Title: Miscellanea Curiosa, Vol. 1

Contributor: M. de Fontenelle
Contributor: George Garden
Contributor: Clopton Havers
Contributor: Richard Mead
Contributor: Isaac Newton
Contributor: Royal Society
Contributor: John Wallis
Editor: Edmond Halley

Release date: August 27, 2015 [EBook #49791]

Language: English

Credits: Produced by Deaurider, Chris Pinfield and the Online
Distributed Proofreading Team at http://www.pgdp.net (This
file was produced from images generously made available
by The Internet Archive)

Transcriber's Note.

Apparent errors in mathematical expressions have been retained, although apparent typographical errors elsewhere in the text have been corrected. Inconsistencies in hyphenation have been retained.

The decimal point may be indicated by a "." or "," while illustrations are referred to as a "Plate" or a "Tab."

The frontispiece probably depicts Charles II.

The Table of Discourses has been amended to include one omitted title and to correct erroneous page numbers.

Fifth roots and "nth" roots are indicated by $\sqrt[5]{}$ and $\sqrt[n]{}$ respectively.

M: V^er Gucht Sculp:

Miscellanea Curiosa.

CONTAINING A

COLLECTION

Of some of the Principal

PHÆNOMENA

IN

NATURE

Accounted for by the Greatest Philosophers of this Age;

BEING THE

Most Valuable DISCOURSES, Read and Delivered to the ROYAL SOCIETY, for the Advancement of Physical and Mathematical Knowledge.

As also a Collection of Curious *Travels*, *Voyages*, *Antiquities*, and *Natural Histories* of Countries; Presented to the same *Society*.

In Three VOLUMES.

The Second Edition; To which is added, A Discourse of the *Influence* of the *Sun* and *Moon* on *Humane Bodies*, &c. By R. *MEAD*, M. D. F. R. S. And also *Fontenelle's Preface* of the *Usefulness* of *Mathematical Learning*.

VOL. I.

LONDON:

Printed by *F. M.* for *R. Smith*, at the *Bible* under the *Piazza* of the *Royal Exchange* in *Cornhill*. 1708.

TO THE

READER.

SOME of the Principal Discoveries and Enquiries, both in *Physical* and *Mathematical* Learning, being register'd in the Voluminous Journals of the *Royal Society*, are amongst a multitude of less useful Matters, so Obscurely hid, that but very few inquisitive Gentlemen ever so much as heard of them.

The Design therefore of the ensuing Collection, is to digest in a convenient Method, all the most curious *Philosophical* and *Mathematical* Discoveries, as they are to be met with, which may any way tend to the Use of Life or Advancement of Arts and Sciences.

And on this Occasion, it will be convenient to intimate to the Reader;

First, That the Theories and Discourses here collected, have already past the Censure of the *Learned World*: Who have acknowleg'd them the most satisfactory Accounts of Nature's Proceedings, wherein some of her greatest Depths are fathom'd, and a Foundation laid for Posterity to build an infinite *Superstructure*.

Secondly, That they are related (*Verbatim*) just as they were delivered in, or read before the *Royal Society*: For it has been the Opinion of the most Judicious among those *Honourable Members*, that it is impossible so to abridge them, (which are but Abridgments themselves) as not to render them obscure and unintelligible.

A Translation of Part of Monsieur Fontenelle's *Preface to the Memoirs of the Royal Academy at* Paris*, in the Year 1699. treating of the Usefulness of Mathematical Learning.*

BUT to what purpose should People become fond of the Mathematicks and Natural Philosophy. Of what use are the Transactions of the Academy? These are common Questions, which most do not barely propose as Questions; and it will not be improper to clear them.

People very readily call useless, what they do not understand. It is a sort of Revenge; and as the Mathematicks and Natural Philosophy are known but by few, they are generally look'd upon as useless. The reason of this is; because they are crabbed and not easily learnt.

We have a Moon to light us in the Night; What is it to us, say they, whether *Jupiter* hath four? Why so many laborious Observations, so many tedious Calculations to know exactly their Course? They'll not afford us the more Light for it; and Nature, which hath plac'd these little Planets without the reach of our Eyes, doth not seem to have made them for us. According to this plausible Argument they ought not to have been observ'd with a Telescope, nor study'd. But it is certain, that we had been considerable Loosers by it: For those who have some insight into the Principles of Geography and Navigation know, that since these four Moons about *Jupiter* have been discover'd, they have been more useful to those Sciences than our own Moon; and that they serve, and shall more and more serve to make new Sea-Charts, infinitely more exact than the Old; and are likely to save the Lives of a vast many Seamen. Did we reap no other advantage from Astronomy than this from these Satellites of *Jupiter*, that wou'd be sufficient to justifie those prodigious Calculations, those assiduous and nice Observations, this great number of elaborate Instruments, and this Noble Edifice built only for this Science. However the greatest part of Mankind know nothing of these Satellites of *Jupiter*, unless perhaps by hear-say, and that too confusedly; or else they are ignorant of what Affinity they have with Navigation, or of the great Improvements which have been lately made in it.

This is the Fate of Sciences, which are study'd and improv'd by few. Most People are not sensible of their Progress, and especially when made in some mean Callings. But what doth it signifie, that we can now more easily direct the Course of Rivers, cut out Canals, and settle new Navigations; because our Method of taking the Level and making Sluces is infinitely better than heretofore? Some Masons and Seamen have thereby found their Business easier, but they themselves were not sensible of the Skill of the Geometrician who directed them. They were mov'd, as the Body by a Soul, it doth not know. Others are yet less sensible of the Genius that presided over the Undertaking; and the World is the better for its succeeding well, but not altogether free from Ingratitude.

Anatomy, which is some time since so carefully study'd, can't become more exact, but Chyrurgical Operations must also be more sure. Surgeons know this; but those who receive the Benefit of their Art know nothing of it. And indeed how should they? They would be oblig'd to

compare Old with Modern Surgery; and this wou'd take too much Time, and go against the Grain: So that since the Operation hath succeeded well, they do not think it material to know whether it had succeeded as well in another Century.

It is strange that so many things are before our Eyes, and that we do not see them. Your Handycraft Shops are full of ingenious Works; but yet we hardly mind them: And very useful and well contriv'd Instruments and Experiments want Spectators, who wou'd be wonderfully pleas'd, wou'd they take the pains to admire them.

If a Learned Society have made some Improvements in Geometry, Anatomy, Mechanicks, or any other useful Science, it must not be expected, that the World will go back to so remote a Spring to thank and applaud them for the Usefulness of their Productions: For it will be more easie to enjoy the Benefit of their Discoveries and Improvements than to know them. The Determination of Longitude by the Satellites, the Discovery of the *Ductus Thoracicus*, a more convenient, and more exact Level, are not Novelties so fit to make a noise as a pleasant Poem, or a handsome Piece of Oratory.

Altho' the Usefulness of Mathematicks and Natural Philosophy is obscure, yet it is real. To consider Mankind in their Natural State, nothing is more useful to them, than what may preserve their Lives, and produce those Arts, which are both great Helps and Ornaments to Publick Societies.

As for what concerns the Preservation of Life, it peculiarly belongs to Physick; which for that reason is divided in the Academy into three Branches, which make three different sorts of Members of this Society, Anatomy, Chymistry, and Botanicks. Every Body knows of what Importance it is to have an exact Knowledge of Human Body, and of what Medicines may be extracted from Minerals and Plants.

As for Arts, too tedious to be reckon'd, they depend some upon Natural Philosophy, others upon Mathematicks.

One wou'd think at first, that if the Mathematicks were to be confin'd to what is useful in them, they ought only to be improv'd in those things, which have an immediate and sensible affinity with Arts, and the rest ought to be neglected as a Vain Theory. But this wou'd be a very wrong Notion. As for Instance, the Art of Navigation hath a necessary Connexion with Astronomy, and Astronomy can never be too much improv'd for the Benefit of Navigation. Astronomy cannot be without Opticks by reason of Perspective Glasses; and both, as all other Parts of Mathematicks, are grounded upon Geometry, and to go as far as you can, even upon Algebra.

Geometry, and especially Algebra, are the Keys of all the Inquiries, that can be made concerning Magnitude. These Sciences which are only conversant about abstruse Relations, and simple Ideas, may seem dry and barren, whilst they keep within the Verge of the Intellectual World; but mixt Mathematicks, which stoop to Matter, and consider the Motion of the Stars, the Augmentation of moving Forces, the different Passages of the Rays of Light through different Mediums; the different Effects of Sound by the Vibration of Things; to conclude all those Sciences, which discover the particular Relations of Sensible Magnitudes go on farther and more securely, when the Art of discovering Relations in General is more perfect. The Universal Instrument cannot be too extensive, too handy, or too easily apply'd: It is useful to all the Sciences, and they cannot be without it: And therefore among the Mathematicians of the Academy, who are design'd to be useful to the Publick, the Geometricians and Algebrists make a Class, as well as the Astronomers and Mechanicks.

However, it is certain, that Speculations purely of Geometry, or of Algebra, are not about useful things: But it is certain too, that those that are not, either lead or belong to those that are. It is in it self a very barren thing to know, that in a Parabola a Subtangant is double the corresponding Abscissæ; but yet it is a Degree of Knowledge necessary to the Art of throwing Bombs, so exactly as they can do now. There are not by far so many evident Uses as Propositions or Truths in the Mathematicks: Yet it is enough if the Concourse of several Truths is generally of some use.

Farther, a Geometrical Speculation, which was not at first applicable to any use, becomes so afterwards. When the greatest Geometricians in the Seventeenth Century set about to study a new Curve, which they call'd a Cycloide, they only engag'd themselves in a meer Speculation out of Vanity, striving to outdo one another by the Discovery of difficult Theorems. They did not even pretend that this was for the Publick Good; however by diving into the Nature of the Cycloide it was found, that it was destin'd to make Pendulums as perfect as may be, and carry the Measure of Time as far as it can go.

It is the same thing with Natural Philosophy as with Geometry. The Anatomy of Animals seems insignificant; and it only concerns us to know that of Human Body. But yet some Parts of it, which are of so nice, or so confus'd a Make, that they are invisible, are sensible and manifest in the Body of an Animal. Hence it is, that Monsters themselves are not to be neglected. The Mechanism conceal'd in a particular Kind or in a common Make, is unfolded in another kind, or in an extraordinary Make; and one wou'd be almost apt to say, that Nature by multiplying and varying so much her Works, can't sometimes forbear betraying her Secrets. All that the Antients

knew of the Load-stone, was, that it attracts Iron. But whether they did not value a Curiosity, which promis'd them nothing; or that their Genius did not lead them to make Experiments, they have not examin'd this Stone as carefully as they might. One Experiment taught them, that it turns of its self towards the Poles of the World, and did put into their Hands the inestimable Treasure of the Mariners Compass. They might easily have made this Discovery important, and yet they did not do it; and if they had spent a little more time upon a Curiosity which seem'd useless to them, the Latent use of it had soon appear'd.

Let us always make a Collection of Mathematical and Physical Truths; happen what it will we can't hazard much by it. It is certain, that they shall be drawn from Springs, whence a great many useful ones have already been drawn. We have reason to presume, that we shall draw from thence, some that shall shine as soon as they are discover'd, and convince us of their Usefulness. Other Truths shall stay some time till a piercing Meditation, or some happy Accident discovers their Use. Some Truths being consider'd by themselves shall be barren, till they are consider'd with reference to one another. Lastly, let the worse come to the worse, some shall be eternally useless.

I mean useless with reference to sensible and gross Uses; for otherwise they shall not be so. An Object upon which alone you cast your Eyes is the clearer and brighter, when the neighbouring Objects, which however you do not look upon, are also enlighten'd; because it hath the Benefit of the Rays, which are reflected from them. Thus those Discoveries, which are palpably useful, and deserve our chiefest Attention, are in some measure enlighten'd by those, which may be call'd useless. For all Truths make one another more lucid.

It is always useful to have right Notions, even of useless Subjects. And tho' we cou'd reap no benefit by the Knowledge of Numbers and Sines, yet it wou'd still be the only certain Knowledge granted to our Natural Light, and they wou'd serve to give our Reason the first Habit of and Inclination to Truth. They wou'd teach us to operate upon Truths; to take the Thread of them, which is generally very fine and almost imperceptible; and to follow it as far as it reaches: In a word, they wou'd make Truth so familiar, that we might on other Occasions know it at first sight, and almost by Instinct.

A Geometrical Genius is not so confin'd to Geometry, but that it may be capable of learning other Sciences. A Tract of Morality, Politicks, or Criticism, and even a Piece of Oratory, supposing the Author qualify'd otherwise for those Performances, shall be the better for being compos'd by a Geometrician. That Order, Perspicuity, *Precision* and Exactness, which some time since are found in good Books, may originally proceed from that Geometrical Genius, which is now more common than ever, and in some manner is communicated by one Relation to another, nay even to those that do not understand Geometry. Sometimes a Great Man draws all his Cotemporaries after him; and he who hath the justest Claim to the Glory of having settled a new Art of Arguing, was an Excellent Geometrician.

Lastly, whatever raises us to Great and Noble Reflexions, tho' they be purely Speculative, afford a Spiritual and Philosophical *Utility*. The Wants of the Mind are perhaps as many as those of the Body. She desires to extend her Knowledge: All that can be known, is necessary to her, and there can be no better Proof than this, that she is design'd for Truth. Nothing perhaps can redound more to her Glory, than the Pleasure that is felt sometimes, in spight of ones self, in the dry and crabbed Questions of Algebra.

But without running counter to the common Notions, and recurring to Advantages which may seem too far fetch'd and refin'd, it may fairly be own'd, that the Mathematicks and Natural Philosophy have some things which are only subservient to Curiosity; and so have those Sciences which are most generally acknowledg'd to be useful, as History, *&c.*

History doth not in every Part of it supply us with Examples of Vertue and Rules for our Behaviour. For besides these, therein you have a View of the perpetual Revolutions of Human Affairs, of the Beginning and Fall of Empires, of Manners, Customs, and Opinions which continually succeed one another; and in a word, of all that rapid, tho' insensible, Motion that carries all before it, and incessantly alters the Face of the Earth.

Had we a mind to oppose Curiosity to Curiosity, we shou'd find that instead of the Motion, which agitates Nations, and gives birth to, and destroys States; Natural Philosophy considers that Great and Universal Motion, which hath put the whole Frame of Nature in Order, and suspended the Cœlestial Bodies in several Spheres, and which illuminates and extinguishes some Stars; and by following always unalterable Laws, diversifies its effects *ad infinitum*. If the surprising difference of Manners and Opinions of Mankind is so entertaining; there is too a great deal of Pleasure to study the prodigious diversity of the Structure of the different Species of Animals, with reference to their different Functions, to the Elements they live in, to the Climates they inhabit, and the Aliments they are to take, *&c.* The most curious strokes of History shall hardly be more curious than the *Phosphorus*, the cold Liquors which being mixt together, break out into a flame; Silver Trees, the almost Magical Operations of the Load-Stone, and a vast number of Secrets, which Art hath discover'd by a near and diligent Scrutiny of Nature.

Lastly, Natural Philosophy doth as much as it is possible unravel the Footsteps of that Infinite Intellect and Wisdom, who hath made all things: Whereas the Object of History are the disorderly Effects of the Passion, and of Humane Caprices; and so odd a Series of Events, that some formerly fancy'd that a Blind and Senseless Deity had the Direction of them.

We must not look upon the Sublime Reflexions which Natural Philosophy leads us to make concerning the Author of the Universe, as meer Curiosities. For this stupendous Work, which appears always more wonderful the more we know it, gives us such exalted Notions of its Maker, that they fill our Minds with Admiration and Respect. But above all, Astronomy and Anatomy are the two Sciences which more palpably lay before us two grand Attributes of our Creator; one his Immensity by the distance, Magnitude and Number of Cœlestial Bodies; the other his Infinite Knowledge by the Mechanism of Animals. True Natural Philosophy is a kind of Theology.

The different views of Humane Understanding are almost infinite; and Nature is really so. So that we may every day expect some Discoveries, either in Mathematicks or Natural Philosophy, which shall be of a new sort of Utility or Curiosity. Make a Collection of all the different Advantages which the Mathematicks afforded a Hundred Years ago, and you'll find nothing to be compar'd to the Perspective Glasses they have furnish'd since that time, and which are a new Organ to the Sight, and cou'd not be expected from Art. How surpriz'd had the Ancients been, if they had been told that their Posterity, by the help of some Instruments, shou'd one day see a vast number of Objects which they did not see; a Heaven that was unknown to them; and Plants and Animals they did not even suspect it was possible to exist. Naturalists had already a great many curious Experiments; but within about half a Century, the Air-Pump hath produced a prodigious quantity of them wholly new, and which by shewing Bodies in a Space void of Air, shews them as transported in a World different from ours, where they undergo Alterations whereof we had no Notion. The Excellency of Geometrical Methods, which are every day invented and improv'd, may perhaps at last exhaust Geometry; that is, The Art of making Geometrical Discoveries, and that is all: Whereas Natural Philosophy, which contemplates an Object of an unlimited Variety, and *Fæcundity*, shall always find room for new Observations, and opportunities to increase its vast Stock, and shall have the Advantage of never being a compleat Science.

There are so many things to be discover'd, whereof a great part, in all likelyhood shall never be known; that they give an opportunity to those who will not encounter with the Thorns and Difficulties of Natural Philosophy, to affect a sort of Discouragement. A great many to vilify this Natural Science, pretend a mighty veneration for the works of Nature, and that they are absolutely incomprehensible. However, Nature is never so admirable, nor so admir'd as when known. True it is, that what is known is inconsiderable in comparison of what is not yet known. Nay, Sometimes what is not known, is exactly what seems shou'd be the soonest known. As for instance, it is not at least certainly known, why a Stone thrown up into the Air falls down again; but we certainly know the cause of the Rainbow, why it doth not exceed a certain height; why its breadth is always the same; why when there are two Rainbows at the same time, the Colours of the one are overset with reference to the Colours of the other; and yet the fall of a Stone in the Air appears a more simple Phænomenon, than the Rainbow. But in a word, altho' we do not know every thing, we are not neither ignorant of every thing. And altho' we are ignorant of the most simple Events, yet we have a knowledge of what seems the most Complex. So that if we have on the one hand reason to fear, lest our Vanity shou'd flatter us with the hopes of attaining to the knowledge of things above our reach; on the other we ought to dread, lest our Slothfulness should also flatter us that we are condemn'd to a greater degree of Ignorance than really we are.

People may think that the Sciences do not begin to exert themselves, either because they cou'd be but imperfect among the Ancients; or because we have almost lost the Footsteps of them during the gloomy Darkness of Barbarity; or because a better method hath been taken about 100 Years ago. Was the Progress Historically examin'd, they have already made in so short a time, notwithstanding the strong, but false Prejudices they had long to encounter with, even sometimes the foreign Obstacles they have met with from Authority and Power; the want of Zeal for Sciences so remote from common use, those few who apply'd themselves to this Work, and the weak Motives which engag'd them in it; a Man would wonder at the Greatness and Rapidity of the Progress of the Sciences, and even we might observe some new ones to start out of nothing, and perhaps be tempted to have too great hopes of future Improvements.

The greater reason we have of future Success, the greater we have to look upon the Sciences as in their Cradles, at least Natural Philosophy. And therefore the Academy is only now employ'd to make an ample Provision of Observations, and Facts well attested, which may one day be the foundation of a System. For before the Systematical Natural Philosophy can raise solid Edifices; Experimental Natural Philosophy must be in a condition to supply it with good Materials.

None but Societies, of those too countenanc'd and encourag'd by the Prince, can successfully make and prepare this Collection of Materials. All the Learning, Care, Life and Wealth of one Private Man can never answer this Design. There are too many different Experiments to be made, which are to be too much vary'd, and a long time prosecuted with the same Temper and Mind.

The Cause of the least Effect is so wrap'd up, that unless you very carefully open all the various Foldings, you cannot come at it.

Hitherto the Academy of Sciences hath consider'd Nature but by parcels: They have fix'd upon no general System, for fear of falling into the inconveniency of hasty Systems, which are very grateful to the impatience of Humane Understanding; and being once settled, are Obstacles to what Truths are afterwards discover'd. This day we are sure of a Fact, to morrow we shall be sure of another that hath no relation with the former. However some Conjectures are ventur'd at upon Causes; but they are only Conjectures. So that this Collection, which the Academy gives to the Publick, is compos'd of separate Fragments, independant of one another; whereof every one who is the Author, warrants the Facts and Experiments; and whose Arguments are approv'd by the Academy, but with Restrictions becoming Wise and Wary Scepticks.

Time perhaps will come, when these scatter'd Fragments shall be united into one regular Body; and if they be such as they are wish'd, they may of themselves Unite. A great many Truths, when their Numbers is considerable, shew so near a Relation to, and so mutual a Dependance upon one another, that it seems, that notwithstanding their violent Separation, they have a natural Tendency to be re-united.

