direction oblique to that in which the Body moves, it will be thereby made to change its direction, and move in a line ſituated between the direction of its former Motion and that of the Force impreſſed. And if a Body at reſt receives two impulſes at the ſame time from Forces whoſe directions do not coincide, it will, by their joint action, be made to move in a line that lies between the directions of the Forces impreſſed. For

inſtance,

inſtance, if on the Body A (fig. 4) a Force be impreſſed ſufficient to make it move, with an uniform velocity, to the point B in a ſecond of time, and if another Force be alſo impreſſed on the Body which alone would make it move to the point C in the ſame time; the Body, by means of theſe two Forces, will deſcribe a line whoſe poſition may be thus determined. Complete the parallelogram A B D C, whoſe ſides A B and A C are by the ſuppoſition proportional to the Forces impreſſed in their directions, draw the diagonal A D; the Body will move along this line and will deſcribe it in the ſame time in which it would have deſcribed either of the ſides A B or A C ſeparately. For ſince the Force impreſſed on the Body to carry it to the point C, is not directed either towards the line B D or from it, but acts in a direction parallel to it, that Force cannot either accelerate or retard the velocity with which the Body approaches the line B D; the Body muſt therefore arrive at the line B D in the ſame time it would have done if no other Force had been

been impreſſed on it but that in the direction A B, and therefore at the end of one ſecond it will be found ſomewhere in the line B D. In the ſame manner, ſince the Force impreſſed in the direction A B, which is parallel to C D, is neither directed towards C D nor from it, it cannot prevent the Body from arriving at the line C D in the ſame time it would have done, had no other Force been impreſſed than that in the direction A C; and therefore the Body will, at the end of one ſecond, be found ſomewhere in the line C D; conſequently, at the end of the ſame time, the Body will be found in both lines, that is, at the point D, the concourſe of thoſe lines. And ſince, from the joint impreſſions of the Forces, it muſt have ſet out from the point A, with a rectilineal Motion, it muſt, during its Motion, have deſcribed the whole line A D, the diagonal of the parallelogram C A B D.

To confirm this by an Experiment: Let three ivory balls, of an equal ſize, be ſuſpended from three pins, by ſtrings of equal lengths, and let the middle ball reſt

over

over one angle of a wooden Square; then let each of the extreme balls be let fall ſeparately, from the ſame height, ſo as to ſtrike the middle ball in the direction of one ſide of the Square; the middle ball will, by each of the ſtrokes made ſeparately, be moved over that ſide of the Square that lies in the direction of the ſtroke; but if the two balls be at the ſame time let fall from equal heights, ſo that they may ſtrike the middle ball at once, and in the directions of the two ſides of the Square, the middle ball will, by the joint Forces impreſſed at the ſame time, be driven over the diagonal of the Square.

FROM what has been ſaid it appears, that when a Body is acted upon at the ſame time by two Forces, that are to each other as the ſides of a parallelogram, A B and A C, and act in the directions of thoſe ſides, it will deſcribe the diagonal in the ſame time in which it would be made to deſcribe the reſpective ſides by each of theſe Forces ſeparately. Therefore the velocity wherewith the Body moves along the diagonal, is to the velocity where-

with

with it would move along the ſides, when acted upon by each Force ſingly, as the diagonal to each ſide reſpectively. And ſince the Force which gives an impulſe to a Body is proportional to the velocity with which it makes the Body move, we may ſay that the Force by which the Body is impelled along the diagonal, is to either of the impelling Forces, as the diagonal is to the ſide in the direction of which that Force acts; and therefore, it will be to the ſum of the impelling Forces, as the diagonal to the ſum of the ſides.

As the line A D may be made the diagonal of numberleſs parallelograms, a Body may be made to move along the line A D by numberleſs pairs of Forces acting in the directions of the ſides of thoſe parallelograms, and proportional thereunto. So that the Force of a Body moving along the line A D may be conſidered as compounded of, or produced by, two Forces acting in any oblique directions, ſuch as A B and A C, or A E and A F, ſince the very ſame Motion would ariſe from ſuch a compoſition. And

consequently the Force of a Body moving in the line A D may be resolved into two Forces acting in those oblique directions. From this composition and resolution of Forces or Motions, we may deduce the following Theorem, which is of great use in Mechanics, for determining the effects of Forces acting against each other in oblique directions.