A

TABLE

OF THE

Discourses contain'd in this *Volume*.

MISCELLANEA CURIOSA. {1}

An Estimate of the Quantity of the Vapours raised out of the Sea derived from Experiment: Together with an Account of the Circulation of the watry Vapours of the Sea, and of the Cause of Springs, presented to the Royal Society. By Mr. E. Halley, F. R. S.

THAT the Quantity of Aqueous Vapours contain'd in the Medium of the Air, is very considerable, seems most evident from the great Rains and Snows which are sometimes observ'd to fall, to that degree, that the Water thus discharg'd out of the Interstices of the Particles of Air, is in weight a very sensible part of the incumbent Atmosphere: But in what proportion these Vapours rise, which are the Sources not only of Rains, but also of Springs or Fountains (as I design to prove) has not, that I know of, been any where well examin'd, tho' it seem to be one of the most necessary Ingredients of a Real and Philosophical Meteorology, and, {2}
as such; to deserve the Consideration of this Honourable Society. I thought it might not be unacceptable to attempt by Experiment to determine the Quantity of the Evaporations of Water, as far as they arise from Heat, which upon Trial succeeded as follows.

We took a Pan of Water, about 4 inches deep, and 7 Inches $^{9}/_{10}$ Diameter, in which we placed a Thermometer, and by means of a Pan of Coals, we brought the Water to the same degree of Heat, which is observed to be that of the Air in our hottest Summer; the Thermometer nicely shewing it: This done, we affixed the Pan of Water, with the Thermometer in it, to one end of the Beam of a Pair of Scales, and exactly counterpois'd it with weights in the other Scale; and by the application or removal of the Pan of Coals, we found it very easie to maintain the Water in the same degree of Heat precisely. Doing thus we found the weight of the Water sensibly to decrease; and at the end of two hours we observed that there wanted half an Ounce *Troy*, all but 7 grains, or 233 grains of Water, which in that time had gone off in Vapour; tho' one could hardly perceive it smoke, and the Water were not sensibly warm. This Quantity in so short a time seem'd very considerable, being little less than 6 ounces in 24 hours, from so small a Surface as a Circle of 8 inches Diameter. To reduce this Experiment to an exact Calculus, and determine the thickness of the Skin of Water that had so evaporated, I assume the Experiment alledg'd by Dr. *Edward Bernard* to have been made in the *Oxford* Society, *viz.* That the Cube-foot *English* of Water weighs exactly 76 Pounds *Troy*; this divided by 1728, the number of Inches in a Foot, will {3}
give 253⅓ grains, or ½ ounce 13⅓ grains for the weight of a Cube-inch of Water; wherefore the weight of 233 grains is $^{233}/_{253}$ or 35 Parts of 38 of a Cube-inch of Water. Now the Area of the Circle whose Diameter is $7^{9}/_{10}$ Inches, is 49 square Inches: by which dividing the Quantity of Water evaporated, *viz.* $^{35}/_{38}$ of an Inch, the Quote $^{35}/_{1862}$ or $^{1}/_{53}$ shews that the thickness of the Water evaporated was the 53d part of an Inch; but we will suppose it only the 60th part, for the Facility of Calculation. If therefore Water as warm as the Air in Summer, exhales the thickness of a 60th part of an Inch in two hours from its whole Surface, in 12 hours it will exhale the ⅒ of an Inch; which Quantity will be found abundantly sufficient to serve for all the Rains, Springs, and Dews; and account for the *Caspian* Sea, being always at a stand, neither wasting nor overflowing; as likewise for the Current said to set always in at the Streights of *Gibralter*, tho' those Mediterranean Seas receive so many and so considerable Rivers.

To estimate the Quantity of Water arising in Vapours out of the Sea, I think I ought to consider it only for the time the Sun is up, for that the Dews return in the Night, as much if not more Vapours than are then emitted; and in Summer the Days being no longer than 12 hours, this

Excess is ballanc'd by the weaker Action of the Sun, especially when rising before the Water be warmed: So that if I allow ¹⁄₁₀ of an Inch of the Surface of the Sea, to be raised *per diem* in Vapours, it may not be an improbable Conjecture.

Upon this Supposition, every 10 square Inches of the Surface of the Water, yields in Vapour *per diem* a Cube-inch of Water; and each square Foot half a Wine-pint; every Space of 4 Foot square, a Gallon; a Mile square, 6914 Tons; a square Degree suppose of 69 *English* Miles, will evaporate 33 Millions of Tons: And if the Mediterranean be estimated at forty degrees long and four broad, allowances being made for the Places where it is broader, by those where it is narrower (and I am sure I guess at the least) there will be 160 Square degrees of Sea; and consequently, the whole Mediterranean must lose in Vapour, in a Summer's day, at least 5280 Millions of Tons. And this Quantity of Vapour, tho' very great, is as little as can be concluded from the Experiment produced: And yet there remains another Cause, which cannot be reduced to Rule, I mean the Winds, whereby the Surface of the Water is licked up some times faster than it exhales by the heat of the Sun; as is well known to those that have consider'd those drying Winds which blow sometimes. {4}

To estimate the Quantity of Water, the Mediterranean Sea receives from the Rivers that fall into it, is a very hard Task, unless one had the Opportunity to measure their Chanels and Velocity; and therefore we can only do it by allowing more than enough; that is, by assuming these Rivers greater than in all probability they be, and then comparing the Quantity of Water voided by the *Thames*, with that of those Rivers, whose Waters we desire to compute.

The Mediterranean receives these considerable Rivers; the *Iberus*, the *Rhone*, the *Tiber*, the *Po*, the *Danube*, the *Neister*, the *Borystenes*, the *Tanais*, and the *Nile*; all the rest being of no great Note, and their Quantity of Water inconsiderable: These nine Rivers, we will suppose each of them to bring down ten times as much Water as the River *Thames*; not that any of them is great in reality, but to comprehend with them all the small Rivulets that fall into the Sea, which otherwise I know not how to allow for. {5}

To calculate the Water of the *Thames*, I assume that at *Kingston* Bridge where the Flood never reaches, and the Water always runs down, the breadth of the Chanel is 100 Yards, and its Depth 3, it being reduced to an Equality (in both which Suppositions I am sure I take with the most) hence the Profil of the Water in this Place is 300 square Yards: This multiplied by 48 Miles (which I allow the Water to run in 24 hours, at 2 Miles an hour) or 84480 Yards, gives 25344000 Cubick-yards of Water to be evacuated every Day; that is, 20300000 Tons *per diem*; and I doubt not, but in the excess of my Measures of the Chanel of the River, I have made more than sufficient allowance for the Waters of the *Brent*, the *Wandel*, the *Lea*, and *Darwent*, which are all worth notice, that fall into the *Thames* below *Kingston*.

Now if each of the aforesaid 9 Rivers yield 10 times as much Water as the *Thames* doth, 'twill follow that each of them yields but 203 Millions of Ton *per diem*, and the whole 9, but 1827 Millions of Tons in a day; which is but little more than ⅓ of what is proved to be raised in vapour out of the Mediterranean in 12 hours time. Now what becomes of this Vapour when rais'd, and how it comes to pass that the Current always sets in at the Mouth, of the Streights of *Gibralter*, shall immediately be shew'd: But first it is necessary to advertise the Reader, that in making the Experiment herein mention'd, the Water used had been salted to the same degree as is the common Sea-water, by the Solution of about a 40th part of Salt. {6}

HAving thus shew'd by Experiment the Quantity of Water raised in Vapour from the Surface of the Sea in a Days time, which was so far approv'd of by some Honourable Members of this Society, that I receiv'd their Commands to prosecute these Enquiries; and particularly, in relation to the Method used by Nature, to return the said Vapours again into the Sea; which is so justly perform'd, that in many hundred of Years we are sufficiently assured that the Sea has not sensibly decreased by the loss in Vapour; nor yet abounded by the immense Quantity of fresh it receives continually from the Rivers. To demonstrate this Equilibre of Receipt and Expence in the whole Sea, is a Task too hard for me to undertake, yet in obedience to those whom I have the Honour to serve, I shall here offer, what to me has hitherto seem'd the most satisfactory Account of this grand *Phænomenon*: I have in another place attempted to explain the manner of the rising of Vapour by Warmth, by shewing, that if an Atom of Water were expanded into a Shell or Bubble, so as to be ten times as big in Diameter as when it was Water; such an Atom would become specifically lighter than Air, and rise so long as that *Flatus* or warm Spirit that first separated it from the Mass of Water, shall continue to distend it to the same Degree; and that Warmth declining, and the Air growing cooler and also specifically lighter, the Vapours consequently shall stop at a certain Region of the Air, or else descend, which may happen upon several accounts, as I shall by and by endeavour to make out; yet I undertake not that this is the only principal of the rise of Vapours, and that there may not be a certain sort of Matter, whose *Conatus* may be contrary to that of Gravity; as is evident in Vegetation, where in the Tendency of the Sprouts is directly upwards, or against the Perpendicular. But what ever is the true Cause, it is in Fact certain, that warmth does separate the Particles of Water, and emit them with a greater {7}

and greater Velocity, as the heat is more and more intense; as is evident in the Steam of a boiling Cauldron, wherein likewise the Velocity of the ascent of the Vapours does visibly decrease till they disappear, being dispersed into and assimulated with the Ambient Air. Vapours being thus raised by warmth, let us for a first Supposition put, that the whole Surface of the Globe were all Water very deep, or rather that the whole Body of the Earth were Water, and that the Sun had its diurnal course about it: I take it, that it would follow, that the Air of it self would imbibe a certain Quantity of aqueous Vapours, and retain them like Salts dissolved in Water; that the Sun warming the Air, and raising a more plentiful Vapour from the Water in the day-time, the Air would sustain a greater proportion of Vapour, as warm Water will hold more dissolved Salts, which upon the absence of the Sun in the Nights would be all again discharged in Dews, analogous to the Precipitation of Salts on the cooling of the Liquors; nor is it to be believed that {8}
in such Case there would be any diversity of Weather, other than periodically, every Year alike; the mixture of all terrestrious, saline, heterogenious Vapours being taken away, which as they are variously compounded and brought by the Winds, seem to be the Causes of those various Seasons which we now find. In this case the Aiery Regions every where, at the same height, would be equally replenished with the Proportion of Water it could contain, regard being only to be had to the different degree of warmth, from the nearness or distance of the Sun; and an eternal East-wind would blow all round the Globe, inclining only to the same side of the *East*, as the Latitude doth from the Equator; as is observed in the Ocean between the Tropicks.

Next let us suppose this Ocean interspersed with wide and spacious Tracts of Land, with high Ridges of Mountains, such as the *Pyrenean*, the *Alps*, the *Apennine*, the *Carpathian* in *Europe*, *Taurus*, *Caucasus*, *Imaus*, and several others in *Asia*; *Atlas* and the *Montes Lunæ*, with other unknown Ridges in *Africa*, whence came the *Nile*, the *Nigre*, and the *Zaire*: And in *America*, the *Andes* and the *Apalatean* Mountains; each of which far surpass the usual height to which the Aqueous Vapours of themselves ascend, and on the tops of which the Air is so cold and rarified, as to retain but a small part of those Vapours, that shall be brought thither by Winds. Those Vapours therefore that are raised copiously in the Sea, and by the Wind, are carried over the low Land to those Ridges of Mountains, are there compelled by the Stream of the Air to mount up with it to the tops of the Mountains, where the Water presently precipitates, gleeting down by the {9}
Crannies of the Stone; and part of the Vapour entering into the Caverns of the Hills, the Water thereof gathers as in an Alembick into the Basons of Stone it finds; which being once fill'd, all the overplus of Water that comes thither runs over by the lowest place, and breaking out by the sides of the Hills, forms single *Springs*. Many of these running down by the Valleys or Guts between the Ridges of the Hills, and coming to unite, form little Rivulets, or Brooks: Many of these again, meeting in one common Valley and gaining the plain Ground, being grown less rapid, become a River; and many of these being united in one common Channel, make such Streams as the *Rhine*, the *Rhone*, the *Danube*; which latter, one would hardly think the Collection of Water condensed out of Vapour, unless we consider how vast a Tract of Ground that River drains, and that it is the Sum of all those Springs which break out on the South side of the *Carpathian* Mountains, and on the North side of the immense Ridge of the *Alps*, which is one continued Chain of Mountains from *Switzerland*, to the *Black-Sea*. And it may almost pass for a Rule, that the magnitude of a River, or the quantity of Water it evacuates, is proportionable to the length and height of the Ridges from whence its Fountains arise. Now this Theory of *Springs* is not a bare *Hypothesis*, but founded on Experience, which it was my luck to gain in my abode at St. *Helena*, where in the Night-time, on the tops of the Hills, about 800 Yards above the Sea, there was so strange a condensation, or rather precipitation of the Vapours, that it was a great Impediment to my Cœlestial Observations; for in the clear Sky, the Dew would fall so fast, as to cover, each half {10}
quarter of an Hour, my Glasses with little drops; so that I was necessitated to wipe them so often, and my Paper on which I wrote my Observations would immediately be so wet with Dew, that it would not bear Ink: By which it may be suppos'd how fast the Water gathers in those mighty high Ridges I but now nam'd.

Thus is one part of the Vapours blown upon the Land return'd by the Rivers into the Sea, from whence they came; another part by the cool of the Night falls in Dews, or else in Rains, again into the Sea before it reaches the Land, which is by much the greatest part of the whole Vapours, because of the great extent of the Ocean, which the motion of the Wind does not traverse in a very long space of Time; and this is the Reason why the Rivers do not return so much into the *Mediterranean*, as is extracted into Vapour. A third part falls on the Low-Lands, and is the *Pabulum* of Plants, where yet it does not rest, but is again exhaled in Vapour by the action of the Sun, and is either carried by the Winds to the Sea to fall in Rain or Dew there, or else to the Mountains to be there turn'd into Springs; and tho' this does not immediately come to pass, yet after several Vicissitudes of rising in Vapour, and falling in Rain or Dews, each Particle of the Water is at length return'd to the Sea from whence it came. Add to this, that the Rain-waters after the Earth is fully sated with moisture, does, by the Vallies or lower parts of the Earth, find its way into the Rivers, and so is compendiously sent back to the Sea. After this manner is the Circulation perform'd, and I doubt not but this Hypothesis is more reasonable than that of those {11}
who derive all Springs from the Rain-waters, which yet are perpetual and without diminution, even when no Rain falls for a long space of time; or that derive them from a Filtration or

Percolation of the Sea-waters, thro' certain imaginary Tubes or Passages within the Earth wherein they lose their Saltness. This, besides many others, labouring under this principal Absurdity, that the greatest Rivers have their most copious Fountains farthest from the Sea, and whether so great quantities of fresh Water cannot reasonably be deriv'd any other way than in Vapour. This, if we may allow final Causes, seems to be the design of the Hills, that their Ridges being plac'd thro' the midst of the Continents, might serve, as it were, for Alembicks to distil fresh Water for the use of Man and Beast, and their heights to give a descent to those Streams to run gently, like so many Veins, of the *Macrocosm* to be the more beneficial to the Creation. If the difference between Rain and Dew, and the cause why sometimes 'tis Cloudy, at other times Serene, be inquir'd, I can offer nothing like a proper Solution thereof, only with submission to propose Conjectures, which are the best I can find, *viz.* That the Air being heaped up by the meeting of two contrary Winds, when the *Mercury* is high, the Vapours are the better sustain'd and kept from Co-agulating or Condensing into Drops, whereby Clouds are not so easily generated, and the Night the Vapours fall down single, as they rose in imperceptible Atoms of Water: Whereas, when the *Mercury* is low, And the Air rarified by the Exhaustion thereof, by two {12}
contrary Winds blowing from the place; the Atoms of Air keep the Vapours not so well separated, and they coalesce into visible Drops in the Clouds, and from thence are easily drawn into greater Drops of Rain; to which 'tis possible and not improbable, that some sort of Saline or Angular Particles of Terrestrial Vapour being immix'd with the Aqueous, which I take to be Bubbles, may cut or break their Skins or Coats, and so contribute to their more speedy Condensation into Rain.

{13}

The True Theory of the Tides, extracted from that admired Treatise of Mr. Isaac Newton*, Intitled,* Philosophiæ Naturalis Principia Mathematica*; Being a Discourse presented with that Book to the late King* James*, by Mr.* Edmund Halley*.*

IT *may, perhaps, seem strange, that this Paper, being no other than a particular Account of a Book long since published, should now appear here; but the Desires of several honourable Persons, which could not be withstood, have obliged us to insert it here, for the sake of such, who being less knowing in Mathematical Matters, and therefore not daring to adventure on the Author himself, are notwithstanding, very curious to be inform'd of the Causes of Things; particularly of so general and extraordinary* Phænomena*, as are those of the Tides. Now this Paper having been drawn up for the late King* James*'s Use, (in whose Reign the Book was publish'd) and having given good Satisfaction to those that got Copies of it; it is hoped the Savans of the higher Form will indulge us this Liberty we take to gratifie their Inferiours in point of Science; and not be offended, that we here insist more largely upon Mr.* Newton*'s* Theory of the Tides*, which, how plain and easie soever we find, is very little understood by the common Reader.*

THE sole Principle upon which this Author proceeds to explain most of the great and {14}
surprizing Appearances of Nature, is no other than that of *Gravity*, whereby in the Earth all Bodies have a tendency towards its Centre; as is most evident: And from undoubted Arguments it's proved, that there is such a Gravitation towards the Centre of the Sun, Moon, and all the Planets.

From this Principle, as a necessary Consequence, follows the Sphærical Figure of the Earth and Sea, and of all the other Cœlestial Bodies: And tho' the tenacity and firmness of the Solid Parts, support the Inequalities of the Land above the Level; yet the Fluids, pressing equally and easily yielding to each other, soon restore the *Æquilibrium*, if disturbed, and maintain the exact Figure of the Globe.

Now this force of Descent of Bodies towards the Centre, is not in all places alike, but is still less and less, as the distance from the Center encreases: And in this Book it is demonstrated, that this Force decreases as the Square of the distance increases; that is, the weight of Bodies, and the Force of their Fall is less, in parts more removed from the Center, in the proportion of the Squares of the Distance. So as for Example, a Ton weight on the Surface of the Earth, if it were raised to the height of 4000 Miles, which I suppose the Semidiameter of the Earth, would weigh but ¼ of a Ton, or 5 Hundred weight: If to 12000 Miles, or 3 Semidiameters from the Surface, that is 4 from the Center, it would weigh but $^1/_{16}$ part of the Weight on the Surface, or a Hundred and Quarter: So that it would be as easie for the Strength of a Man at that height to carry a Ton {15}
weight, as here on the Surface a 100¼. And in the same Proportion does the Velocities of the fall of Bodies decrease: For whereas on the Surface of the Earth all things fall 16 Foot in a second; at one Semidiameter above, this fall is but four Foot; and at three Semidiameters, or four from the Centre, it is but $^1/_{16}$ of the Fall at the Surface, or but one Foot in a second: And at greater Distances both Weight and Fall become very small, but yet at all given Distances is still some thing, tho' the Effect become insensible. At the distance of the Moon (which I will suppose 60 Semidiameters of the Earth) 3600 Pounds weigh but one Pound, and the fall of Bodies is but of

$^{1}/_{3600}$ a Foot in a second, or 16 Foot in a Minute; that is, a Body so far off descends in a Minute no more than the same at the Surface of the Earth would do in a Second of Time.

As was said before, the same force decreasing after the same manner is evidently found in the Sun, Moon, and all the Planets; but more especially in the Sun, whose Force is prodigious; becoming sensible even in the immense distance of *Saturn*: This gives room to suspect, that the force of Gravity is in the Cœlestial Globes proportional to the quantity of Matter in each of them: And the Sun being at least ten Thousand times as big as the Earth, its Gravitation or attracting Force, is found to be at least ten Thousand times as much as that of the Earth, acting on Bodies at the same distance.

This Law of the decrease of Gravity being demonstratively proved, and put past contradiction; the Author with great Sagacity, inquires into the necessary Consequences of this Supposition; {16}
whereby he finds the genuine Cause of the several Appearances in the Theory of the Moon and Planets, and discovers the hitherto unknown Laws of the Motion of Comets, and of the Ebbing and flowing of the Sea. Each of which are Subjects that have hitherto taken up much larger Volumes; but Truth being uniform, and always the same, it is admirable to observe how easily we are enabled to make out very abstruse *and difficult Matters*, when once true and genuine Principles are obtain'd: And on the other hand it may be wondred; that, notwithstanding the great facility of truth, and the perplexity and nonconsequences that always attend erroneous Suppositions, these great Discoveries should have escaped the acute Disquisitions of the best Philosophical Heads of all past Ages, and be reserv'd to these our Times. But that wonder will soon cease, if it be consider'd how great improvements Geometry has receiv'd in our Memory, and particularly from the profound Discoveries of our incomparable Author.