If three Forces or Powers, acting on a Body in oblique directions, be to each other respectively as the sides of a triangle, drawn parallel to their directions, those Powers will balance one another and keep the Body at rest.

Let three Powers, drawing the Body A (fig. 4.) in the directions A B, A C, and A G, be to one another as the sides of the triangle A B D, which are respectively parallel to their directions, they will balance each other, and the Body will remain unmoved. For taking A C equal to B D, let the parallelogram A B D C be completed; then, from what was said of the composition of Forces, the Powers which draw the Body A in the directions

of

of the sides A B and A C, will, by their joint action, urge that Body from A towards D, in the direction of A D, with a Force which is to that of either of these Powers, as A D to either of the sides, respectively; but the body is drawn in the opposite direction from A towards G, by the third Power, whose Force, by the supposition, is to that of either of the other Powers, as the line A D is to A B or A C respectively; therefore the Force of this third Power is equal to the joint action of the other two Powers; consequently the three Powers must balance each other, and the Body A, being drawn equally in opposite directions, will remain unmoved. In the same manner we may prove that the joint Force of any two of these Powers act in a direction opposite to that of the third, and is equal thereunto; and therefore any three Powers which are to one another as the sides of a triangle, and act in directions parallel to these sides, will destroy each other's effect, and remain in Æquilibrio. And from hence it follows, that when three Powers, acting

against each other in oblique directions, are in Æquilibrio, they will be to each other as the sides of a triangle, which are respectively parallel to their lines of direction.

To confirm this by an Experiment: Let the sides of a triangle A B D, drawn on an horizontal Plane, be as two, three, and four; and let A C be parallel to the sides B D, and let D A be continued towards G; let then three small cords be tied together at A, and stretched over three pulleys at the points G, H, and L, so that one cord may cover the line A G, another the line A B, and the third the line A C; this being done, if a weight of four ounces be hung to the cord which covers A G, and one of three ounces to that which covers A B, and one of two ounces to that which covers A C, these three weights, which are to one another as the sides of the triangle that are parallel to their lines of direction, will continue in Æquilibrio.

The third Law of Motion, which arises from the Inertness of Matter, is, that reaction

action is always equal to action, and in a direction contrary thereto; or, that whatever Motion one Body can by its action produce in another, the ſame Motion will be produced in it by the reaction of that other, and in a contrary direction.

In my Lecture on Gravity, I obſerved, that it has been demonſtrated that each of the Planets gravitates towards the Sun, and the Sun towards each of them with a reciprocal and equal Force. The ſame equality of Attraction obtains likewiſe between the Loadſtone and Iron; for if a Loadſtone and a piece of Iron be ſet on two pieces of Cork, and made to float on water near each other, they will come together with equal quantities of Motion; that is, if their weights are equal, they will approach with equal velocities, or if the weight of the Loadſtone be double that of the Iron, the velocity of the Iron will be double that of the Loadſtone, ſo that the attractions between thoſe Bodies are equal and reciprocal. When two light Bodies are ſuſpended near each other, if one be electrified and the other

not, they will equally and mutally attract each other, and come together.

If a man, placed in a boat, draws another boat by means of a rope, the one wherein the man is placed will be equally drawn with the other, and the two boats will come together with equal quantities of Motion. So that if they are of the ſame weight, ſize, and ſhape, they will move with equal velocities; but if one boat be in weight double the other, it will move with only half the velocity of the other, and they will ſtill approach each other with equal quantities of Motion. This will appear by the following Experiment.