The Theory of the Motion of the primary *Planets* is here shewn to be nothing else, but the contemplation of the Curve Lines which Bodies cast with a given Velocity, in a given Direction, and at the same time drawn towards the Sun by its gravitating Power, would describe. Or, which is all one, that the Orbs of the Planets are such Curve Lines as a Shot from a Gun describes in the Air, being cast according to the direction of the Piece, but bent in a crooked Line by the supervening Tendency towards the Earths Centre: And the Planets being supposed to be projected with a given Force, and attracted towards the Sun, after the aforesaid manner, are {17}
here proved to describe such Figures, as answer punctually to all that the Industry of this and the last Age has observed in the Planetary Motions. So that it appears, that there is no need of solid Orbs and Intelligences, as the Antients imagin'd, nor yet of *Vortices* or Whirlpools of the Cœlestial Matter, as *Des Cartes* supposes; but the whole Affair is simply and mechanically performed, upon the sole Supposition of a Gravitation towards the Sun; which cannot be denied.

The Motion of *Comets* is here shewn to be compounded of the same Elements, and not to differ from Planets, but in their greater swiftness, whereby overpowering the Gravity that should hold them to the Sun, as it doth the Planets, they flie off again, and distance themselves from the Sun and Earth, so that they soon are out of our sight. And the imperfect Accounts and Observations Antiquity has left us, are not sufficient to determine whether the same Comet ever return again. But this Author has shewn how Geometrically to determine the Orb of a Comet from Observations, and to find his Distance from the Earth and Sun, which was never before done.

The third thing here done is the Theory of the Moon, all the Inequalities of whose Motion are proved to arise from the same Principles, only here the effect of two Centers operating on, or attracting a projected Body, comes to be considered; for the Moon, though principally attracted by the Earth, and moving round it, does together with the Earth, move round the Sun once a Year, and is, according as she is nearer or farther from the Sun, drawn by him more or less than the Center of the Earth, about which she moves; whence arise several Irregularities in her {18}
Motion, of all which, the Author in this Book, with no less Subtility than Industry, has given a full account. And though by reason of the great Complication of the Problem, he has not yet been able to make it purely Geometrical, 'tis to be hoped, that in some farther Essay he may surmount the difficulty: And having perfected the Theory of the Moon, the long desir'd Discovery of the Longitude (which at Sea is only practicable this way) may at length be brought to light, to the great Honour of your Majesty, and Advantage of your Subjects.

All the surprising Phænomena of the Flux and Reflux of the Sea, are in like manner shewn to proceed from the same Principle; which I design more largely to insist on, since the Matter of Fact is in this Case much better known to your Majesty than in the foregoing.

If the Earth were alone, that is to say, not affected by the Actions of the Sun and Moon, it is not to be doubted, but the Ocean, being equally press'd by the force of Gravity towards the Center, would continue in a perfect Stagnation, always at the same height, without either Ebbing or Flowing; but it being here demonstrated, that the Sun and Moon have a like Principle of Gravitation towards their Centers, and that the Earth is within the Activity of their Attractions, it will plainly follow, that the Equality of the pressure of Gravity towards the Center will thereby be disturb'd; and though the smallness of these Forces, in respect of the Gravitation towards the Earth's Center, renders them altogether imperceptible by any Experiments we can devise, yet the {19}

Ocean being fluid and yielding to the least force, by its rising shews where it is less press'd, and where it is more press'd by its sinking.

Now if we suppose the force of the Moon's Attaction to decrease as the Square of the Distance from its Center increases (as in the Earth and other Cœlestial Bodies) we shall find, that where the Moon is perpendicularly either above or below the Horizon, either in Zenith or Nadir, there the force of Gravity is most of all diminished, and consequently that there the Ocean must necessarily swell by the coming in of the Water from those parts where the Pressure is greatest, *viz.* in those places where the Moon is near the Horizon: But that this may be the better understood, I thought it needful to add the following Figure, (*Vide Fig. 1. Plate 1.*) where *M* is the Moon, *E* the Earth, *C* its Center, and *Z* the place where the Moon is in the Zenith, *N* where in the Nadir.

Now by the Hypothesis it is evident, that the Water in *Z*, being nearer, is more drawn by the Moon, than the Center of the Earth *C*, and that again more than the Water in *N*; wherefore the Water in *Z* hath a tendency towards the Moon, contrary to that of Gravity, being equal to the excess of the Gravitation in *Z*, above that in *C*: And in the other case, the Water in *N*, tending less towards the Moon than the Center *C*, will be less pressed, by as much as is the difference of the Gravitation towards the Moon in *C* and *N*. This rightly understood, it follows plainly, that the Sea, which otherwise would be Spherical, upon the Pressure of the Moon, must form it self into a Spheroidal or Oval Figure, whose longest Diameter is where the Moon is vertical, and shortest {20}
where she is in the Horizon; and that the Moon shifting her Position as she turns round the Earth once a Day, this Oval of Water shifts with her, occasioning thereby the two Floods and Ebbs observable in each 25 Hours.

And this may suffice, as to the general Cause of the Tides; it remains now to shew how naturally this Motion accounts for all the Particulars that have been observ'd about them; so that there can be no room left to doubt, but that this is the true cause thereof.

The Spring Tides upon the New and Full Moons, and Neap Tides on the Quarters, are occasion'd by the attractive Force of the Sun in the New and Full, conspiring with the Attraction of the Moon, and producing a Tide by their united Forces: Whereas in the Quarters, the Sun raises the Water where the Moon depresses it, and the contrary; so as the Tides are made only by the difference of their Attractions. That the force of the Sun is no greater in this Case, proceeds from the very small Proportion the Semi-diameter of the Earth bears to the vast distance of the Sun.

It is also observ'd, that *cæteris paribus*, the Æquinoctial Spring Tides in *March* and *September*, or near them, are the Highest, and the Neap Tides the lowest; which proceeds from the greater Agitations of the Waters, when the fluid *Spheroid* revolves about a great Circle of the Earth, than when it turns about in a lesser Circle; it being plain that if the Moon were constituted in the Pole, and there stood, that the *Spheroid* would have a fix'd Position, and that it would be always high Water under the Poles, and low Water every where under the Æquinoctial: And therefore the {21}
nearer the Moon approaches the Poles, the less is the agitation of the Ocean, which is of all the greatest, when the Moon is in the Æquinoctial, or farthest distant from the Poles. Whence the Sun and Moon, being either conjoined or opposite in the Æquinoctial, produce the greatest Spring Tides; and the subsequent Neap Tides, being produc'd by the Tropical Moon in the Quarters, are always the least Tides; whereas in *June* and *December*, the Spring Tides are made by the Tropical Sun and Moon, and therefore less vigorous; and the Neap Tides by the Æquinoctial Moon, which therefore are the stronger: Hence it happens, that the difference between the Spring and Neap Tides in these Months, is much less considerable than in *March* and *September*. And the reason why the very highest Spring Tides are found to be rather before the Vernal and after the Autumnal Equinox, *viz.* in *February* and *October*, than precisely upon them, is, because the Sun is nearer the Earth in the Winter Months, and so comes to have a greater effect in producing the Tides.

Hitherto we have consider'd such Affections of the Tides as are Universal, without relation to particular Cases; what follows from the differing Latitudes of places, will be easily understood by the following Fig. (*Vide Fig. 2. Plate 1.*)

Let *ApEP* be the Earth cover'd over with very deep Waters, *C* its Center, *P*, *p*, its Poles, *AE* the Æquinoctial, *F*, *f*, the parallel of Latitude of a Place, *D*, *d*, another Parallel at equal distance on the other side of the Æquinoctial, *H*, *h*, the two Points where the Moon is vertical, and let *K*, *k*, be the great Circle, wherein the Moon appears Horizontal. It is evident, that a Spheroid describ'd upon *Hh*, and *Kk*, shall nearly represent the Figure of the Sea, and *Cf*, *CD*, *CF*, *Cd*, shall be the {22}
heighths of the Sea in the places *f*, *D*, *F*, *d*, in all which it is High-water: And seeing that in twelve Hours time, by the diurnal Rotation of the Earth, the Point *F* is transferr'd to *f*, and *d* to *D*: The height of the Sea *CF* will be that of the High-water when the Moon is present, and *Cf* that of the other High-water, when the Moon is under the Earth: Which in the case of this Figure is less than the former *CF*. And in the opposite Parallel *Dd*, the contrary happens. The Rising of the Water being always alternately greater and less in each place, when it is produc'd by the Moon declining sensibly from the Æquinoctial; that being the greatest of the two High-waters in each

diurnal Revolution of the Moon, wherein she approaches nearest either to the Zenith or Nadir of the place: Whence it is, that the Moon in the Northern Signs, in this part of the World, makes the greatest Tides when above the Earth, and in Southern Signs, when under the Earth; the Effect being always the greatest where the Moon is farthest from the Horizon, either above or below it. And this alternate Increase and Decrease of the Tides has been observ'd to hold true on the Coast of *England*, at *Bristol* by Captain *Sturmy*, and at *Plymouth* by Mr. *Colepresse*.

But the Motions hitherto mentioned are somewhat alter'd by the Libration of the Water, whereby, though the Action of the *Luminaries* should cease, the Flux and Reflux of the Sea would for some time continue: This Conservation of the impress'd Motion diminishes the differences that otherwise would be between two consequent Tides, and is the reason why the highest {23}
Spring-Tides are not precisely on the New and Full Moons, nor the Neaps on the Quarters; but generally they are the third Tides after them, and sometimes later.

All these things would regularly come to pass, if the whole Earth were cover'd with Sea very deep; but by reason of the shoalness of some places, and the narrowness of the Streights, by which the Tides are in many cases propagated, there arises a great diversity in the Effect, and not to be accounted for, without an exact Knowledge of all the Circumstances of the Places, as of the Position of the Land, and the Breadth and Depth of the Channels by which the Tide flows; for a very slow and imperceptible Motion of the whole Body of the Water, where it is (for Example) 2 Miles deep, will suffice to raise its Surface 10 or 12 Feet in a Tides time; whereas, if the same quantity of Water were to be convey'd up a Channel of 40 Fathoms deep, it would require a very great Stream to effect it, in so large Inlets as are the Channel of *England*, and the *German* Ocean; whence the Tide is found to set strongest in those places where the Sea grows narrowest; the same quantity of Water being to pass through a smaller Passage: This is most evident in the *Streights*, between *Portland* and *Cape de Hague* in *Normandy*, where the Tide runs like a Sluce; and would be yet more between *Dover* and *Calais*, if the Tide coming about the Island from the North did not check it. And this force being once impress'd upon the Water, continues to carry it above the level of the ordinary height in the Ocean, particularly where the Water meets a direct Obstacle, as it is at St. *Malo's*; and where it enters into a long Channel, which running far into {24}
the Land, grows very streight at its Extremity; as it is in the *Severn-Sea* at *Chepstow* and *Bristol*.

This shoalness of the Sea, and the intercurrent Continents are the reason, that in the open Ocean the time of High water is not at the Moons appulse to the Meridian, but always some Hours after it; as it is observ'd upon all the West Coast of *Europe* and *Africa*, from *Ireland* to the *Cape of Good Hope*: In all which a S. W. Moon makes High-water, and the same is reported to be on the West side of *America*. But it would be endless to account all the particular Solutions, which are easie Corollaries of this *Hypothesis*; as why the *Lakes*, such as the *Caspian Sea*, and *Mediterranean Seas*, such as the *Black Sea*, the *Streights* and *Baltick*, have no sensible Tides: For *Lakes* having no Communication with the Ocean, can neither increase nor diminish their Water, whereby to rise and fall; and Seas that communicate by such narrow Inlets, and are of so immense an Extent, cannot in a few Hours time receive or empty Water enough to raise or sink their Surface any thing sensibly.

Lastly, to demonstrate the Excellency of this Doctrine, the Example of the Tides in the Port of *Tunking* in *China*, which are so extraordinary, and differing from all others we have yet heard of, may suffice. In this Port there is but one Flood and Ebb in 24 Hours; and twice in each Month, *viz.* when the Moon is near the Æquinoctial there is no Tide at all, but the Water is stagnant; but with the Moons Declination there begins a Tide, which is greatest when she is in the Tropical Signs: Only with this difference, that when the Moon is to the Northward of the Æquinoctial, it Flows when she is above the Earth, and Ebbs when she is under, so as to make High-water at {25}
Moons-setting, and Low-water at Moons-rising: But on the contrary, the Moon being to the Southward, makes High-water at rising, and Low-water at setting; it Ebbing all the time she is above the Horizon. As may be seen more at large in the *Philosophical Transactions*, Numb. 162.

The Cause of this odd Appearance is propos'd by Mr. *Newton*, to be from the concurrence of two Tides; the one propagated in six Hours out of the great *South-Sea* along the Coast of *China*; the other out of the *Indian-Sea*, from between the Islands in twelve Hours, along the Coast of *Malacca* and *Cambodia*. The one of these Tides, being produc'd in North Latitude, is, as has been said, greater, when the Moon being to the North of the Equator is above the Earth, and less when she is under the Earth. The other of them, which is propagated from the *Indian Sea*, being raised in South-Latitude, is greater when the Moon declining to the South, is above the Earth, and less when she is under the Earth: So that of these Tides alternately greater and lesser, there comes always successively two of the greater and two of the lesser together every Day; and the High-water falls always between the times of the arrival of the two greater Floods; and the Low-water between the arrival of the two lesser Floods. And the Moon coming to the Æquinoctial, and the alternate Floods becoming equal, the Tide ceases, and the Water stagnates: But when she has pass'd to the other side of the Equator, those Floods which in the former Order were the least, now becoming the greatest, that That before was the time of High-water, now becomes the Low-water, and the Converse. So that the whole appearance of these strange Tides, is without any {26}
forcing naturally deduc'd from these Principles, and is a great Argument of the Certainty of the

whole *Theory*.

{27}

A Theory of the Variation *of the* Magnetical Compass*. By Mr.* Ed. Halley*, Fellow of the Royal Society.*

THE Variation of the Compass (by which I mean the Deflection of the Magnetical Needle from the true Meridian) is of that great Concernment in the Art of Navigation, that the neglect thereof, does little less than render useless one of the noblest Inventions Mankind ever yet attained to. And for this cause all Ships of Consequence (especially those bound beyond the Equator) carry with them Instruments on purpose to observe this Variation: That so the Course steer'd by the Compass, may be reduc'd to the true Course in respect of the Meridian.

Now although the great utility that a perfect Knowledge of the Theory of the Magnetical Direction would afford to Mankind in general, and especially to those concern'd in Sea Affairs, seems as sufficient incitement to all Philosophical and Mathematical Heads, to take under serious Consideration the several *Phænomena*, and to endeavour to reconcile them by some general Rule: Yet so it is; that almost all the Authors, from whom a Discourse of this kind ought to have been expected, pass by in silence the Difficulties they here Encounter. And those that mention this Variation: By affirming it to proceed from Causes altogether uncertain (as are the casual lying of Iron Mines and Loadstones in the Earth) put a stop to all further Contemplation; and give {28}
discouragement to those that would otherwise undertake this Enquiry. 'Tis true, that not long since one Mr. *Bond*, an old Teacher of Navigation, put forth a small Treatise, wherein he pretends to calculate the Variation: But he limits his Hypothesis to the City of *London*, affirming himself (as he had a great deal of reason) that the same *Calculus* is not sufficient for other Places; whereby it appears that this Rule is far short of the so much desir'd general one.

Now although (through want of sufficient Observations, and some other Difficulties, which I shall anon shew) I cannot pretend perfectly to establish the Numbers and Rules of a *Calculus*, which shall precisely answer to the Variations of all parts of the World: Yet I suppose it will not be unacceptable to the Curious to propose something of a Light into this abstruse Mystery; which, if no other, may have this good Effect, to stir up the Philosophical *Genii* of the Age to apply themselves more attentively to this useful Speculation. But before I proceed, 'twill be necessary to lay down the Grounds upon which I raise my Conclusions; and at once to give a Synopsis of those Variations, which I have reason to look upon as sure, being mostly the Observations of Persons of good Skill and Integrity.

{29}

A TABLE OF VARIATIONS.

Names of Places.	*Longitude from Lon.*		*Latitude*		*Anno Dom.*	*Variation Observ'd.*	
	d	*m*	*d*	*m*		*d*	*m*
London	0	0	51	32 N	1580	11	15 E
					1622	6	0 E
					1634	4	5 E
					1672	2	30 W
Paris	2	25 E	48	51 N	1683	4	30 W
					1640	3	00 E
					1666	0	0
					1681	2	30 W
Uraniburg	13	0 E	55	54 N	1672	2	35 W
Copenhagen	12	53 E	55	41 N	1649	1	30 E
					1672	3	35 W
Dantzick	19	0 E	54	23 N	1679	7	00 W
Mompelier	4	0 E	43	37 N	1674	1	10 W
Brest	4	25 W	48	23 N	1680	1	45 W
Rome	13	0 E	41	50 N	1681	5	0 W
Bayonne	1	20 W	43	30 N	1680	1	20 W
Hudson's Bay	79	40 W	51	00 N	1668	19	15 W
In *Hud.* Straights	57	00 W	61	00 N	1668	29	30 W
In *Baffin's* Bay at Sir *Thomas Smith's* Sound	80	00 W	78	00 N	1616	57	00 W
At Sea	50	00 W	38	40 N	1682	7	30 W
At Sea	31	30 W	43	50 N	1682	5	30 W
At Sea	42	0 W	21	0 N	1678	0	40 E
Cape St. *Aug.* of *Brazile*	35	30 W	8	0 S	1670	5	30 E
Cape *Frio*	41	10 W	22	40 S	1670	12	10 E
At Sea off of the Mou. of the River *Plate*	53	00 W	39	30 S	1670	20	33 E
At the East Entrance of *Magellan* Straits	68	00 W	52	30 S	1670	17	00 E

{30}

At the W. Entrance of the *Magellan* Straits	75	00	W	53	00	S	1670	14	10	E
Baldivia	73	00	W	40	00	S	1670	8	10	E
At Cape d'*Agulbas*	16	30	E	34	50	S	1622	2	99	W
							1675	8	00	W
At Sea	1	0	E	34	30	S	1675	0	00	
At Sea	20	0	W	34	0	S	1675	10	30	E
At Sea	32	0	W	24	0	S	1675	10	30	E
At St. *Helena*	6	30	W	16	00	S	1677	0	40	E
At *Ascension*	14	30	W	7	50	S	1678	1	00	E
At *Johanna*	44	00	E	12	15	S	1675	19	30	W
At *Monbasa*	40	00	E	4	00	S	1675	16	00	W
At *Zocatra*	56	00	E	12	30	N	1674	17	00	W
At *Aden*, at the Mo. of the *Red Sea*	47	30	E	13	00	N	1674	15	00	W
At *Diego Roiz*	61	0	E	20	0	S	1676	20	30	W
At Sea	64	30	E	0	0		1676	15	30	W
At Sea	55	0	E	27	0	S	1676	24	00	W
At *Bombay*	72	30	E	19	0	N	1676	12	00	W
At Cape *Comorin*	76	00	E	8	15	N	1680	8	48	W
At *Ballafore*	87	00	E	21	30	N	1680	8	20	W
At Fort St. *George*	80	00	E	13	15	N	1680	8	10	W
At the W. Point of *Java*	104	00	E	6	40	S	1676	3	10	W
At Sea	58	00		39	0	S	1677	27	30	W
At the Isle of St. *Paul*	72	0	E	38	0	S	1677	23	30	W
At *Van Dimen's* Land	142	0	E	42	25	S	1642	0	0	
At *New Zealand*	170	0	E	40	50	S	1642	9	0	E
At *Three Kings Isle* in *New Zealand*.	169	30	E	34	35	S	1642	8	40	E
At the Isle *Rotterdam* in the South Sea	184	00	E	20	15	S	1642	6	20	E
On the Coast of *N. Guin.*	149	00	E	4	30	S	1643	8	45	E
At the W. P. of *N. Guin.*	126	00	E	0	26	S	1643	5	30	E

Tho' I could wish we could obtain from the *Spaniards* what Variations they find in their Voyages from the *Manilhas* towards *Acapulco*, through the North part of the South Sea; as likewise what it is at *Japan* from the *Dutch*: Yet (considering the number of these Observations I have collected, and that they are made in parts of the World so remote from *Europe*, and from one another) I suppose that the Theory that answers these will scarce fail in those Regions from whence we have as yet no account. But first we must make some Remarks upon the foregoing Table: And, First,

That in all *Europe* the Variation at this time is West, and more in the Eastern Parts thereof than the Western: As likewise, that it seems throughout to be upon the increase that way.

Secondly, That on the Coast of *America*, about *Virginia*, *New-England* and *New-Foundland*, the Variation is likewise Westerly; and that it increases all the way as you go Northerly along the Coast, so as to be above 20 Degrees at *New-Found-Land*, nearly 30 gr. in *Hudson's Straights*, and not less than 57 Degrees in *Baffin's Bay*; also, that as you Sail Eastward from this Coast, the {32} Variation diminishes. From these two it is a Legitimate Corollary: That *Somewhere between* Europe, *and the North part of* America, *there ought to be an Easterly Variation, or at least no Westerly*. And so I conjecture it is about the Eastermost of the *Tercera Islands*.

Thirdly, That on the Coast of *Brasile* there is East Variation, which increases very notably as you go to the Southward, so as to be 12 Degrees at *Cape Frio*, and over against the River of *Plate* 20½ Degrees: And from thence Sailing South-Westerly to the Straits of *Magellan* it decreases 17 Degrees, and at the West Entrance but 14 Degrees.

Fourthly, That at the Eastward of *Brasile*, properly so call'd, this Easterly Variation decreases, so as to be very little at St. *Helena* and *Ascension*, and to be quite gone, and the Compass Point true about 18 Degrees of Longitude West from the Cape of *Good-hope*.

Fifthly, That to the Eastward of the aforesaid Places a Westward Variation begins, which Reigns in the whole *Indian* Sea, and arises to no less than Eighteen Degrees under the Equator it self, about the Meridian of the Northern part of *Madagascar*; and near the same Meridian, but in 39 Degrees South Latitude it is found full 27½ Degrees: From thence Easterly the West Variation decreases, so as to be little more than eight Degrees at *Cape Comorin*, and than three Degrees upon the Coast of *Java*; and to be quite extinct about the *Molucca Islands*, as also a little to the Westwards of *Van Diemens* Land found out by the *Dutch* in 1642. {33}

Sixthly, That to the Eastward of the *Molucca's* and *Van Diemens* Land in South Latitude there arises another Easterly Variation, which seems not so great as the former, nor of so large Extent; for that at the Island *Rotterdam* it is sensibly less than upon the East Coast of *New Guinea*; and, at the rate it decreases, it may well be suppos'd, that about 20 Degrees farther East, or 225 Degrees East Longitude from *London*, in the Latitude of 20 Degrees South, a Westerly Variation begins.

Seventhly, That the Variations observ'd by the Honourable Sir *John Norborough* at *Baldivia*,

and at the West Entrance of the *Straights* of *Magellan* do plainly shew, that That East Variation, noted in our third Remark, is decreasing apace; and that it cannot reasonably extend many Degrees into the South Sea from the Coast of *Peru* and *Chili*, leaving room for a small Westerly Variation, in that Tract of the unknown World that lies in the mid-way between *Chili* and *New-Zealand*, and between *Hounds-Island* and *Peru*.

Eighthly, That in Sailing North-West from St. *Helena* by *Ascension*, as far as the Equator, the Variation continues very small East, and as it were constantly the same: So that in this part of the World the Course, wherein there is no Variation, is evidently no Meridian, but rather North-West.

Ninthly, That the Entrance of *Hudson's Straights*, and the Mouth of the River of *Plate*, being nearly under the same Meridian, at the one place the Needle varies 29½ Degrees to the *West*; at {34}
the other 20½ Degrees to the *East*. This plainly demonstrates the impossibility of reconciling these Variations by the Theory of *Bond*; *which is by two Magnetical Poles and an Axis, inclin'd to the Axis of the Earth*; from whence it would follow, That *under the same Meridian the Variation should be in all places the same way*.

These things being premised may serve as a sure Foundation to raise the Superstructure of a Theory upon. But first it would not be amiss to shew hereby the mistake of *Gilbert* and *Des Cartes*: The first whereof supposes, that *the Earth it self being in all its parts Magnetical, and the Water not; wheresoever the Land is, thither also should the Needle turn, as to the greater quantity of Magnetical Matter*. But this in many Instances is not true; but most remarkably upon the Coast of *Brazile*, where the Needle is so far from being attracted by the Land, that it turns the quite contrary way, leaving the Meridian to lye N b E, which is just along the Coast. As to the Position of *Des Cartes*, *that the Iron and Loadstones hid in the Bowels of the Earth and the Bottom of the Sea, may be the Causes that the Needle varies*; if we consider for how great a part of the Earths Surface, *ex. gr*. in the whole *Indian* Sea, the Needle declines the same way, and that regularly, 'twill follow that the attracting Substance that occasions it, must be very far distant. Now by Experience we find the little force that Iron Guns have upon the Compass in Ships (their Vertue, though they be Demiculverin, or greater Cannon, being not perceptible at four or five Yards distance) and the Experiments now before the *Royal Society* do plainly shew, how little a {35}
Magnetism there is in most crude Iron Oars: What quantity thereof must be then suppos'd to make so powerful a Diversion at two or three Thousand Miles distance? Yet I cannot deny that in some places near the Shoar, or in Shoal-Water, the Needle may be irregularly directed from the aforesaid Causes, and that not a little, as *Gassendus* gives a notable instance of the Island *Elba* in the Mediterranean Sea: But these differences from the general Direction are always signs of the nearness of those Magnetical Substances, for the Production whereof that Island *Elba* has been famous from all Antiquity. Besides, against both *Des Cartes* and *Gilbert*, the change of the Variation, which has been within these Hundred Years last past more than 15 gr. at *London*, is an entire Demonstration; tho' *Des Cartes* does not stick to say, that the transportation of Iron from place to place, and the growth of new Iron within the Earth, where there was none before, may be the cause thereof. The same holds likewise against the *Hypothesis* of *Magnetical Fibres*, which *Kircher* maintains.

Now to propose something that may answer the several appearances, and introduce nothing strange in Philosophy, after a great many close Thoughts, I can come to no other Conclusion than that, *The whole Globe of the Earth is one great Magnet, having four Magnetical Poles, or Points of Attraction, near each Pole of the Equator. Two; and that, in those parts of the World which lie near adjacent to any one of those Magnetical Poles, the Needle is govern'd thereby, the nearest Pole being always predominant over the more remote*. The parts of the Earth wherein these {36}
Magnetical *Poles* lie, cannot as yet be exactly determin'd for want of sufficient *Data* to proceed Geometrically; but, as near as Conjecture can reach, I reckon that the *Pole*, which is at present nearest to us, lies in or near the Meridian of the Lands-end of *England*, and not above seven Degrees from the Pole Arctick; by this *Pole* the Variations in all *Europe* and *Tartary*, and the *North Sea* are principally govern'd, though with regard to the other Northern Pole, whose situation is in a *Meridian* passing about the middle of *California*, and about 15 gr. from the North Pole of the World; to this the Needle has chiefly respect in all the North *America*, and in the two Oceans on either side thereof, from the *Azores* Westward to *Japan*, and farther. The two Southern Poles are rather farther distant from the South Pole of the World: The one about sixteen Degrees therefrom, is in a Meridian, some twenty Degrees to the Westward of *Magellan Straights*, or ninety five Degrees West from *London*: This commands the Needle in all the *South-America*, in the *Pacifick Sea*, and the greatest part of the *Ethiopick* Ocean. The Fourth and last *Pole* seems to have the greatest Power, and largest Dominions of all, as it is the most remote from the *Pole* of the World, being little less than 20 Degrees distant therefrom in the Meridian, which passes through *Hollandia Nova*, and the Island *Celebes* about one hundred and twenty Degrees East from *London*; this Pole is predominant in the South part of *Africa*, in *Arabia* and the *Red Sea*, in *Persia*, *India*, and its Islands, and all over the *Indian Sea*, from the Cape of *Good-Hope* Eastwards to the middle of the great South Sea, that divides *Asia* from *America*. This seems to be the {37}
present Disposition of the Magnetical Vertue throughout the whole Globe of the Earth; it remains

to shew how this Hypothesis makes out all the Variations that have been observ'd of late; and how it answers to our several Remarks drawn from the Table. And first it is plain, that (our *European* North *Pole* being in the Meridian of the Lands-end of *England*) all places more Easterly than that will have it on the West side of their Meridian, and consequently the Needle, respecting it with its Northern Point, will have a Westerly Variation, which will still be greater as you go to the Eastwards, till you come to some Meridian of *Russia*, where 'twill be greatest, and from thence decrease again. Thus at *Brest* the Variation is but 1¾ Degrees, at *London* 4½ Degrees; but at *Dantzick* seven Degrees West. To the Westward of the Meridian of the Lands-end, the Needle ought to have an Easterly Variation; were it not that (by approaching the *American* Northern *Pole*, which lies on the West side of the Meridian, and seems to be of greater force than this other) the Needle is drawn thereby Westwards, so as to counterballance the Direction given by the *European Pole*, and to make a small West Variation in the Meridian of the Lands-end it self. Yet I suppose that about the Meridian of the Isle *Tercera*, our nearest *Pole* may so far prevail as to give the Needle a little turn to the East, though but for a very small space: The Counterballance of those two *Poles* permitting no considerable Variation in all the Eastern Parts of the *Atlantick* Ocean; nor upon the West Coasts of *England* and *Ireland*, *France*, *Spain* and *Barbary*. But to the Westwards of the *Azores* the Power of the *American* Pole overcoming that of {38}
the *European*, the Needle has chiefly respect thereto, and turns still more and more towards it as you approach it. Whence it comes to pass, that on the Coast of *Virginia*, *New-England*, *New-found-Land*, and in *Hudson's-Straights* the Variation is Westward; that it decreases as you go from thence towards *Europe*, and that it is less in *Virginia* and *New-England*, than in *New-found-Land*, and *Hudson's-Straights*. This Westerly Variation again decreases, as you pass over the *North America*; and about the Meridian of the middle of *California* the Needle again points due North; and from thence Westward to *Yedzo* and *Japan*, I make no doubt but the Variation is Easterly, and half the Sea over no less than fifteen Degrees, if there be any truth in this Hypothesis of mine. Therefore I propose this as a Trial, that the whole may be scann'd thereby; and I conceive it will not be hard to know of the *Spaniards* how it is, who so frequently sail through that Ocean, in their return from the *Manilha* Isles. This East Variation extends over *Japan*, *Yedzo*, *East-Tartary*, and part of *China*, till it meet with the Westerly, which is govern'd by the *European* North Pole, and which I said was greatest some where in *Russia*.

Towards the Southern Pole the effect is much the same, only that here the South Point of the Needle is attracted. Hence it will follow, that the Variation on the Coast of *Brazile*, at the River of *Plate*, and so on to the Straights of *Magellan*, should be Easterly (as in our third Remark); if we suppose a Magnetical Pole situate about twenty Degrees more Westerly than the Straights of *Magellan*. And this Easterly Variation doth extend Eastward over the greatest part of the {39}
Ethiopick Sea, till it be counterpoised by the Vertue of the other Southern *Pole*; as it is about mid-way between the Cape of *Good-Hope*, and the Isles of *Tristan d' Acuntia*. From thence Eastwards, the *Asian* South Pole (as I must take the liberty to call it) becoming prevalent, and the South point of the Needle being attracted thereby, there arises a West Variation, very great in quantity and extent, because of the great distance of this Magnetical Pole of the World. Hence it is, that in all the *Indian* Sea as far as *Hollandia Nova*, and farther, there is constantly West Variation; at that under the Equator it self it arises to no less than eighteen Degrees, where 'tis most. About the Meridian of the Island *Celebes*, being likewise that of this Pole, this Westerly Variation ceases, and an Easterly begins; which reaches, according to my Hypothesis, to the middle of the *South-Sea*, between *Zelandia Nova*, and *Chili*, leaving room for a small *West Variation* govern'd by the *American* South Pole, which I shew'd to be in the *Pacifick Sea*, in the sixth and seventh Remark.

What I have now said, does plainly shew the sufficiency of this Hypothesis for solving the Variations that are at this time observ'd in the temperate and frigid *Zones*, where the Direction of the Needle chiefly depends upon the Counterpoise of the forces of two Magnetical Poles of the same Nature; and I suppose I have shewn how it comes to pass, that under the same Meridian the Variation should be in one place 29½ West, and another 20½ East; as I have noted in my ninth Remark.

In the *Torrid Zone*, and particularly under the Equinoctial, respect must be had to all four {40}
Poles, and their Positions well consider'd, otherwise it will not be easie to determine what the Variations shall be; the nearest *Pole* being always the strongest; yet not so, as not to be counterballanc'd sometimes by the united forces of two more remote; a notable Instance whereof is in our eighth Remark, where I took notice, that in sailing from St. *Helena* by the Isle of *Ascension*, to the Equator, on a N. W. Course, the Variation is very little Easterly, and in that whole Tract unalterable; for which I give this Reason, That the South *American* Pole (which is considerably the nearest in the aforesaid Places) requiring a great Easterly Variation, is counterpoised by the contrary Attraction of the *North-American* and the *Asian-South-Pole*; each whereof singly are in these Parts, weaker than the *American-South-Pole*; and upon the North West Course, the Distance from this latter is very little varied; and as you recede from the *Asian-South-Pole*, the Ballance is still preserv'd by the access towards the *North-American-Pole*. I mention not in this Case the *European-North-Pole*, its Meridian being little remov'd from those of

these places; and of it self requiring the same Variations we here find. After the same manner we might proceed to conclude the Variations in other places under and near the Equator; but I purposely leave it for an Exercise to the Thoughts of the serious Reader, who is desir'd to help his Imagination, by having before him a Map or Globe of the Earth: And to mark thereon the Magnetical *Poles* in the *Longitudes* and *Latitudes* I assign them. (*Vide Plate 2.*)

Thus, I hope, I have not lost my Pains and Study in this difficult Subject; believing that I have {41}
put it past doubt, *That there are in the Earth four such Magnetical Points or Poles, which occasion the great variety and seeming irregularity which is observed in the Variations of the Compass*. But to calculate exactly what it is, in any place assign'd, is what I dare not yet pretend to, though I could wish it were my happiness to be able to oblige the World with so useful a piece of Knowledge; there are Difficulties that occur, that render the thing as yet not feasible; for first there are a great many Observations requisite, which ought to be made at the same time; not at Sea, but ashore, with greater Care and Attention than the generality of Sailors apply. And besides, it remains undetermin'd in what proportion the attractive Power decreases, as you remove from the *Pole* of a Magnet, without which it were a vain attempt to go about to calculate. There is yet a further Difficulty, which is the Change of the Variation, one of the Discoveries of this last Century; which shews, that it will require some hundreds of Years to establish a compleat Doctrine of the Magnetical System. From the foregoing Table it should seem, that all the Magnetical *Poles* had a motion Westward: But if it be so, 'tis evident, that it is not a Rotation about the Axis of the Earth; for then the Variations would continue the same, in the same parallel of *Latitude* (the *Longitude* only chang'd) as much as is the motion of the Magnetical *Poles*, but the contrary is found by Experience; for there is no where in the Latitude of 15½ North between *England* and *America*, a Variation of eleven Degrees East at this time; as it was once here at {42}
London; it seems therefore, that our *European* Pole is grown nearer the Pole *Arctick* than it was heretofore, or else that it has lost part of its Vertue. But whether these Magnetical Poles move altogether with one motion, or with several; whether equally or unequally; whether Circular or Libratory: If Circular, about what Center; if Libratory, after what manner; are Secrets as yet utterly unknown to Mankind, and are reserv'd for the Industry of future Ages.

{43}

An Account of the Cause of the Change of the Variation of the Magnetical Needle, with an Hypothesis of the Structure of the Internal Parts of the Earth; as it was proposed to the Royal Society *in one of their late Meetings. By Mr.* Edmund Halley*.*

HAving in the precedent Discourse delivered a Theory of the Variation of the Magnetical Compass, wherein I did collect as many Observations as at that time I could procure, and having carefully compar'd them together, I came at length to this general conclusion, *That the Globe of the Earth might be supposed to be one great Magnet, having four Magnetical Poles or Points of Attraction, near each Pole of the Equator two; and that in those parts of the World which lie near adjacent to any one of those Magnetical Poles, the Needle is chiefly govern'd thereby; the nearest Pole being always predominant ever the more remote*. And I there have endeavour'd to state and limit the present Position of those Poles in the Surface of our Globe, which the Reader pleasing to consult, will save us the pains of repeating. But after all, tho' that Discourse was favourably receiv'd both at home and abroad, as seeming to render a tolerable account of the observ'd Variations, yet I found two Difficulties not easie to surmount; the one {44}
was, that no Magnet I had ever seen or heard of, had more than two opposite *Poles*, whereas the Earth had visibly four, and perhaps more. And secondly, it was plain that these *Poles* were not, at least all of them, fixt in the Earth, but shifted from place to place, as appear'd by the great Changes in the Needles Direction within this last Century of Years, not only at *London*, (where this great Discovery was first made) but almost all over the Globe of Earth; whereas it is not known or observ'd that the *Poles* of a Load-stone ever shifted their place in the Stone, nor (considering the compact hardness of that Substance) can it easily be suppos'd; though the Matter of Fact be too notorious and universal, not to be accounted for.

These Difficulties had wholly made me despond, and I had long since given over an Inquiry I had so little hopes of, when in accidental Discourse, and least expecting it, I stumbl'd on the following Hypothesis; in delivering whereof, if I shall seem to advance any thing that looks like Extravagant or Romantick, the Reader is desir'd to suspend his Censure, till he have consider'd the force and number of the many Arguments which concur to make good so new and so bold a Supposition.

Though it be sufficiently known and allow'd, that the Needles Variation changes, it will be necessary however to give a few Instances, whereby it may appear that this Change is gradual and universal, and the effect of a great and permanent motion: For which take the following Examples.

At *London*, in the Year 1580, the Variation was observ'd by Mr. *Burrows* to be 11° 15' East. In {45}
Anno 1622, the same was found by Mr. *Gunter* to be but 6° 0' East. In the Year 1634, Mr.

Gellibrand found it 4° 5' East. In 1657, Mr. *Bond* observ'd that there was no Variation at *London*. *Anno* 1672, my self observ'd it 2° 30' to the West; and in the Year 1692, I again found it 6° 00' West. So that in 112 Years the Direction of the Needle has chang'd no less than seventeen Degrees.

At *Paris*, *Orontius Finæus* about the Year 1550, did account it about eight or nine Degrees East Variation. *Anno* 1640, it was found three Degrees East. *Anno* 1660, there was no Variation there, and *Anno* 1681, I found it to be 2° 30' to the West.

At *Cape d' Agulhas*, the most Southerly Promontary of *Africa*, about the Year 1600, the Needle pointed due North and South without Variation, whence the *Portugueze* gave its name. *Anno* 1622, there was two Degrees West Variation. *Anno* 1675, it was 8° 50' West; and in the Year 1691, it was curiously observ'd not less than eleven Degrees West.

At St. *Helena*, about the Year 1600, the Needle declin'd eight Degrees to the East. *Anno* 1623, it was but 6° 0' East. *Anno* 1677, when I was there, I observ'd it accurately on Shoar to be 0° 40' East; and in 1692 it was found about 1° to the Westward of the North.

At *Cape Comorine* in *India*, in the Year 1620, there was 14° 20' West Variation. In the Year 1680, there was 8° 48', but now lately in the Year 1688, it was no more than 7° 30', so that here the Needle has return'd to the East about seven Degrees in seventy Years.

In all the other Examples the Needle has gradually mov'd towards the West, and the places are too far asunder to be influenc'd by the removal of any Magnetical Matter, which may by accident be transplac'd within the Bowels, or on the Surface of the Earth. If more Examples are desir'd, the Reader may be furnished with them in the *Portugueze Routier* of *Aleixo de Motta* (written about the Year 1600) and in the Voyage of *Beaulieu*, both publish'd in Mr. *Thevenot*'s first Collection of curious Voyages, Printed at *Paris*, *Anno* 1663; which he is to compare with the Journals of our late *East India* Voyagers, and I am assur'd, that it will be thereby evident, that the Direction of the Needle is in no place fix'd and constant, tho' in some it change faster than in others: And where for a long time it has continu'd as it were unalter'd, it is there to be understood, that the Needle has its greatest Deflection, and is become Stationary in order to return, like the Sun, in the Tropick. This, at present, is in the *Indian Sea*, about the Island *Mauritius*, where is the highest West Variation, and in a Tract tending from thence into the N. N. W. towards the *Red-Sea* and *Egypt*. And in all Places to the Westward of this Tract, all over *Africa* and the Seas adjoining, the West Variation will be found to have encreas'd; and to the Eastwards thereof as in the Example of *Cape Comorine*, to have decreased, *viz.* all over the *East-Indies*, and the Islands near it. {46}

After the like manner in that Space of East Variation, which, beginning near St. *Helena*, is found all over the South *America*, and which at present is highest about the Mouth of *Rio de la Plata*, it has been observ'd, that in the Eastern Parts thereof, the Variation of the Needle gradually decreases; but whether on the contrary it increases in those places which lie more Westerly than that Tract wherein the highest East Variation is found; or how it may be in the vast *Pacifick Sea*, we have not Experience enough to ascertain, only we may by Analogy infer, that both the East and West Variations therein do gradually increase and decrease after the same Rule. {47}

These *Phænomena* being well understood and duly consider'd, do sufficiently evince, That the whole Magnetical System is by one, or perhaps more motions translated, whether Eastwards or Westwards, I shall anon discuss; that this moving thing is very great, as extending its effects from Pole to Pole, and that the motion thereof is not *per saltum*, but a gradual and regular motion.