Let a cord be made faſt to one end of a ſmall boat, and let it paſs over a pulley fixed to the end of another ſmall boat of the ſame ſize and ſhape, and let a weight be tied to the end of the cord, and hang in the water, then let the boats be placed at ſuch a diſtance, as that the cord may be ſtretched; when the boats are let go, the weight will deſcend, and thereby draw the boat to whoſe end the cord is faſtened towards the other, and at the ſame time

time the other will move towards it. And the quantities of Motion in both boats will be equal, for their velocities will be equal when their weights are so; and when their weights are unequal, their velocities will be inversely as their weights; for when they meet, the Spaces they have described will be found to be in that proportion.

As Action and Reaction are equal in all attractions, so are they likewise equal in respect to strokes or impulses made by Bodies one upon another; for the Force of two Bodies, striking each other, affects equally the Motion of both, and produces equal changes therein towards contrary Parts; so that when one Body strikes against another and communicates Motion to it in a certain direction, just so much Motion does the striking Body lose in that direction, or just so much Motion is there communicated to it in the contrary direction. I shall therefore confirm this third Law of Motion, by shewing that what I have now said, holds true in all cases, from Experiments made by the

collision of Bodies both non-elastic and elastic: but first I must lay before you the method of making these Experiments.

THE Bodies that are to strike each other must be formed into Spheres; and then suspended from two pins by threads of an equal length, and in such a manner, as that, when they hang freely, they may just touch one another, and that their centres and point of Contact may lie in a right line parallel to the Horizon. Now, that you may understand the manner of estimating the velocities with which these Bodies are made to strike each other, I must lay down some things concerning the Motion of Bodies thro' the arches of Circles, the truth of which shall be demonstrated when I come to treat of Pendulums.

AND first, all the arches of a Circle, provided they be not large, are described in equal times by pendulous Bodies descending along them; and therefore if two pendulous Bodies be let fall at the same time, one from C and the other from E, in the periphery of a Circle whose radius

radius is A B (fig. 5.) they will both arrive at the lowest point B at the same time; and the stroke of the subsequent Body upon the preceding will be made at B: and for the same reason if one be let fall from C or E, and the other from D or F, they will meet and strike one another at B.

SECONDLY; the velocity which a Body acquires in falling thro' the arch of a Circle, is as the cord of the arch; that is, the velocity of a Body which has fallen from C to B, is to the velocity of a Body that has fallen from E to B, as the cord C B to the cord E B. And here I must observe to you, that when, in the following Experiments, I speak of a Body falling from, or rising to any height, as four, six, or ten inches, I mean it of a Body's falling thro', or moving up, an arch whose cord is of such a length.

THIRDLY; the velocity wherewith a Body begins to rise up thro' the arch of a circle, is as the cord of the arch

which the Body deſcribes in its aſcent. Thus the velocity wherewith a Body begins to move from the point B towards D, if it aſcends as high as D, is as the cord B D; but if it riſes only to F, the velocity is as the cord B F: ſo that in the Experiments the cords of the arches, through which the Bodies deſcend, expreſs the velocities of the Bodies in the point B, at the time of the ſtroke; and the cords of the arches, thro' which the Bodies aſcend after the ſtroke, expreſs the velocities of the Bodies immediately after the ſtroke.

THESE things being premiſed, I now proceed to the Experiments made firſt with Bodies that are non-elaſtic, that is, ſoft Bodies whoſe parts yield to a ſmall Force, and, when compelled to change their ſhape, do not again return to it.

LET two equal balls of ſoft clay or putty be ſuſpended in the manner above-mentioned, and while one of them continues at reſt, let the other fall upon it from the height of ſix inches; ſince the Bodies

Bodies are void of elasticity, they will not separate after the stroke, but both together ascend with a common velocity to the height of three inches. Therefore the common velocity of both Bodies, after the stroke, is but half the velocity which the striking Body had before the stroke, and consequently, since the Bodies are equal, each of them will have half the quantity of Motion which the striking Body had before the stroke; so that the striking Body has lost, by the stroke, half its quantity of Motion, and just so much has the quiescent Body gained.