Now considering the Structure of our *Terraqueous* Globe, it cannot be well suppos'd that a very great part thereof can move within it, without notably changing its Center of Gravity and the Equilibre of its Parts, which would produce very wonderful Effects in changing the Axis of diurnal Rotation, and occasion strange alteration in the Seas Surface, by Inundations and Recesses thereof, such as History never yet mention'd. Besides, the solid parts of the Earth are not to be granted permeably by any other than fluid Substances, of which we know none that are any ways Magnetical. So that the only way to render this motion intelligible and possible, is to suppose it to turn about the Center of the Globe, having its Center of Gravity fix'd and immoveable in the same common Center of the Earth: And there is yet requir'd, that this moving internal Substance be loose and detached from the external Parts of the Earth whereon we live; for otherwise, were it affix'd thereto, the whole must necessarily move together. {48}

So then the External Parts of the Globe may well be reckon'd as the Shell, and the Internal as a *Nucleus* or inner Globe, included within ours, with a fluid Medium between, which having the same Common Center and Axis of diurnal Rotation, may turn about with our Earth each twenty four Hours; only this outer Sphere having its turbinating motion some small matter either swifter or slower than the internal Ball: And a very minute Difference in length of time, by many Repetitions becoming sensible, the Internal Parts will by degrees recede from the External, and not keeping pace with one another, will appear gradually to move either Eastwards or Westwards by the difference of their motions.

Now supposing such an Internal Sphere having such a motion, we shall solve the two great Difficulties we encounter'd in my former Hypothesis: For if this exteriour Shell of Earth be a Magnet, having its Poles at a distance from the Poles of diurnal Rotation; and if the Internal *Nucleus* be likewise a Magnet, having its Poles in two other places, distant also from the Axis; and these latter by a gradual and slow motion change their place in respect of the External; we may then give a reasonable account of the four Magnetical Poles I presume to have demonstrated before; as likewise of the Changes of the Needles Variations, which till now hath been unattempted.

The Period of this Motion being wonderful great, and there being hardly an hundred Years {49}
since these Variations have been duly observ'd, it will be very hard to bring this Hypothesis to a Calculus, especially since, though the Variations do increase and decrease regularly in the same place, yet in differing places, at no great distance, there are found such casual Changes thereof as can no ways be accounted for by a regular Hypothesis; as depending upon the unequal and irregular distribution of the Magnetical Matter within the Substance of the External Shell or Coat of the Earth, which deflect the Needle from the Position it would acquire from the effect of the general Magnetism of the whole. Of this the Variations at *London* and *Paris* give a notable Instance, for the Needle has been constantly about 1°½ more Easterly at *Paris* than at *London*; though it be certain that according to the general effect, the Difference ought to be the contrary way: Notwithstanding which, the Variations in both places do change alike.

Hence, and from some other of like Nature, I conclude, That the two Poles of the External Globe are fixt in the Earth, and that if the Needle were wholly govern'd by them, the Variations thereof would be always the same, with some little Irregularities upon the account I but just now mention'd: But the Internal Sphere having such a gradual translation of its Poles, does influence the Needle, and direct it variously, according to the result of the attractive or directive Power of each Pole; and consequently there must be a Period of the Revolution of this Internal Ball, after which the Variations will return again as before. But if it shall in future Ages be observ'd {50}
otherwise, we must then conclude that there are more of these Internal Spheres, and more Magnetical Poles than Four, which at present we have not a sufficient number of Observations to determine, and particularly in that vast *Mar del Zur*, which occupies so great a part of the whole Surface of the Earth.

If then two of the Poles be fixt and two moveable, it remains to ascertain which they are that keep their place; and though I could wish we had the Experience of another Century of Years to found our Conclusions upon, yet I think we may safely determine, That our *European North Pole* (which in the precedent Discourse I suppos'd near the Meridian of the Lands-end of *England*, and about seven Degrees therefrom) is that That is moveable of the two Northern Poles, and that That has chiefly influenc'd the Variations in these parts of the World: For in *Hudson*'s Bay, which is under the Direction of the *American* Pole, the Change is not observ'd to be near so fast as in these parts of *Europe*, though that Pole be much farther remov'd from the Axis.

As to the South Poles, I take the *Asian* Pole, which I place about the Meridian of the Island *Celebes* to be the fixt, and consequently the *American* Pole to move; from the like Observation of the slow Decrease of the Variation on the Coast of *Java*, and near the Meridian of the *Asian* Pole; though I must confess to have no account of the effects of the other beyond *Magellan*'s Streights.

If this be allow'd me, 'tis plain that the fixt Poles are the Poles of this External Shell or Cortex of the *Earth*, and the other two the Poles of a Magnetical *Nucleus* included and moveable within {51}
the other. It likewise follows, that this Motion is Westwards, and by consequence that the aforesaid *Nucleus* has not precisely attained the same degree of Velocity with the exteriour Parts in their diurnal Revolution; but so very nearly equals it, that in 365 Revolves the difference is scarce sensible. This I conceive to arise from the Impulse whereby this diurnal Motion was imprest on the Earth, being given to the External Parts, and from thence in time communicated to the Internal; but not so as perfectly to equal the Velocity of the first Motion impress'd on, and still conserv'd by the superficial Parts of the Globe.

As to the quantity of this Motion it is almost impossible to define it, both from the Nature of this kind of Observation, which cannot be very accurately perform'd, as also from the small time these Variations have been observ'd, and their Change discover'd. It appears by all Circumstances, that its Period is of many Centuries of Years, and as far as may be collected from the Change of the Place, where there was no Variation, by reason of the Equilibre of the two Southern Magnetical Poles, *viz.* from *Cape d' Agulhas* to the Meridian of St. *Helena* (which is about 23 *degr.* in about ninety Years) and of the place where the Westerly Variation is in its ἀκμὴ or greatest Deflection, being about half so much, *viz.* from the Isle of *Diego Roiz* to the South West Parts of *Madagascar*. We may with some Reason conjecture, that the *American* Pole has mov'd Westwards forty six Degrees in that time, and that the whole Period thereof is perform'd in seven hundred Years, or thereabouts; so that the nice Determination of this, and of several other Particulars in the {52}
Magnetick System is reserv'd for remote Posterity; all that we can hope to do, is to leave behind us Observations that may be confided in, and to propose an Hypothesis which after Ages may examine, amend or refute. Only here I must take leave to recommend to all Masters of Ships, and

all others, Lovers of Natural Truths, that they use their utmost Diligence to make, or procure to be made, Observations of these Variations in all parts of the World, as well in the North as South Latitude (after the laudable Custom of our *East India* Commanders) and that they please to communicate them to the *Royal Society*, in order to leave as compleat a History as may be to those that are hereafter to compare all together, and to compleat and perfect this abstruse Theory.

And by the way it will not be amiss to amend a receiv'd Error in the Practice of observing the Variation, which is, to take it by the Amplitude of the Rising and Setting Sun, when his Center appears in the visible Horizon; whereas he ought to be observ'd when his under Limb is still above the Horizon about ⅔ of his Diameter, or twenty Minutes, upon the score of the Refraction, and the height of the Eye of the Observer above the Surface of the Sea: Or else they are to work the Amplitudes as they do the Azimuth, reckoning the Suns Distance from the Zenith 90° 36': This, though it be of little consequence near the Æquinoctial, will make a great Error in high Latitudes, where the Sun rises and sets obliquely.

But to return to our Hypothesis, In order to explain the Change of the Variations, we have adventur'd to make the Earth hollow, and to place another Globe within it; and I doubt not but {53}
this will find Opposers enough. I know 'twill be Objected, That there is no Instance in Nature of the like thing; that if there was such a middle Globe it would not keep its place in the Center, but be apt to deviate therefrom, and might possibly chock against the Concave Shell, to the ruin, or at least endammaging thereof; That the Water of the Sea would perpetually leak through, unless we suppose the Cavity full of Water; That were it possible, yet it does not appear of what use such an inward Sphere can be of, being shut up in Eternal Darkness, and therefore unfit for the Production of Animals or Plants; with many more Objections, according to the Fate of all such new Propositions.

To these, and all other that I can foresee, I briefly Answer, That the Ring environing the Globe of *Saturn* is a notable Instance of this kind, as having the same common Center, and moving along with the Planet, without sensibly approaching him on one side more than the other. And if this Ring were turn'd on one of its Diameters, it would then describe such a Concave Sphere as I suppose our External one to be. And since the Ring, in any Position given, would, in the same manner, keep the Centre of *Saturn* in its own, it follows, that such a Concave Sphere may move with another included in it, having the same common Centre. Nor can it well be suppos'd otherwise, considering the Nature of Gravity; for should these Globes be adjusted once to the same common Centre, the Gravity of the parts of the Concave would press equally towards the Centre of the inner Ball, which equality must necessarily continue till some External Force {54}
disturb it, which is not easie to imagine in our Case. This perhaps I might more intelligibly express, by saying that the inner Globe being posited in the Centre of the Exteriour, must necessarily ascend which way soever it move; that is, it must overcome the force of Gravity pressing towards the common Centre, by an impulse it must receive from some outward Agent; but all outward Efforts being sufficiently fenc'd against by the Shell that surrounds it, it follows, that this *Nucleus* being once fixt in the common Centre, must always there remain.

As to the leaking of the Water through this Shell, when once a passage shall be found for it to run through, I must confess it is an Objection seemingly of weight; but when we consider how tightly great Beds of Chalk or Clay, and much more Stone do hold Water, and even Caves arch'd with Sand; no Man can doubt but the Wisdom of the Creator has provided for the Macrocosm by many more ways than I can either imagine or express, especially since we see the admirable and innumerable Contrivances wherewith each worthless Individual is furnish'd both to defend it self, and propagate its Species. What Curiosity in the Structure, what Accuracy in the Mixture and Composition of the parts, ought not we to expect in the Fabrick of this Globe, made to be the lasting Habitation of so many various Species of Animals, in each of which there want not many Instances that manifest the boundless Power and Goodness of their Divine Author; and can we then think it a hard Supposition, that the Internal Parts of this Bubble of Earth should be replete with such Saline and Vitriolick Particles as may contribute to Petrefaction, and dispose the {55}
transuding Water to shoot and coagulate into Stone, so as continually to fortifie, and, if need were, to consolidate any breach or flaw in the Concave Surface of the Shell.

And this perhaps may not without Reason be suppos'd to be the final Cause of the admixture of the Magnetical Matter in the Mass of the Terrestrial parts of our Globe, *viz.* To make good and maintain the Concave Arch of this Shell: For by what the Excellent Mr. *Newton* has shewn in his *Principia Philosophiæ*, it will follow, that according to the general Principle of Gravity, visible throughout the whole Universe, all those Particles that by length of time, or otherwise, shall moulder away, or become loose on the Concave Surface of the External Sphere, would fall in, and with great force descend on the Internal, unless those Particles were of another sort of Matter capable by their stronger tendency to each other, to suspend the force of Gravity; but we know no other Substances capable of supporting each other by their mutual Attraction but the Magnetical, and these we see miraculously to perform that Office, even where the Power of Gravity has its full effect, much more within the Globe where it is weaker. Why then may we not suppose these said Arches to be lin'd throughout with a Magnetical Matter, or rather to be one

great Concave Magnet, whose two Poles are the Poles we have before observ'd to be fixt in the Surface of our Globe.

Another Argument, favouring this Hypothesis, is drawn from a Proposition of the same Mr. *Newton*, where he determines the force wherewith the *Moon* moves the *Sea* in producing the {56}
Tides: His Words are, *Densitas Lunæ est ad densitatem Terra ut 680 ad 387 seu 9 ad 5 quamproximé. Est igitur corpus Lunæ densius ac magis terrestre quam Terra nostra*, p. 466. Now if the Moon be more solid than the Earth, as 9 to 5, why may we not reasonably suppose the Moon, being a small Body, and a secondary Planet, to be solid Earth, Water, Stone, and this Globe to consist of the same Materials, only four Ninths thereof to be Cavity, within and between the Internal Spheres; which I would render not improbable.

To those that shall enquire of what use these included Globes can be, it must be allow'd, that they can be of very little service to the Inhabitants of this outward World, nor can the Sun be serviceable to them, either with his Light or Heat. But since it is now taken for granted, that the Earth is one of the Planets, and they all are with Reason suppos'd Habitable, though we are not able to define by what sort of Animals; and since we see all the parts of the Creation abound with Animate Beings, as the Air with Birds and Flies, the Water with the numerous varieties of Fish, and the very Earth with Reptiles of so many sorts; all whose ways of Living would be to us incredible did not daily Experience teach us. Why then should we think it strange that the prodigious Mass of Matter, whereof this Globe does consist, should be capable of some other improvement than barely to serve to support its Surface? Why may not we rather suppose that the exceeding small quantity of solid Matter, in respect of the fluid Æther, is so dispos'd by the Almighty Wisdom, as to yield as great a Surface for the use of living Creatures, as can consist {57}
with the conveniency and security of the whole? We our selves, in Cities where we are pressed for Room, commonly build many Stories one over the other, and thereby accommodate a much greater multitude of Inhabitants.

But still it will be said, That without Light there can be no living, and therefore all this *apparatus* of our inward Globes must be useless: To this I Answer, That there are many ways of producing Light which we are wholly ignorant of; the Medium it self may be always luminous after the manner of our *Ignes fatui*. The Concave Arches may in several places shine with such a Substance as invests the Surface of the Sun; nor can we, without a boldness unbecoming a Philosopher, adventure to assert the impossibility of peculiar Luminaries below, of which we have no sort of *Idea*. I am sure the Poets *Virgil* and *Claudian* have gone before me in this Thought, inlightning their *Elysian Fields* with Sun and Stars proper to those infernal, or rather internal Regions. *Virg. Æneid. 6.*

Largior hic compos Æther & lumine vestit
Purpureo; Solemque suum sua Sidera norunt.

And *Claudian lib 2. De Raptu Proserpinæ.*

Amissum ne crede diem, sunt altera nobis
Sidera, sunt orbes alii, luménque videbis
Purius, Elysiumque magis mirabere Solem.

And though this be not to be esteem'd as an Argument, yet I may take the liberty I see others do, to quote the Poets when it makes for my purpose.

Lastly, To explain yet farther what I mean, I have adventur'd to adjoin the following Scheme, {58}
(*Tab. 1. Fig. 3*) wherein the Earth is represented by the outward Circle, and the three inward Circles are made nearly proportionable to the Magnitudes of the Planets *Venus*, *Mars* and *Mercury*, all which may be included within the Globe of Earth, and all the Arches more than sufficiently strong to bear their weight. The Concave of each Arch, which is shaded differently from the rest, I suppose to be made up of Magnetical Matter; and the whole to turn about the same common Axis *pp*, only with this difference, that the Outer Sphere still moves somewhat faster than the Inner. Thus the Diameter of the Earth being about eight thousand *English* Miles, I allow five hundred Miles for the thickness of its Shell, and another space of five hundred Miles for a Medium between, capable of an immense Atmosphere for the use of the Globe of *Venus*: *Venus* again I give a Shell of the same thickness, and leave as great a space between her Concave and *Mars*; so likewise from *Mars* to *Mercury*, which latter Ball we will suppose solid, and about two thousand Miles Diameter. Thus I have shew'd a possibility of a much more ample Creation, than has hitherto been imagin'd; and if this seem strange to those that are unacquainted with the Magnetical System, it is hop'd that all such will endeavour, first, to inform themselves of the Matter of Fact, and then try if they can find out a more simple Hypothesis, at least a less absurd, even in their own Opinions. And whereas I have adventur'd to make these Subterraneous Orbs capable of being Inhabited, 'twas done designedly for the sake of those who will be apt to ask *cui* {59}
bono, and with whom Arguments drawn from *Final Causes* prevail much. If this short Essay shall find a kind Acceptance, I shall be encourag'd to enquire farther, and to Polish this rough Draft of a Notion till hitherto not so much as started in the World, and of which we could have no Intimation from any other of the *Phænomena* of Nature.

Since this was written, a Discovery I have made in the Cœlestial Motions, seems to render a farther Account of the Use of the Cavity of the Earth, *viz.* To diminish the Specifick Gravity thereof, in respect of the Moon; for I think I can demonstrate that the Opposition of the Æther to the Motions of the Planets in long time becomes sensible; and consequently the greater Body must receive a less Opposition than the smaller, unless the Specifick Gravity of the smaller do proportionably exceed that of the greater, in which case only they can move together; so that the Cavity I assign in the Earth, may well serve to adjust its weight to that of the Moon, for otherwise the Earth would leave the Moon behind it, and she become another Primary Planet.

{61}

An Historical Account of the Trade Winds *and* Monsoons*, observable in the Seas between and near the* Tropicks*, with an attempt to assign the Physical Cause of the said Winds, by Mr.* Ed. Halley*.*

AN exact Relation of the constant and periodical Winds, observable in several Tracts of the Ocean, is a part of Natural History not less desireable and useful, than it is difficult to obtain, and its *Phænomena* hard to explicate: I am not ignorant that several Writers have undertaken this Subject, and although *Varenius* (*Lib. 1. Chap. 21. Geo. Gen.*) seems to have endeavour'd after the best information from *Voyagers*, yet cannot his Accounts be admitted for accurate, by those that shall attentively consider and compare them together, and some of them are most evident Mistakes; which, as near as I can, I shall attempt to rectify, having had the opportunity of conversing with Navigators, acquainted with all parts of *India*, and having liv'd a considerable time between the *Tropicks*, and there made my own Remarks.

The Substance of what I have collected is briefly as follows.

The Universal *Ocean* may most properly be divided into three Parts, *viz.* 1. The *Atlantick* and *Æthiopick-Sea*. 2. The *Indian Ocean*. 3. The Great *South Sea*, or the *Pacifick Ocean*; and though {62}
these Seas do all communicate by the South, yet as to our present purpose of the *Trade Winds*, they are sufficiently separated by the interposition of great Tracts of *Land*; the first lying between *Africa* and *America*, the second between *Africa* and the *Indian Islands*, and *Hollandia Nova*; and the last between the *Phillipine Isles*, *China*, *Japan* and *Hollandia Nova* on the *West*, and the Coast of *America* on the *East*. Now following this natural division of the Seas, so will we divide our History into three parts in the same order.

I. In the *Atlantick* and *Æthiopick* Seas between the *Tropicks*, there is a general *Easterly Wind* all the Year long, without any considerable Variation, excepting that it is subject to be deflected therefrom, some few Points of the Compass towards the *North* or *South*, according to the Position of the place. The Observations which have been made of these Deflections, are the following.

1. That near the Coast of *Africa*, as soon as you have pass'd the *Canary Isles*, you are sure to meet a fresh Gale of *North East* Wind, about the Latitude of 28 Degrees *North*, which seldom comes to the *Eastwards* of the *East North-East*, or passes the *North North-East*. This Wind accompanies those bound to the Southward, to the Latitude of ten North, and about a hundred Leagues from the *Guinea* Coast, where, till the fourth Degree of North Latitude, they fall into the Calms and Tornadoes; of which more hereafter.

2. That those bound to the *Caribbee Isles*, find, as they approach the *American* side, that the {63}
aforesaid *North-East* Wind becomes still more and more Easterly, so as sometimes to be *East*, sometimes *East* by *South*, but yet most commonly to the *Northward* of the *East* a Point or two, seldom more. 'Tis likewise observ'd, that the strength of these Winds does gradually decrease, as you sail to the *Westwards*.

3. That the limits of the Trade and variable Winds, in this Ocean, are farther extended on the *American* side than the *African*; for whereas you meet not with this certain Wind till after you have pass'd the Latitude of twenty eight Degrees on this side; on the *American* side it commonly holds to thirty, thirty one, or thirty two Degrees of Latitude; and this is verified likewise to the Southwards of the Æquinoctial, for near the *Cape* of *Good-Hope* the limits of the Trade Winds, are three or four Degrees nearer the Line, than on the Coast of *Brazile*.