Let now one of the equal balls fall from the height of nine inches, and the other from the height of three in a contrary direction; the Motions of those Bodies before the stroke are respectively nine and three, and their difference six; after the stroke they will ascend together in the direction of the striking, that is the strongest, Body, to the height of three inches; therefore the Motion of

each Body will then be three, and the ſum of their Motions ſix, which is the ſame with the difference of their Motions before the ſtroke; conſequently the ſtriking Body, whoſe Motion before was nine, has, by the ſtroke, loſt ſix; and the other Body, which is turned back with three parts of Motion, muſt have had a Motion as ſix communicated to it by the ſtroke, by one half of which its former Motion (which was three) is deſtroyed, and with the other half it moves in a direction contrary to its former one, ſo that the Motion loſt by the ſtriking Body is the ſame with that communicated to the other.

It is evident in all caſes, when the Bodies come together moving in oppoſite directions, that the difference of their Motions before the ſtroke will be the ſum of their Motions after it. For the ſtrongeſt Body muſt deſtroy the whole Motion of the weaker, and by the reaction of the weaker, it muſt loſe as much of its own Motion: therefore at the inſtant of the ſtroke

ſtroke there will remain only the difference of their Motions in the ſtriking Body, and with this it will move on in its former direction, carrying the weaker Body along with it.

If therefore the Bodies moving in oppoſite directions come together with equal quantities of Motion, they will upon the ſtroke loſe all their Motion, and continue at reſt. To prove which by an Experiment,

Let two equal balls of clay fall at the ſame time from equal heights, and in oppoſite directions; upon the ſtroke they will ceaſe to move. And the ſame thing will happen when the balls are unequal, provided the heights from which they fall are reciprocally proportional to their quantities of Matter, for then their quantities of Motion are equal; for inſtance, if the balls be as one and two; let the former fall from the height of ſix inches and the latter from the height of three in an oppoſite direction, and upon their meeting they will loſe all Motion; each Body communicating to the other a quantity of Motion equal to what that

other

other had before the ſtroke, and in an oppoſite direction; and therefore theſe Motions muſt neceſſarily deſtroy each other. From theſe experiments it appears, that whatever Motion one non-elaſtic Body communicates to another, ſo much does it loſe itſelf by the reaction of that other.

I AM now to ſhew that when two elaſtic Bodies ſtrike together, the Motion loſt by one will be equal to that communicated to the other. Bodies are ſaid to be elaſtic, whoſe parts yield and give way when preſſed, and reſtore themſelves again to their former ſituation when the preſſure is removed; and if the Force wherewith they reſtore themſelves be exactly equal to the Force whereby they are bent inwards, then the Bodies are ſaid to be perfectly elaſtic; and ſuch are all thoſe Bodies ſuppoſed to be, with which Experiments are made for confirming the theory relating to the coliſion of elaſtic Bodies. But, as there is not perhaps in nature any Body perfectly elaſtic, where the Experiments vary a little from the Theory, ſuch variation muſt be

aſcribed

aſcribed rather to the want of perfect Elaſticity in the Bodies, than to any error in the Theory itſelf.

If of two Bodies, perfectly elaſtic, one be at reſt and the other in Motion, or if they both move the ſame or contrary ways, ſo that they may ſtrike each other directly; the quantity of Motion which is acquired by one Body, will be equal to that which is loſt by the other.

For it appears, from what has been already ſaid, that the quantity of Motion communicated to one Body merely by the ſtroke, will be equal to that which the ſtriking Body loſes by the ſtroke when the Bodies are non-elaſtic; now I ſhall ſhew that theſe quantities of Motion will be juſt doubled by means of the Elaſticity, and conſequently they muſt ſtill be equal. Since the Bodies are ſuppoſed to be perfectly elaſtic, their parts, when bent inwards by the ſtroke, will reſtore themſelves to their former ſituation with a force equal to that which bends them in; but this Force is meaſured by the quantity of Motion, which the ſtriking Body communi-

cates

cates to the other; therefore, after the ſtroke, this elaſtic Force will throw the Bodies different ways, and each with a quantity of Motion equal to that which the ſtriking Body communicates to the other, which, added to the communicated Motion, will make that double, being in the ſame direction therewith, and which, ſubducted from the Motion of the ſtriking Body (as contrary thereto) will make the loſs double which is ſuſtained by the ſtroke. And therefore the whole Motion which one Body acquires will be equal to that which the other loſes; or, in other Words, the Force of the two Bodies ſtriking each other will equally affect the Motion of both, and produce equal changes therein towards contrary parts; ſo that the action of the ſtriking Body, and the re-action of the other upon it are equal in all caſes. What has been now proved will be confirmed by the following Experiments.

If two equal balls of ivory be ſuſpended, as were thoſe of clay, and be let fall from equal heights in oppoſite directions, they

they will be both reflected back by the ſtroke, and will riſe to almoſt the ſame height from which they fell. When the balls were void of elaſticity, after the ſtroke they continued at reſt, each having communicated its whole Motion to the other, which communicated Motion in each Body ſerved only to deſtroy its former Motion, being equal and in a contrary direction thereto; now it is plain that the balls will, merely by the ſtroke, communicate the ſame Motion to each other, whether they be elaſtic or not; and therefore, ſince the balls deſtroy each other's Motion by the ſtroke, and recover very nearly their whole Motions by means of their elaſticity, (each Body being thrown back with almoſt the ſame velocity it had before the ſtroke) we may conclude that the parts, when compreſſed by the ſtroke, reſtore themſelves with a Force nearly equal to the compreſſing Force, and which may therefore be meaſured by the Motion communicated.

Let a ball of ivory fall from any height, and ſtrike an equal ball at reſt; the ball which

which receives the ſtroke will aſcend to nearly the ſame height from which the other fell, and the other will remain at reſt; ſo that the ſtriking Body loſes its whole Motion, and the quieſcent Body acquires as much. In this caſe, when the Bodies were non-elaſtic, the ſtriking Body communicated only half its Motion to the quieſcent one, and loſt ſo much itſelf.

We ſee therefore, from theſe Experiments, that the Elaſticity of the Bodies, were it perfect, would double the quantities of Motion which are communicated and loſt merely by the ſtroke, and that it equally increaſes them both, tho' it is imperfect; and conſequently we may conclude, that whenever two Bodies, either non-elaſtic or elaſtic, ſtrike each other, the Force of the ſtroke will make equal changes in the Motions of each, or that equal quantities of Motion will be communicated to each in oppoſite directions; ſo that the ſum of their Motions, when they move the ſame way, or the Difference of their Motions, when they

they move contrary ways, taken in the direction of the ſtriking Body, will be the ſame after the ſtroke as it was before.

If, inſtead of one, there be two, three, or more quieſcent balls contiguous to each other, that which is fartheſt removed from the ſtriking ball will fly off with the velocity of the ſtriking ball, leaving it and all the intermediate balls at reſt. For as the ſtriking ball imparts all its Motion to the firſt of the quieſcent balls, ſo does that in like manner to the ball that lies next beyond it, and that again to the third, and ſo on, till the laſt ball, meeting no other to reſiſt it, flies off with all the Motion which the ſtriking ball had before the ſtroke.

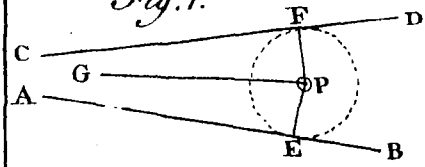
I shall add one Experiment more, by which we may ſee that an elaſtic Body, by ſtriking another, may communicate to it more Motion than it had itſelf. If an ivory ball falls from the height of nine inches, and ſtrikes another, at reſt, that has double its quantity of Matter;