4. That from the Latitude of four Degrees *North*, to the aforesaid Limits on the *South* of the Æquator, the Winds are generally and perpetually between the *South* and *East*, and most commonly between the *South-East* and *East*, observing always this Rule, That on the *African* side they are more *Southerly*, on the *Brazilian* more *Easterly*, so as to become almost due *East*, the little deflection they have being still to the *Southwards*. In this part of the Ocean it has been my fortune to pass a full Year, in an Employment that oblig'd me to regard more than ordinary the Weather, and I found the Winds constantly about the *South-East*, the most usual Point *S E b E*; when it was Easterly, it generally blew hard, and was gloomy, dark, and sometimes rainy {64}
Weather; if it came to the Southwards it was generally Serene, and a small Gale next to a Calm, but this not very common. But I never saw it to the Westwards of the South, or Northwards of the East.

5. That the Season of the Year has some small effect on these Trade Winds, for that when the Sun is considerable to the Northwards of the Æquator, the South-East Winds, especially in the Straight of this Ocean (if I may so call it) between *Brazile* and the Coast of *Guinea*, do vary a Point or two to the Southwards, and the North-East become more Easterly; and on the contrary, when the Sun is towards the Tropick of *Capricorn* the South-Easterly Winds become more Easterly, and the North-Easterly Winds on this side the Line veere more to the Northwards.

6. That as there is no general Rule that admits not of some Exception, so there is in this Ocean a Tract of Sea wherein the Southerly and South-West Winds are perpetual, *viz.* all along the Coast of *Guinea*, for above five hundred Leagues together, from *Sierra Leona* to the Isle of St. *Thomas*; for the South-East Trade Wind having pass'd the Line, and approaching the Coast of *Guinea* within eighty or 100 Leagues, inclines towards the Shore, and becomes S. S. E. and by Degrees, as you come nearer, it veeres about to South, S. S. W. and in with the Land South-West, and sometimes West South-West; which Variation is better express'd in the Mapp hereto annexed, (*Vide Plate 2*) than it can well be in Words. These are the Winds which are observ'd on this Coast when it blows true, but there are frequent Calms, violent sudden Gusts call'd {65}
Tornado's, from all Points of the Compass, and sometimes unwholsome foggy Easterly Winds, call'd *Hermitaa* by the Natives, which too often infest the Navigation of these parts.

7. That to the Northwards of the Line, between four and ten Degrees of Latitude, and between the Meridians of *Cape Virde*, and of the Eastermost Islands that bear that Name, there is a Tract of Sea wherein it were improper to say there is any Trade Wind, or yet a Variable; for it seems condemn'd to perpetual Calms, attended with terrible Thunder and Lightning, and Rains so frequent, that our Navigators from thence call this part of the Sea the *Rains*; the little Winds that are, be only some sudden uncertain Gusts, of very little Continuance and less Extent; so that sometimes each Hour you shall have a different Gale, which dies away into a Calm before another succeed, and in a Fleet of Ships in sight of one another, each shall have the Wind from a several Point of the Compass; with these weak *Breezes* Ships are oblig'd to make the best of their way to the Southward through the aforesaid six Degrees, wherein 'tis reported some have been detain'd whole Months for want of Wind.

From the three last Observables is shewn the Reason of two notable Occurents in the *East-India* and *Guinea* Navigations: The one is, why, notwithstanding the narrowest part of the Sea between *Guinea* and *Brazile* be about five hundred Leagues over, yet Ships bound to the Southward, sometimes, especially in the Months of *July* and *August*, find a great difficulty to pass it. This happens because of the South-East Winds, at that time of the Year commonly extending {66}
some Degrees beyond the ordinary limit of four Degrees North Latitude, and withal they come so much Southerly, as to be sometimes South, sometimes a Point or two to the West; there remains then only to ply to Windward, and if on the one side they stand away W. S. W. they gain the Wind still more and more Easterly; but there is danger of not weathering the *Brazilian* Shoar, or at least the Shoals upon that Coast. But if upon the other Tack they go away E. S. E. they fall into the Neighbourhood of the Coast of *Guinea*, from which there is no departing without running Easterly, as far as the Isle of St. *Thomas*, which is the constant practice of all the *Guinea* Ships, and which may seem very strange, without the consideration of the sixth Remark, which shews the Reason of it: For being in with the Coast, the Wind blows generally at S. W. and W. S. W. with which Winds they cannot go to the Northward for the Land; and on the other Tack they can lie no nearer the Wind than S. S. E. or South; with these Courses they run off the Shoar, but in so doing they always find the Winds more and more contrary; so that when near the Shoar they could lie South, at a greater distance they can make their way no better than S. E. and afterwards E. S. E. with which Courses they fetch commonly the Isle of St. *Thomas* and Cape *Lopez*, where finding the Winds to the Eastward of the South, they keep them favourable, by running away to the Westward in the South Latitude, of three or four Degrees, where the S. E. Winds are perpetual.

For the sake of these general Winds, all those that use the *West-Indian* Trade, even those {67}
bound to *Virginia*, count it their best Course to get as soon as they can to the Southwards, that so they may be certain of a fair and fresh Gale to run before it to the Westwards; and for the same Reason those homewards bound from *America*, endeavour to gain the Latitude of thirty Degrees, as soon as possible, where they first find the Winds begin to be variable; tho' the most ordinary Winds in the Northern part of the *Atlantick* Ocean come from between the South and West.

As to those furious Storms call'd *Hurricanes*, which are, as it were, peculiar to the *Caribbee* Isles; and which so dreadfully afflict them in the Month of *August*, or not much before or after, they do not so properly belong to this place, both by Reason of their small continuance and extent, as likewise because they are not Anniversary, some Years having more than one, and sometimes for several Years together there being none at all. But their Violence is so unconceivable, and their other *Phænomena* so surprising, that they merit well to be consider'd apart.

What is here said, is to be understood of the Sea Winds at some distance from the Land; for upon and near the Shoars, the Land and Sea Breezes are almost every where sensible; and the great Variety which happens in their Periods, Force and Direction, from the situation of the

Mountains, Vallies and Woods, and from the various Texture of the Soil, more or less capable of retaining and reflecting Heat, and of exhaling or condensing Vapours, is such, that it were an endless task, to endeavour to account for them.

II. In the *Indian* Ocean, the Winds are partly general, as in the *Æthiopick* Ocean, partly Periodical; that is, half the Year they blow one way, and the other half near upon the opposite Points; and these Points and Times of shifting are different in different parts of this Ocean; the limits of each Tract of Sea, subject to the same Change or *Monsoon*, are certainly very hard to determine, but the diligence I have used to be rightly inform'd, and the care I have taken therein, has, in a great measure, surmounted that Difficulty; and I am perswaded that the following Particulars may be relied upon. {68}

1. That between the Latitudes of ten Degrees and thirty Degrees South, between *Madagascar* and *Hollandia Nova*, the general Trade Wind about the S. E. by E. is found to blow all the Year long, to all Intents and Purposes after the same manner as in the same Latitudes in the *Æthiopick* Ocean, as it is describ'd in the fourth *Remark* aforegoing.

2. That the aforesaid S. E. Winds extend to within two Degrees of the *Æquator*, during the Months of *June*, *July*, *August*, &c. to *November*; at which time between the *South Latitudes* of three and ten Degrees, being near the Meridian of the North end of *Madagascar*, and between two and twelve South Latitude, being near *Sumatra* and *Java*, the contrary Winds from the N. W. or between the North and West, set in and blow for half the Year, *viz.* from the beginning of *December* till *May*; and this *Monsoon* is observ'd as far as the *Molucca* Isles, of which more anon.

3. That to the Northward of three Degrees South Latitude, over the whole *Arabian* or *Indian-Sea* and Gulph of *Bengall*, from *Sumatra* to the Coast of *Africa*, there is another *Monsoon*, blowing from *October* to *April* upon the North East Points; but in the other half Year, from *April* to *October*, upon the opposite Points of S. W. and W. S. W. and that with rather more force than the other, accompanied with dark rainy Weather, whereas the N. E. blows clear; 'tis likewise to be noted, that the Winds are not so constant, either in strength or point in the Gulph of *Bengall*, as they are in the *Indian-Sea*, where a certain and steady Gale scarce ever fails. 'Tis also remarkable, that the S. W. Winds in these Seas are generally more Southerly on the *African* side, more Westerly on the *Indian*. {69}

4. That as an *Appendix* to the last describ'd *Monsoon*, there is a Tract of Sea to the Southwards of the Æquator, subject to the same Changes of the Winds, *viz.* near the *African* Coast, between it and the Island *Madagascar* or St. *Lawrence*, and from thence Northwards as far as the Line; wherein from *April* to *October* there is found a constant fresh S. S. W. Wind, which, as you go more Northerly, becomes still more and more Westerly, so as to fall in with the W. S. W. Winds, mention'd before, in those Months of the Year to be certain to the Northward of the Æquator: What Winds blow in these Seas, for the other half Year, from *October* to *April*, I have not yet been able to obtain to my full satisfaction, for that our Navigators always return from *India* without *Madagascar*, and so are little acquainted in this Matter; the Account that has been given me is only this, that the Winds are much Easterly hereabouts, and as often to the North of the true East as to the Southwards thereof. {70}

5. That to the Eastward of *Sumatra* and *Malacca*, to the Northwards of the Line, and along the Coast of *Cambodia* and *China*, the *Monsoons* blow North and South, that is to say, the N. E. Winds are much Northerly, and the S. W. much Southerly: This Constitution reaches to the Eastwards of the *Philippine* Isles, and as far Northerly as *Japan*. The Northern *Monsoon* setting in, in these Seas, in *October* or *November*, and the Southern in *May*, blowing all the Summer Months: Here it is to be noted, That the Points of the Compass, from whence the Wind comes in these Parts of the World, are not so fixt as in those lately describ'd; for the Southerly will frequently pass a Point or two to the Eastwards of the South, and the Northerly as much to the Westwards of the North, which seems occasion'd by the great quantity of Land, which is interspers'd in these Seas.

6. That in the same *Meridians*, but to the Southwards of the Æquator, being that Tract lying between *Sumatra* and *Java* to the West, and *New Guinea* to the East, the same Northerly *Monsoons* are observ'd, but with this difference, that the inclination of the Northerly is towards the N. West, and of the Southerly towards the S. E. but the *plagæ venti* are not more constant here than in the former, *viz.* variable five or six Points; besides the times of the Change of these Winds, are not the same as in the *Chinese* Seas, but about a Month or six Weeks later.

7. That these contrary Winds do not shift all at once, but in some places the time of the Change is attended with Calms, in others with variable Winds; and it is particularly remarkable, that the end of the Westerly *Monsoon* on the Coast of *Coromandel*, and the two last Months of the Southerly *Monsoon* in the Seas of *China*, are very subject to be tempestuous: The violence of these Storms is such, that they seem to be of the Nature of the *West-India Hurricanes*, and render the Navigation of these parts very unsafe about that time of the Year. These Tempests are by our Seamen usually term'd, *The breaking up of the Monsoons*. {71}

By reason of the shifting of these Winds, all those that sail in these Seas, are oblig'd to observe the Seasons proper for their Voyages, and so doing they fail not of a fair Wind and speedy Passage; but if so be they chance to out-stay their time, till the contrary *Monsoon* sets in, as it frequently happens, they are forc'd to give over the hopes of accomplishing their intended Voyages, and either return to the Port from whence they came, or else put in to some other Harbour, there to spend the time till the Winds shall come favourable.

III. The third Ocean call'd *Mare Pacificum*, whose Extent is equal to that of the other two (it being from the West Coast of *America* to the *Philippine* Islands, not less than 150 Degrees of Longitude) is that which is least known to our own or the Neighbour Nations; that Navigation that there is on it, is by the *Spaniards*, who go Yearly from the Coast of *New Spain* to the *Manilha's*, but that but by one beaten track; so that I cannot be so particular here as in the other {72}
two. What the *Spanish* Authors say of the Winds they find in their Courses, and what is confirm'd by the old Accounts of *Drake* and *Cavendish*; and since by *Schooten*, who sail'd the whole breadth of this Sea in the Southern Latitude of fifteen or sixteen Degrees, is, that there is a great conformity between the Winds of this Sea, and those of the *Atlantick* and *Æthiopick*; that is to say, that to the Northwards of the Æquator, the predominant Wind is between the East and North-East; and to the Southwards thereof there is a constant steady Gale between the East and South-East, and that on both sides the Line with so much constancy, that they scarce ever need to attend the Sails, and Strength, that it is rare to fail of crossing this vast Ocean in ten Weeks time, which is about 130 Miles *per diem*; besides, 'tis said that Storms and Tempests are never known in these parts: So that here is the very best of Sailing; no want of a fresh fair Wind, and yet no danger of having too much: Wherefore some have thought it might be as short a Voyage to *Japan* and *China*, to go by the Streights of *Magellan*, as by the *Cape* of *Good Hope*.

The Limits of these general Winds are also much the same as in the *Atlantick* Sea, *viz.* about the thirtieth Degree of Latitude on both sides; for the *Spaniards* homewards bound from the *Manilha's*, always take the advantage of the Southerly *Monsoon*, blowing there in the Summer Months, and run up to the Northwards of that Latitude, as high as *Japan*, before they meet with variable Winds, to shape their Course to the Eastwards. And *Schooten* and others that have gone about by the *Magellan* Streights, have found the Limits of S. E. Winds, much about the same {73}
Latitude to the Southwards; besides a farther *Analogy* between the Winds of this Ocean, and the *Æthiopick*, appears in that, upon the Coast of *Peru*, they are always much Southerly, like as they are found near the Shoars of *Angola*.

Thus far Matter of Fact, wherein if the information I have receiv'd be not in all parts Accurate, it has not been for want of inquiry from those I conceiv'd best able to instruct me; and I shall take it for a very great Kindness if any Master of a Ship, or other Person, well inform'd of the Nature of the Winds, in any of the aforemention'd parts of the World, shall please to communicate their Observations thereupon; so that what I have here Collected may be either confirm'd or amended, or by the addition of some material Circumstances enlarg'd. It is not the work of one, nor of few, but of a multitude of Observers, to bring together the Experience requisite to compose a perfect and compleat History of these Winds; however I am not much doubtful that I have err'd in, or omitted any of the principal Observables, whatever lesser Particulars may have escaped my Knowledge.

To help the Conception of the Reader in a manner of so much difficulty, I believ'd it necessary to adjoin a Scheme, (*Plate 2.*) shewing at one view all the various Tracts and Courses of these Winds; whereby 'tis possible the thing may be better understood, than by any verbal Description whatsoever.

The Limits of these several Tracts are design'd every where by prickt Lines, as well in the *Atlantick* and *Æthiopick*, where they are the boundaries of the Trade and variable Winds, as in {74}
the *Indian* Ocean, where they also shew the Extent of the several *Monsoons*. I could think of no better way to design the Course of the Winds on the Map, than by drawing rows of stroaks in the same Line that a Ship would move going always before it; the sharp end of each little stroak pointing out that part of the Horizon, from whence the Wind continually comes; and where there are *Monsoons*, the rows of the stroaks run alternately backwards and forwards, by which means they are thicker there than elsewhere. As to the great South Sea, considering its vast Extent, and the little Variety there is in its Winds, and the great *Analogy* between them, and those of the *Atlantick* and *Æthiopick* Oceans; besides, that the greatest part thereof is wholly unknown to us; I thought it unnecessary to lengthen the Map therewith.

In the foregoing History are contained several Problems, that merit well the Consideration of our acutest Naturalists, both by reason of the constancy of the Effect, and of the immense Extent thereof; near half the Surface of the Globe being concerned. The chief of these Problems are, 1. Why these Winds are perpetually from the East in the *Atlantic* and *Æthiopick*; as likewise in the *Pacifick* Ocean, between the Latitudes of 30 North and South? 2. Why the said Winds extend no farther with constancy than to the Latitude of 30 Degrees? 3. Why there should be a constant

South-Westerly Wind upon and near the Coast of *Guinea*? 4. Why in the North part of the *Indian* Ocean, the Winds, which for one half Year do agree with those of the other two Oceans, should change in other half Year, and blow from the opposite Points; whilst the Southern part of that {75} Ocean follows the General Rule, and has perpetual Winds about S. E? 5. Why in these General Trade-Winds it should be always true, that to the Northward of the *Æquator* it is inclin'd to the Northwards of the East; and in South Latitudes, to the Southward thereof? 6. Why in these Seas of *China* there should be so great an Inclination from the East to the North, more than elsewhere? with many more, which it would be much easier to propose than answer.

But lest I should seem to propose to others, Difficulties which I have not thought worth my own Time and Pains, take here the result of an earnest Endeavour after the true reason of the aforesaid *Phænomena*; wherein if I am not able to account for all Particulars, yet 'tis hoped the Thoughts I have spent thereon, will not be judged wholly lost, by the Curious in Natural Enquiries.

Wind is most properly defined to be the Stream or Current of the Air, and where such a Current is perpetual and fixt in its Course, 'tis necessary that it proceed from a permanent un-intermitting Cause. Wherefore some have been inclin'd to propose the diurnal *Rotation* of the Earth upon its *Axis*, by which, as the *Globe* turns Eastwards, the loose and *fluid* Particles of the Air, being so exceeding light as they be, are left behind, so that in respect of the Earths *Surface* they move Westwards, and become a constant Easterly Wind. This Opinion seems confirm'd, for that these Winds are found only near the *Æquinoctial*, in those Parallels of Latitude where the diurnal Motion is swiftest; and I should readily assent to it, if the constant Calms in the *Atlantick* Sea, near the *Æquator*, the Westerly Winds near the Coast of *Guinea*; and the *Periodical* Westerly {76} *Monsoons* under the *Æquator* in the *Indian* Seas, did not declare the insufficency of that *Hypothesis*. Besides the Air being kept to the Earth by the Principle of *Gravity*, would acquire the same degree of *Velocity* that the Earths *Surface* moves with, as well in respect of the diurnal *Rotation*, as of the Annual about the Sun, which is about thirty times swifter.

It remains therefore to substitute some other Cause, capable of producing a like constant Effect, not liable to the same Objections, but agreeable to the known Properties of the Elements of Air and Water, and the Laws of the Motion of fluid Bodies. Such an one is, I conceive, the Action of the Sun Beams upon the Air and Water, as he passes every Day over the Oceans, consider'd together with the Nature of the Soil, and Situation of the adjoining Continents: I say therefore, first, that according to the Laws of *Staticks*, the Air which is less rarified or expanded by heat, and consequently more ponderous, must have a Motion towards those parts thereof, which are more rarified, and less ponderous, to bring it to an *Æquilibrium*; and secondly, That the Presence of the Sun continually shifting to the Westwards, that part towards which the Air tends, by reason of the Rarifaction made by his greatest *Meridian* Heat, is with him carried Westward, and consequently the tendency of the whole Body of the lower Air is that way.

Thus a general Easterly Wind is formed, which being impressed upon all the Air of a vast Ocean, the Parts impel one the other, and so keep moving till the next return of the Sun, whereby {77} so much of the Motion as was lost, is again restored, and thus the Westerly Wind is made perpetual.

From the same Principle it follows, that this Easterly Wind should on the North side of the *Æquator*, be to the Northwards of the East, and in South Latitudes to the Southwards thereof; for near the *Line*, the Air is much more rarified, than at a greater distance from it; because of the Sun twice in a Year Vertical, and at no time distant above 23 Degr. and a half; at which distance the Heat, being as the Sine of the Angle of Incidence, is but little short of that of the perpendicular Ray. Whereas under the Tropicks, though the Sun stay long Vertical, yet he is as long 47 Degr. off; which is a kind of Winter, wherein the Air so cools, as that the Summer-heat cannot warm it to the same degree with that under the Æquator. Wherefore the Air to the Northwards and Southwards, being less rarified than that in the middle, it follows, that from both sides it ought to tend towards the Æquator: This Motion compounded with the former Easterly Wind, answers all the *Phænomena* of the general Trade-winds; which, if the whole Surface of the Globe were Sea, would undoubtedly blow all round the World, as they are found to do in the *Atlantick*, and *Æthiopick* Oceans.

But seeing that so great Continents do interpose, and break the continuity of the Oceans, regard must be had to the Nature of the Soil, and the Position of the high Mountains, which I suppose the two principal Causes of the several Variations of the Winds, from the former general Rule: For if a Country lying near the Sun, prove to be flat, sandy, low Land, such as the Desarts {78} of *Lybia* are usually reported to be, the Heat occasion'd by the Reflection of the Suns Beams, and the retention thereof in the Sand, is incredible to those that have not felt it; whereby the Air being exceedingly rarified, it is necessary that the cooler and more dense Air should run thitherwards to restore the *Æquilibrium*: This I take to be the cause, why near the Coast of *Guinea* the Wind always sets in upon the Land, blowing Westerly instead of Easterly, there being sufficient Reason to believe, that the Inland Parts of *Africa* are prodigiously hot, since the Northern Borders thereof were so intemperate, as to give the Ancients cause to conclude, that all

beyond the *Tropick*, was made uninhabitable by excess of Heat: From the same Cause it happens, that there are so constant Calms in that part of the Ocean, called the *Rains*, (described in the 7th Remark on the *Atlantick* Sea) for this Tract being placed in the middle, between the Westerly Winds blowing on the Coast of *Guinea*, and the Easterly Trade-winds, blowing to the Westwards thereof, the tendency of the Air here, is indifferent to either, and so stands in *Æquilibrio* between both; and the weight of the incumbent Atmosphere being diminished by the continual contrary Winds blowing from hence, is the reason that the Air here holds not the copious Vapour it receives, but lets it fall into frequent Rains.

But as the cool and dense Air, by reason of its greater Gravity, presses upon the hot and rarified, 'tis demonstrative that this latter must ascend in a continued Stream as fast it rarifies; and that being ascended, it must disperse it self to preserve the *Æquilibrium*: that is, by a contrary Current, the upper Air must move from those Parts where the greatest Heat is: So by a kind of Circulation, the North-East Trade-Wind below, will be attended with a South-Westerly {79}
above, and the South-Easterly with a North-West Wind above; that this is more than a bare Conjecture, the almost instantaneous Change of the Wind to the opposite Point, which is frequently found in passing the limits of the Trade-winds, seems to assure us; but that which above all confirms this *Hypothesis* is the *Phænomenon* of the *Monsoons*, by this means most easily solved, and without it hardly explicable.

Supposing therefore such a Circulation, as above, 'tis to be considered that to the Northward of the *Indian* Ocean there is every where Land within the usual limit of the Latitude of 30, *viz. Arabia*, *Persia*, *India*, *&c.* which for the same reason as the *Mediterranean* Parts of *Africa*, are subject to unsufferable Heats when the Sun is to the North, passing nearly Vertical; but yet are temperate enough when the Sun is removed towards the other *Tropick*; because of a ridge of Mountains at some distance within the Land, said to be frequently in Winter cover'd with Snow, over which the Air, as it passes, must needs be much chill'd. Hence it comes to pass, that the Air coming according to the general Rule, out of the N. E. in the *Indian* Seas, is sometimes hotter, sometimes colder, than that which by this Circulation is return'd out of the S. W. and by consequence, sometimes the under Current or Wind, is from the N. E. sometimes from the S. W.

That this has no other Cause, is clear from the times wherein these Winds set in, *viz.* in *April*, when the Sun begins to warm those Countries to the North, the S. W. *Monsoon* begins, and blows during the Heats till *October*; when the Sun being retir'd, and all things growing cooler {80}
Northward, and the Heat increasing to the South, the North-East Winds enter and blow all the Winter till *April* again. And it is undoubtedly from the same Principle that to the Southwards of the Æquator, in part of the *Indian* Ocean, the North-West Winds succeed to the South-East, when the Sun draws near the *Tropick* of *Capricorn*; but I must confess, that in this latter occurs a difficulty, not well to be accounted for, which is, why this Change of the *Monsoons* should be any more in this Ocean, than in the same Latitudes in the *Æthopick*, where there is nothing more certain than a S. E. Wind all the Year.

'Tis likewise very hard to conceive why the limits of the Trade-wind should be fixt, about the thirtieth Degree of Latitude all round the Globe; and that they should so seldom transgress or fall short of those bounds; as also that in the *Indian* Sea, only the Northern Part should be subject to the changeable *Monsoons*, and in the Southern there be a constant S. E.

These are Particulars that merit to be consider'd more at large, and furnish a sufficient Subject for a just Volume, which will be a very commendable Task for such, who being us'd to Philosophick Contemplation, shall have leisure to apply their serious Thoughts about it.

Plate 2 pag. 80

A new & Correct SEA CHART of the WHOLE WORLD
Shewing the Variations *of y^e* COMPASS *as they were found Año 1700 with a View of the Generall and Coasting* Trade Winds *and* Monsoons *or shifting* Trade Winds *by the Direction of* Cap^t. Edm. Halley.

A Discourse of the Rule of the Decrease of the height of the Mercury *in the* {81}

Barometer, according as Places are elevated above the Surface of the Earth; with an Attempt to discover the true Reason of the Rising and Falling of the Mercury*, upon Change of Weather. By* Edm. Halley*.*

THE Elastick Property of the Air has been long since made out, by Experiments before the *Royal Society*, and elsewhere; and the Resistance of its Spring is found to be nearly equal to the Weight or Force that compresses it; as also, that the Spaces the same Air occupies, under differing Pressures, are reciprocally as those Pressures: It has been shewn likewise by undoubted Experiment, that the specifick Gravity of the Air, near the Earth's Surface to that of Water, was once as 1 to 840; again as 1 to 852; and a third time, in a very large Vessel holding 10 Gallons, as 1 to 860; all which, considering the Difficulty of the Experiment, agree well enough, the Mercury standing at all those times about 29 Inches ¾: But by Reason 'twas Summer-weather, and consequently the Air rarified, when all these were tried, we may without sensible Error say in {82} round numbers, that the Barometer standing at 30 Inches, and in a mean State of Heat and Cold, the specifick Gravity of the Air to Water, is as 1 to 800. By the like Trials the weight of Mercury to Water, is as 13½ to 1, or very near it; so that the weight of Mercury to Air, is as 10800 to 1; and a Cylinder of Air of 10800 Inches or 900 Feet, is equal to an Inch of Mercury; and were the Air of an equal density like Water, the whole Atmosphere would be no more than 5,1 Miles high, and in the Ascent of every 900 Feet the Barometer would sink an Inch. But the Expansion of the Air increasing in the same proportion as the incumbent weight of the Atmosphere decreases; that is, as the Mercury in the Barometer sinks; the upper Parts of the Air are much more rarified than the lower, and each Space answering to an Inch of Quicksilver, grows greater and greater; so that the Atmosphere must be extended to a much greater height. Now, upon these Principles, to determine the height of the Mercury at any assigned height in the Air; and *è contra*, having the height of the *Mercury* given, to find the height of the Place where the Barometer stands, are Problems not more difficult than curious; and which I thus resolve.

The Expansions of the Air being reciprocally as the heights of the Mercury, it is evident, that by the help of the Curve of the *Hyperbola* and its *Asymptotes*, the said Expansions may be expounded to any given height of the *Mercury*: For by the 65th *Prop. lib. 2. Conic. Mydorgii*, *the Rectangles*, *ABCE*, *AKGE*, *ALDE*, *&c.* (in *Plate 1. Fig. 4.*) are always equal, and consequently the {83} sides, *CB*, *GK*, *LD*, &c. are reciprocally as the sides *AB*, *AK*, *AL*, &c. If then the Lines *AB*, *AK*, *AL*, be supposed equal to the heights of the *Mercury*, or the pressures of the Atmosphere, the Lines *CB*, *GK*, *LD*, answering thereto, will be as the Expansions of the Air under those Pressures, or the Bulks that the same quantity of Air will occupy; which Expansions being taken infinitely many, and infinitely little, (according to the Method of Indivisibles) their Summ will give the Spaces of Air between the several heights of the *Barometer*; that is to say, the Summ of all the Lines between *CB* and *KG*, or the *Area CBKG*, will be proportioned to the Distance or Space intercepted between the Levels of two Places in the Air, where the *Mercury* would stand at the heights represented by the Lines *AB*, *AK*; so then the Spaces of Air answering to equal Parts of *Mercury* in the *Barometer*, are as the *Area's CBKG*, *GKLD*, *DLFM*, &c. These *Area's* again are, by the Demonstration of *Gregory* of St. *Vincent*, proportionate to the *Logarithms* of the Numbers expressing the *Rationes* of *AK* to *AB*, of *AL* to *AK*, of *AM* to *AL*, &c. So then by the common Table of *Logarithms*, the height of any Place in the *Atmosphere*, having any assign'd height of the *Mercury*, may most easily be found: For the Line *CB* in the *Hyperbola*, whereof the *Area's* design the *Tabular Logarithms*, being 0,0144765; 'twill be, as 0,0144765, to the difference of the *Logarithms* of 30, or any other lesser Number, for 900 Feet, or the Space answering to an Inch of *Mercury*, if the Air were equally prest with 30 Inches of *Mercury*, and every where alike, to the height of the *Barometer* in the Air, where it will stand at that lesser number of Inches: And by the {84} Converse of this Proportion may the height of the *Mercury* be found, having the Altitude of the Place given. From these Rules I deriv'd the following Tables.

A Table shewing the Altitude, to given heights of the Mercury*.*

Inch.	Feet.
30	0
29	915
28	1862
27	2844
26	3863
25	10947
15	18715
10	29662
5	48378
1	91831
0.5	110547
0.25	129262

0.1	29 m. or 154000
0.01	41 m. or 216169
0.001	53 m. or 278338

A Table shewing the heights of the Mercury*, at given Altitudes.*

Feet.	Inch.
0	30 00
1000	28 91
2000	27 86
3000	26 85
4000	35 87
5000 feet	24 93
1 mile	24 67
2	20 29
3	16 68
4	13 72
5	11 28
10	4 24
15	1 60
20	0 95
25	0 23
30	0 08
40	0 012

UPON these Suppositions it appears, that at the height of 41 Miles the Air is so rarified, as to take up 3000 times the Space it occupies here, and at 53 Miles high it would be expanded above 30000 times; but it's probable that the utmost Power of its Spring cannot exert it self, to so great an Extension, and that no part of the *Atmosphere* reaches above 45 Miles from the Surface of the Earth. {85}

This seems confirm'd from the Observations of the *Crepusculum*, which is observ'd commonly to begin and end when the Sun is about 18 Degrees below the Horizon; for supposing the Air to reflect light from its most rarified Parts, and that as long as the Sun illuminates any of its *Atoms*, they are visible to an Eye not intercepted by the Curvity of the Earth, it will follow from *Fig. 5. Plate 1.* that the proportion of the height of the whole Air, to the Semi-diameter of the Earth, is much about, as 1 to 90, or as the excess of the *Secant* of about 8½ Degrees to the *Radius*. For if *E* be the Eye of the Observer, *S* a Place where the Sun sets at the end of Twilight in *E*, and the Arch *ECS*, or *TCA*, be found 18 Degrees, the excess of the *Secant* of half thereof *ECH*, would be the height of the Air, *viz. GH*: But the Beam of the Sun *ASH*, and the Visual Ray *EH*, do each of them suffer a Refraction of about 32 or 33 Minutes, whereby being bent inwards from *H* towards *G*, the height of the Air need not be so great as if they went streight; and having from the Angle *ECS* taken the double Refraction of the *Horizontal Ray*, the half of the Remainder will be 8½ Degrees *circiter*, whose *Secant* being 10,111, it follows, that as 10000 to 111, so the Semi-diameter of the Earth supposed 4000 Miles, to 44,4 Miles; which will be the height of the whole Air, if the Places *E*, *S*, whose visible Portions of the *Atmosphere ERZH*, and *SHKB*, just touch one the other, be 18 Degrees asunder. {86}

At this height the Air is expanded into above 3000 times the space it occupies here, and we have seen the Experience of condensing it into the 60th part of the same Space, so that it should seem, that the Air is a Substance capable of being compressed into the 180000th part of the Space it would naturally take up, when free from pressure. Now what Texture or Composition of Parts shall be capable of this great Expansion and Contraction, seems a very hard Question; and which, I suppose, is scarce sufficiently accounted for, by comparing it to Wool, Cotten, and the like springy Bodies.

Hitherto I have only consider'd the *Air* and *Atmosphere*, as one unalter'd Body, as having constantly at the Earth's Surface the 800th part of the weight of Water, and being capable of Rarifaction and Condensation *in infinitum*; neither of which *Hypotheses* are rigidly true: For here in *England* it is notoriously known, that the weight of the whole *Atmosphere* is various, being counterpoised sometimes by 28½ Inches of *Mercury*, and at other times by no less than 30½; so that the under parts being pressed by about a 15th part, less weight, the *specifick* Gravity of the Air upon that score will sometimes be a 15th part lighter than another; besides Heat and Cold, does very considerably dilate and contract the Air, and consequently alter its Gravity; to which add the mixture of *Effluvia*, or steams arising from almost all Bodies, which assimulating into the Form of Air, are kept suspended therein, as Salts dissolv'd in Liquors, or Metals in corroding *Menstrua*; which Bodies being all of them very much heavier than Air, their Particles by their Admixture must needs encrease the weight of that Air they lie incorporated withal, after the {87}

same manner as melted Salts do augment the specifick Gravity of Water. The other Consideration is, that the Rarifaction and Condensation of the Air is not precisely according to the proportion here laid down; for the Experiment very nearly agrees thereto, as may be seen in the 58th Chapter of Mr. *Hook's Micrography*; yet are the Condensations not possible beyond certain degrees: For being compressed into an 800th part of the Space it takes up here, its consistence would be equally dense with that of Water; which yields not to any force whatsoever, as hath been found by several Experiments tried here, and at *Florence*, by the *Academia del Cimento*. Nor can the Rarifaction proceed *in infinitum*; for supposing the Spring whereby it dilates it self, occasion'd by what Texture of Parts you please, yet must there be a determinate Magnitude of the natural State of each Particle, as we see it is in Wool, and the like, whose Bodies being compressable into a very small Space, have yet a determinate bulk which they cannot exceed, when free'd from all manner of Pressure.

These Objections being true, do disturb the Geometrical Accuracy of these Conclusions, drawn from the specifick Gravity of the Air observ'd at any time; but the Method here shewn will compute by a like Calculation, the heights of the Quick-silver, and the Rarifactions of the Air from {88} any assign'd height of the *Barometer* at the Earth's Surface, and any specifick Gravity given. As to the Condensation and Rarifaction by Heat and Cold, and the various mixture of Aqueous and other Vapours, these two Objections seem generally to compensate each other; for when the Air is rarified by Heat, they are raised most copiously; so that though the Air properly so call'd, be expanded, and consequently lighter, yet the *Interstices* thereof being crouded full of Vapours of much heavier Matters, bulk for bulk, the weight of the *Compositum* may continue much the same, at least a most curious Experiment made by the Ingenious Mr. *John Caswell*, of *Oxford*, upon the top of *Snowdon* Hill, in *Carnarvanshire*, seems to prove, that the first Inches of *Mercury* have their Portions of Air near enough to what I now determine: For the height of the Hill being 1240 Yards, or very near it, he found the *Mercury* to have subsided to 25,6 Inches, or 4 inches below the mean Altitude thereof at the Level of the Sea, (which is a greater difference than has been found in any of our former Experiments,) and the Space answering to 4 Inches, by my Calculation, should be 1288 Yards; and it agrees as well with the Observations in the Appendix to Mr. *Pascall*'s Book, *del Equilibre des Liqueurs*, made on the high Hill in *Auvergne*, call'd *le puy de Domme*. So that the Rarifaction and Vapours seem not to have alter'd considerably, the Gravity of the under Parts of the *Air*; and much above the height where these Experiments were made, do few Vapours ascend, and the Cold is such that the Snow lies continually, so that for the more elevated Parts of the Sphere of *Air*, there is much less Reason to doubt.

But now we have had occasion to mention the difference there is between the height of the {89} *Mercury* at one time, from the height thereof at another, it may not be unacceptable to offer at some Reasons for the said difference; which, at least to my self, seem to have some appearance of Truth. *First*, Then it's undoubtedly demonstrable, that the height of the Cylinder of *Mercury* is equal to the weight of the whole incumbent Air, and consequently that that whole is sometimes a fifteenth more than at other times; which cannot otherwise be, but by the access of new Matter when 'tis heavy, and its diminution when 'tis light; that *Hypothesis* therefore that shews how the Air shall be encreased or diminished, in any particular place, will give a Reason for the greater and lesser height of the *Mercury* in the *Baroscope*: But to direct us in the choice of the several Causes, which may be assign'd for the Increase and Decrease of the Air, 'twill not be unnecessary to enumerate some of the principal Observations made upon the *Barometer*, most whereof are sufficiently known already to all those that are curious in these Matters.

The *First* is, That in calm Weather, when the Air is inclin'd to Rain, the *Mercury* is commonly low.

2. That in serene good settled Weather, the *Mercury* is generally high.

3. That upon very great Winds, though they be not accompanied with Rain, the *Mercury* sinks lowest of all, with relation to the Point of the Compass the Wind blows upon.

4. That *cæteris paribus* the greatest heights of the *Mercury* are found upon Easterly and North- {90} Easterly Winds.

5. That in calm frosty Weather the *Mercury* generally stands high.

6. That after very great Storms of Wind, when the *Quicksilver* has been low, it generally rises again very fast.

7. That the more Northerly places have greater Alterations of the *Baroscope*, than the more Southerly.

8. That within the *Tropicks* and near them, those Accounts I have had from others, and my own Observation at St. *Helena*, make very little or no Variation of the height of the *Mercury* in all Weathers.

Now that Theory that can well account for all these appearances, will, in all probability, approach nearer the true cause of the *Barometers* Variations, than any thing hitherto afforded;

and such an one I am bound to believe, is that which I here lay down with submission to better Judgments.

I conceive that the principal Cause of the rise and fall of the *Mercury*, is from the variable Winds, which are found in the *Temperate Zones*, and whose great unconstancy here in *England* is most notorious. I shall not at present inquire into the Cause of its uncertainty, but the Matter of Fact being most undoubted, the Legitimate Consequences thereof must be allow'd me, let it proceed from what it will.

A second Cause is the uncertain Exhalation and Præcipitation of the Vapours lodging in the Air, {91}
whereby it comes to be at one time much more crowded than at another, and consequently heavier; but this latter in a great measure depends upon the former. Now from these Principles I shall endeavour to explicate the several *Phænomena* of the *Barometer*, taking them in the same order I laid them down.

1. *Why in calm Weather the Air being inclin'd to Rain, the* Mercury *is commonly low?* I Answer, That the *Mercury*'s being low, inclines it to Rain; for the Air being light, the Vapours are no longer supported thereby, being become specifically heavier than the Medium wherein they floated; so that they descend towards the Earth, and in their fall meeting with other aqueous Particles, they incorporate together, and form little drops of Rain; but the *Mercury*'s being at one time lower than another, is the effect of two contrary Winds blowing from the place whence the *Barometer* stands; whereby the Air of that place is carried both ways from it, and consequently the incumbent Cylinder of Air is diminished, and accordingly the *Mercury* sinks; as for Instance, if in the *German Ocean* it should blow a Gale of Westerly Wind, and at the same time an Easterly Wind in the *Irish Sea*; or if in *France* it should blow a Southerly Wind, and in *Scotland* a Northern; it must be granted me, that That part of the *Atmosphere* impendent over *England*, would thereby be exhausted and attenuated, and the *Mercury* would subside, and the Vapours which before floated in those parts of the *Air* of equal Gravity with themselves, would sink to the Earth.

2. *Why in serene good settled weather the* Mercury *is generally high?* To this I Answer, That {92}
the greater height of the *Barometer*, is occasion'd by two contrary Winds blowing towards the place of Observation, whereby the Air of other places is brought thither and accumulated; so that the incumbent Cylinder of Air being encreas'd both in height and weight, the *Mercury* press'd thereby must needs rise and stand high, as long as the Winds continue so to blow; and then the Air being specifically heavier, the Vapours are better kept suspended, so that they have no inclination to Præcipitate and fall down in Drops, which is the reason of the serene good Weather, which attends the greater heights of the *Mercury*.

3. *Why upon very great Winds or Storms, tho' accompanied with no Rain, the* Mercury *sinks lowest of all, with relation to the Point of the Compass upon which the Wind blows?* This is caus'd by the very rapid Motion of the Air in these Storms; for the Tract or Region of the Earths Surface, wherein these Winds rage, not extending all round the Globe, that stagnant Air which is left behind, as likewise that on the sides, cannot come in so fast as to supply the Evacuation made by so swift a Current; so that the Air must necessarily be attenuated, when and where the said Winds continue to blow, and that more or less, according to their Violence; add to which, that the *Horizontal* Motion of the Air being so quick as it is, may in all probability take off some part of the perpendicular pressure thereof; and the great Agitation of its Particles, is the Reason why the Vapours are dissipated, and do not condense into Drops, so as to form Rain, otherwise the {93}
natural Consequence of the Airs Rarifaction.