after the ſtroke the ſmaller ball will be reflected back to the height of three inches, and the larger ball will riſe to the height of ſix inches, ſo that its velocity ſix multiplied into two, its quantity of Matter, gives twelve for its quantity of Motion after the ſtroke, which is three parts of Motion more than the ſtriking body had before the ſtroke. To account for this, we muſt conſider, that if the balls were non-elaſtic, the whole Motion of the ſtriking ball, which was nine, would after the ſtroke be divided between the balls, in proportion to their quantities of Matter, becauſe they would then move on together with a common velocity; therefore the larger ball would, merely by the ſtroke, acquire two thirds of the leſſer ball's Motion, that is, ſix, and ſo much would the leſſer ball loſe; ſince therefore, by means of the Elaſticity, the Motion communicated and loſt is doubled, the larger ball muſt acquire twelve parts of Motion, and therefore muſt riſe to the height of ſix inches; and the leſſer ball muſt loſe twelve parts of

of Motion, which is three more than it had before the ſtroke, therefore it will be reflected back to the height of three inches; for a Body is properly enough ſaid to loſe more Motion than it had in a certain direction, when its Motion is deſtroyed, and it is made to move in the contrary direction. Hence it follows, whenever a ſmaller elaſtic ball ſtrikes a larger one at reſt, that there will be an augmentation of Motion, and that the exceſs of Motion in the larger ball, above the Motion which the ſmaller has before the ſtroke, will be ever equal to the Motion wherewith the ſmaller ball is reflected back after the ſtroke, as is evident from what has been ſaid. If therefore Motion be communicated from a ſmaller elaſtic Body to a larger, by means of ſeveral intermediate Bodies, each larger than the other, the Motion will be augmented in each of them, and the Motion of the laſt will greatly exceed that of the firſt.

FROM the increaſe of Motion in elaſtic Bodies, a reaſon may be drawn for the

augmentation of ſound in ſpeaking-trumpets; for as the ſpeaking-trumpet is narroweſt at the mouth-piece, and thence widens and enlarges continually to the extremity, the Air within it, which is an elaſtic Fluid, may be conſidered as divided into a great number of cylindrical Bodies of very ſmall but equal altitudes, the baſis of the firſt being equal to the aperture of the trumpet, to which the mouth is applied, and the baſis of the reſt increaſing one above another as they are more and more removed from the mouth; upon which account the Motion, that is impreſſed by the Force of the Voice on the firſt cylindrical Body of Air, grows greater in the ſecond, and greater ſtill in the third, and ſo on, till at length, at the exit of the Tube, it becomes ſo great as to magnify the ſound very conſiderably.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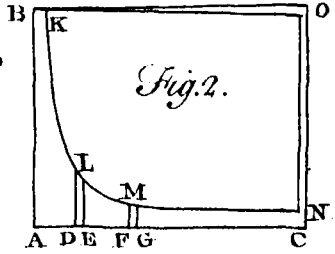
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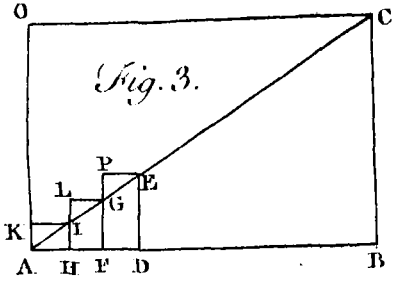
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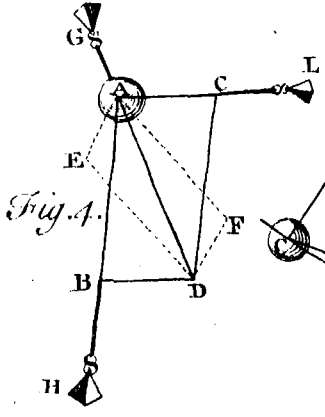
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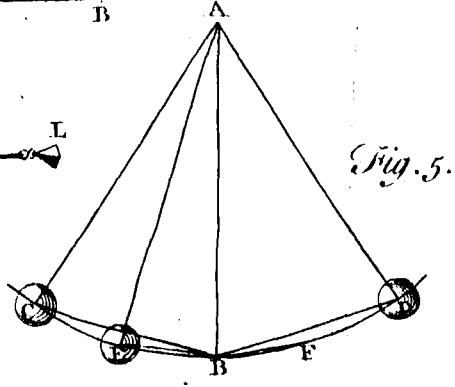
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