4. *Why* cæteris paribus *the* Mercury *stands highest upon an Easterly or North-Easterly Wind?* This happens because that in the great *Atlantick Ocean*, on this side the thirty fifth Degree of North Latitude, the Westerly and South-Westerly Trade-Winds blow almost always; so that whenever here the Wind comes up at East and North-East, 'tis sure to be checked by a contrary Gale, as soon as it reaches the Ocean; wherefore, according to what is made out in our second Remark, the Air must needs be heaped over this Island; and consequently the *Mercury* must stand high, as often as these Winds blow. This holds true in this Country, but is not a general Rule for others, where the Winds are under different Circumstances; and I have sometimes seen the *Mercury* here as low as twenty nine Inches, upon an Easterly Wind, but then it blows exceeding hard, and so comes to be accounted for by what was observ'd upon the third Remark.

5. *Why in calm Weather the* Mercury *generally stands high?* The cause hereof is, as I conceive, that it seldom freezes but when the Winds come out of the Northern and North-Eastern Quarters, or at least unless those Winds blow at no great distance off; for the Northern Parts of *Germany*, *Denmark*, *Sweden*, *Norway*, and all that Tract from whence North-Eastern Winds come, are subject to almost continual Frost all the Winter; and thereby the lower Air is very much condens'd, and in that State is brought hitherwards by these Winds, and being accumulated by {94}
the opposition of the Westerly Wind blowing in the Ocean, the *Mercury* must needs be prest to a more than ordinary height, and as a concurring Cause, the shrinking of the lower parts of the Air into lesser room by cold, must needs cause a descent of the upper parts of the Atmosphere, to reduce the Cavity made by this contraction to an *Æquilibrium*.

6. *Why after very great Storms of Wind, when the* Mercury *has been very low, it generally rises again very fast?* This I have frequently observed, and once found it risen an Inch and a half in less than six Hours, after a long continu'd Storm of South-West Wind. This seems to be occasion'd by the sudden Accession of new Air to supply the great Evacuation which such continu'd Storms make thereof, in those places whence they happen (as in the third Remark) and by the Recoile of the Air, after the force ceases that impelled it; and the Reason why the *Mercury* rises so fast, is because the Air being very much rarify'd beyond its mean density, the Neighbouring Air runs in the more swiftly to bring it to an *Æquilibration*, as we see Water runs the faster for having a great declivity.

7. *Why in more Northerly places the Variations of the* Baroscope *are greater than in the Southerly?* The truth of the Matter of Fact is prov'd from Observations made at *Clermont* and *Paris*, compar'd with others, made at *Stockholm*, as may be seen in the Appendix to Mr. *Pascal*'s Book before-cited. The Reason I conjecture to be, that the more Northerly Parts have usually greater Storms of Wind than the more Southerly, whereby the *Mercury* should sink lower in that {95}
Extream; and then the Northerly Winds bringing the condens'd and ponderous Air from the Neighbourhood of the Pole, and that again being check'd by a Southerly Wind, at no great distance, and so heaped, must of necessity make the *Mercury* in such case stand higher in the other Extream.

8. And Lastly, *Why near the* Æquinoctial*, as at* Barbadoes *and St.* Helena*, there is very little or no Variation of the height of the Barometer?* This Remark, above all others, confirms the Hypothesis of the variable Winds, being the cause of these Variations of the height of the *Mercury*; for in the Places above-named, there is always an easie Gale of Wind blowing nearly upon the same Point, *viz.* E. N. E. at *Barbadoes*, and E. S. E. at St. *Helena*; so that there being no contrary Currents of the Air, to exhaust or accumulate it, the Atmosphere continues much in the same State. However, upon Hurricanes, the most violent of Storms, the *Mercury* has been observ'd very low, but this is but for once in two or three Years, and it soon recovers its settled state of about 29½ Inches. I doubt not but the same thing is in the East Coast of *Africa*, and in *India*, where the Monsoons or Trade-Winds are for half the Year one way, and half the Year another; only it's probable, that there may something worth noting happen, about the times of the change or shifting of the Winds, which might be obtain'd, if any Body had the Curiosity to keep the *Barometer* at our Factories in *India*.

I doubt not but this Doctrine will find some Opposers, and that one principal Objection will be, that I suppose the Air sometimes to move from those Parts where it is already evacuated below {96}
the *Æquilibrium*, and sometimes again towards those parts, where it is condens'd and crouded above the mean State, which may be thought contradictory to the Laws of Staticks and the Rules of the *Æquilibrium* of Fluids. But those that shall consider how, when once an impetus is given to a Fluid Body, it is capable of mounting above its Level, and checking others that have a contrary tendency to descent by their own Gravity, will no longer regard this as a material Obstacle, but will rather conclude, that the great *Analogy* there is between the rising and falling of the Water upon the Flux and Reflux of the Sea, and this of the accumulating and extenuating the Air, is a great Argument for the Truth of this Hypothesis: For as the Sea over against the Coast of *Essex*, rises and swells by the meeting of the two contrary Tides of Flood, (whereof the one comes from the S. W. along the Channel of *England*, and the other from the North); and on the contrary sinks below its Level upon the retreat of the Water both ways in the Tide of Ebb; so it is very probable that the Air may Ebb and Flow, after the same manner; but by reason of the diversity of Causes, whereby the Air may be set in moving, the times of these Fluxes and Refluxes thereof, are purely Casual, and not reducible to any Rule, as are the Motions of the Sea, depending wholly upon the regular Course of the Moon.

{97}

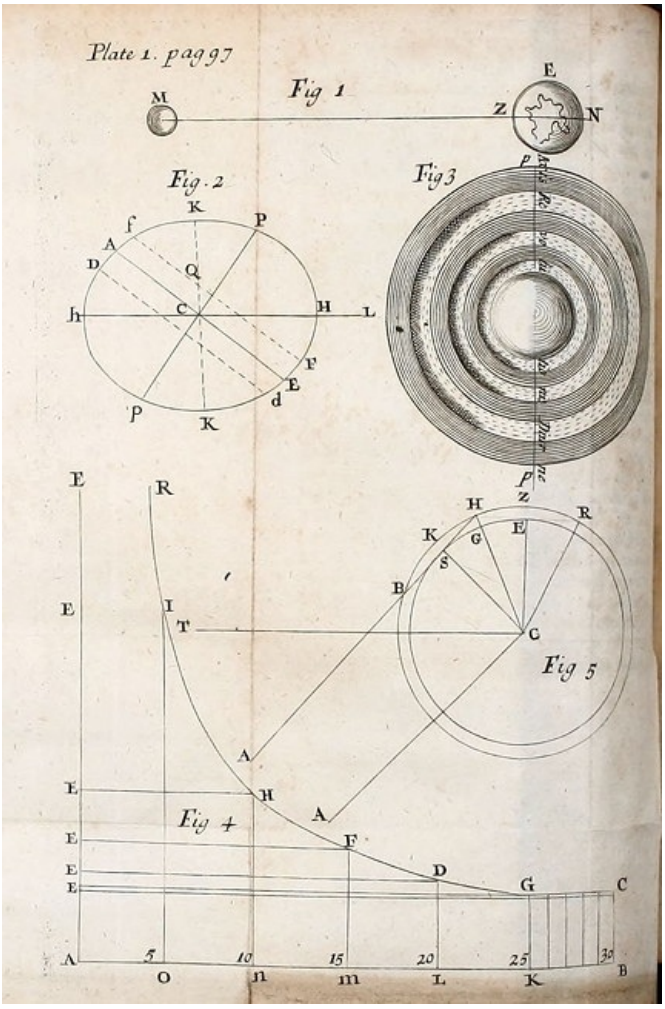


Plate 1. pag. 97

A Letter of Mr. Isaac Newton*, Professor of the Mathematicks in the University of* Cambridge*; containing his New Theory about* Light *and* Colours*: Sent by the Author to the Publisher from* Cambridge*, Feb. 6. 1671/2; in order to be communicated to the* Royal Society*.*

S I R,

TO perform my late promise to you, I shall without further Ceremony acquaint you, That in the beginning of the Year 1666 (at which time I apply'd my self to the grinding of Optick-glasses of other Figures than *Spherical*,) I procur'd me a Triangular Glass-Prism, to try therewith the celebrated *Phænomena* of *Colours*. And in order thereto, having darken'd my Chamber, and made a small hole in my Window-shuts, to let in a convenient quantity of the Sun's Light, I plac'd my Prism at his entrance, that it might be thereby refracted to the opposite Wall. It was at first a very pleasing Divertisement, to view the vivid and intense Colours produced thereby; but after a while applying my self to consider them more circumspectly, I became surpriz'd to see them in an *oblong* Form; which, according to the received Laws of Rarefraction, I expected should have been *Circular*.

They were terminated at the sides with streight Lines, but at the ends, the decay of Light was so gradual, that it was difficult to determine justly, what was their Figure; yet they seem'd *Semicircular*. {98}

Comparing the length of this colour'd *Spectrum* with its breadth, I found it about five times greater; a disproportion so extravagant, that it excited me to a more than ordinary Curiosity of examining, from whence it might proceed. I could scarce think, that the various thickness of the Glass, or the termination with shadow or darkness, could have any Influence on Light to produce such an effect; yet I thought it not amiss, first to examine those Circumstances, and so try'd what would happen by transmitting Light through parts of the Glass of divers thicknesses, or through holes in the Window of divers bignesses, or by setting the Prism without, so that the Light might pass through it, and be refracted before it was terminated by the hole: But I found none of those Circumstances material. The fashion of the Colours was, in all these Cases, the same.

Then I suspected, whether by any unevenness in the Glass, or other contingent Irregularity, these Colours might be thus dilated. And to try this, I took another Prism like the former, and so plac'd it, that the Light passing through them both, might be refracted contrary ways, and so by

the latter return'd into that Course, from which the former had diverted it. For, by this means, I thought the *regular* effects of the first Prism would be destroy'd by the second Prism, but the *irregular* ones more augmented by the multiplicity of Refractions. The Event was, that the Light, which by the first Prism was diffused into an *oblong* Form, was, by the second, reduc'd into an {99} *orbicular* one, with as much regularity, as when it did not at all pass through them. So that whatever was the cause of that length, 'twas not any contingent Irregularity.

I then proceeded to examine more critically, what might be effected by the difference of the incidence of Rays coming from divers parts of the Sun; and to that end, measur'd the several Lines and Angles belonging to the Image. Its distance from the Hole or Prism was twenty two Foot; its utmost length 13¼ Inches; its breadth 2⅝; the Diameter of the Hole ¼ of an Inch; the Angle, with the Rays, tending towards the middle of the Image, made with those Lines, in which they would have proceeded without Refraction, was 44° 56'. And the Vertical Angle of the Prism, 63° 12'. Also the Refractions on both sides the Prism, that is, of the Incident, and Emergent Rays, were as near, as I could make them, equal, and consequently about 54° 4'. And the Rays fell perpendicularly upon the Wall. Now subducting the Diameter of the Hole from the length and breadth of the Image, there remains 13 Inches the length, and 2⅜ the breadth, comprehended by those Rays, which passed thro' the Center of the said Hole, and consequently the Angle of the Hole, which that breadth subtended, was about 31', answerable to the Sun's Diameter; but the Angle, which its length subtended, was more than five such Diameters, namely 2° 49'.

Having made these Observations, I first computed from them the refractive Power of that Glass, and found it measur'd by the *ratio* of the Sines, twenty to thirty one. And then, by that *ratio*, I computed the Refractions of two Rays flowing from opposite parts of the Sun's *discus*, so {100} as to differ 31' in their obliquity of Incidence, and found that the emergent Rays should have comprehended an Angle of about 31', as they did, before they were incident.

But because this Computation was founded on the Hypothesis of the proportionality of the Sines of Incidence and Refraction, which, tho' by my own Experience I could not imagine to be so erroneous as to make that Angle but 31', which in reality was 2° 49'; yet my Curiosity caus'd me again to take my Prism. And having plac'd it at my Window, as before, I observ'd, that by turning it a little about its *Axis* to and fro, so as to vary its obliquity to the light, more than an Angle of four or five Degrees, the Colours were not thereby sensibly translated from their place on the Wall, and consequently by that Variation of Incidence, the quantity of Refraction was not sensibly varied. By this Experiment therefore, as well as by the former Computation, it was evident, that the difference of the Incidence of Rays, flowing from divers parts of the Sun could not make them, after decussation, diverge at a sensibly greater Angle, than that at which they before converged; which being, at most, but about thirty one or thirty two Minutes, there still remain'd some other cause to be found out, from whence it could be two Deg. 49 Min.

Then I began to suspect, whether the Rays, after their Trajection through the Prism, did not move in curve Lines, and according to their more or less Curvity, tend to divers parts of the Wall. And it increas'd my suspicion, when I remember'd that I had often seen a Tennis-Ball, struck with an oblique Racket, describe such a curve Line. For a Circular as well as a Progressive Motion {101} being communicated to it by that stroak, its parts on that side, where the Motions conspire, must press and beat the contiguous Air more violently than on the other, and there excite a Reluctancy and Reaction of the Air proportionably greater. And for the same Reason, if the Rays of Light should possibly be globular Bodies, and by their oblique Passage out of one Medium into another, acquire a circulating Motion, they ought to feel the greater resistance from the ambient Æther, on that side, where this Motion conspires, and thence be continually bowed to the other. But notwithstanding this plausible ground of suspicion, when I came to examine it, I could observe no such Curvity in them. And besides (which was enough for my purpose) I observ'd, that the difference 'twixt the length of the Image, and Diameter of the Hole, through which the Light was transmitted, was proportionable to their distance.

The gradual removal of these suspicions, at length led me to the *Experimentum Crucis*, which was this; I took two Boards, and plac'd one of them close behind the Prism at the Window, so that the light might pass through a small hole, made in it for the purpose, and fall on the other Board, which I plac'd at about twelve Feet distance, having first made a small hole in it also, for some of that incident Light to pass through. Then I plac'd another Prism behind this second Board, so that the Light, trajected through both the Boards, might pass thro' that also, and be again refracted before it arrived at the Wall. This done, I took the first Prism in my Hand, and turn'd it to and fro slowly about its *Axis*, so much as to make the several parts of the Image, cast on the second Board, successively pass through the hole in it, that I might observe to what places on the Wall {102} the second Prism would refract them. And I saw by the Variation of those places, that the Light, tending to that end of the Image, towards which the Refraction of the first Prism was made, did, in the second Prism, suffer a Refraction considerably greater than the Light tending to the other end. And so the true cause of the length of that Image was detected to be no other, than that *Light* consists of *Rays differently refrangible*, which, without any respect to a difference in their incidence, were, according to their degrees of Refrangibility, transmitted towards divers parts of the Wall.

When I understood this, I left off my aforesaid Glass Works; for I saw, that the perfection of Telescopes was hitherto limited, not so much for want of Glasses truly figur'd, according to the prescriptions of Optick Authors (which all Men have hitherto imagin'd), as because that Light it self is a *Heterogeneous mixture of differently refrangible Rays*. So that, were a Glass so exactly figur'd, so as to collect any one sort of Rays into one Point, it could not collect those also into the same Point, which having the same Incidence upon the same Medium, are apt to suffer a different Refraction. Nay, I wonder'd, that seeing the difference of Refrangibility was so great, as I found it, Telescopes should arrive to that perfection they are now at. For, measuring the Refractions in one of my Prisms, I found, that, supposing the common Sine of Incidence upon one of its plains, was forty four Parts, the Sine of Refraction of the utmost Rays on the red end of the Colours, made out of the Glass into the Air, would be sixty eight parts, and the Sine of Refraction {103}
of the utmost Rays on the other end, sixty nine parts; so that the difference is about a twenty fourth or twenty fifth part of the whole Refraction. And consequently the Object glass of any Telescope cannot collect all the Rays, which come from one point of an Object, so as to make them convene at its *Focus* in less room than in a Circular space, whose Diameter is the fiftieth part of the Diameter of its Aperture; which is an irregularity, some hundred of times greater, than a circularly figur'd *Lens*, of so small a section as the Object-glasses of long Telescopes are, would cause by the unfitness of its Figure, were Light *uniform*.

This made me take *Reflections* into Consideration, and finding them regular, so that the Angle of Reflection of all sorts of Rays was equal to their Angle of Incidence; I understood, that by their mediation, Optick Instruments might be brought to any degree of Perfection imaginable, provided a *Reflecting* Substance could be found, which would polish as finely as Glass, and *reflect* as much Light as Glass *transmits*; and the art of communicating to it a *Parabolick* Figure be also attain'd. But there seem'd very great Difficulties, and I have almost thought them insuperable, when I further consider'd, that every Irregularity in a reflecting Superficies makes the Rays stray five or six times more out of their due course, than the like Irregularities in a refracting one; So that a much greater Curiosity would be here requisite, than in Figuring Glasses for Refraction.

Amidst these Thoughts I was forc'd from *Cambridge* by the Intervening Plague, and it was more than two Years before I proceeded further. But then having thought on a tender way of polishing, proper for Metal, whereby, as I imagin'd, the Figure also would be corrected to the last; I began {104}
to try what might be effected in this kind, and by degrees so far perfected an Instrument (in the essential parts of it like that I sent to *London*,) by which I could discern *Jupiter*'s four Concomitants, and shew'd them divers times to two others of my Acquaintance. I could also discern the Moon-like Phase of *Venus*, but not very distinctly, nor without some niceness in disposing the Instrument.

From that time I was interrupted, till this last Autumn, when I made the other. And as that was sensibly better than the first (especially for Day-Objects,) so I doubt not but they will be still brought to a much greater perfection by their Endeavours, who, as you inform me, are taking care about it at *London*.

I have sometimes thought to make a *Microscope*, which in like manner should have, instead of an Object-glass, a reflecting piece of Metal. And this I hope they will also take into Consideration: For those Instruments seem as capable of improvement as *Telescopes*, and perhaps more, because but one reflective piece of Metal is requisite in them, as you may perceive in *Plate 3. Fig. 1.* where *AB* representeth the Object Metal, *CD* the Eye-glass, *F* their common Focus, and *O* the other Focus of the Metal, in which the Object is placed.

But to return from this digression, I told you, that Light is not similar, or homogeneal, but consists of *difform* Rays, some of which are more refrangible than others: So that of those, which are alike incident on the same Medium, some shall be more refracted than others, and that not by any virtue of the Glass, or other external Cause, but from a predisposition, which every particular {105}
Ray hath to suffer a particular degree of Refraction.

I shall now proceed to acquaint you with another more notable deformity in its Rays, wherein the *Origin of Colours* is unfolded: Concerning which I shall lay down the *Doctrine* first, and then, for its Examination, give you an Instance or two of the *Experiments*, as a Specimen of the rest.

The Doctrine you will find comprehended and illustrated in the following Propositions.

1. As the Rays of Light differ in degrees of Refrangibility, so they also differ in their disposition to exhibit this or that particular Colour. Colours are not *Qualifications of Light*, derived from Refractions, or Reflections of natural Bodies, (as 'tis generally believed) but *Original* and *connate Properties*, which in divers Rays are divers. Some Rays are disposed to exhibit a red Colour and no other; some a yellow and no other, some a green and no other, and so of the rest. Nor are there only Rays proper and particular to the more eminent Colours, but even to all their intermediate Gradations.

2. To the same degree of Refrangibility ever belongs the same Colour, and to the same Colour ever belongs the same degree of Refrangibility. The *least Refrangible* Rays are all disposed to

exhibit a *Red* Colour, and contrarily those Rays, which are disposed to exhibit a *Red* Colour, are all the least Refrangible: So the *most Refrangible* Rays are all disposed to exhibit a deep *Violet Colour*, and contrarily those which are apt to exhibit such a *Violet Colour*, are all the most Refrangible. And so to all the intermediate Colours in a continued Series belong intermediate degrees of Refrangibility. And this Analogy 'twixt Colours, and Refrangibility, is very precise and {106} strict; the Rays always either exactly agreeing in both, or proportionally disagreeing in both.

3. The Species of Colour, and Degree of Refrangibility proper to any particular sort of Rays, is not mutable by Refraction, nor by Reflection from Natural Bodies, nor by any other Cause, that I could yet observe. When any one sort of Rays hath been well parted from those of other kinds, it hath afterwards obstinately retain'd its Colour, notwithstanding my utmost Endeavours to change it. I have refracted it with Prisms, and reflected it with Bodies, which in Day-light were of other Colours; I have intercepted it with the colour'd Film of Air interceding two compressed Plates of Glass; transmitted it through colour'd Mediums, and through Mediums irradiated with other sorts of Rays, and diversly terminated it, and yet could never produce any new Colour out of it. It would by contracting and dilating become more brisk, or faint, and by the loss of many Rays in some Cases very obscure and dark; but I could never see it chang'd *in specie*.

4. Yet seeming Transmutations of Colours may be made, where there is any mixture of divers sorts of Rays. For in such mixtures, the component Colours appear not, but by their mutual allaying each other, constitute a midling Colour. And therefore, if by Refraction, or any other of the aforesaid Causes, the differm Rays, latent in such a mixture, be separated, there shall emerge Colours different from the colour of the Composition. Which Colours are not new generated, but only made apparent by being parted; for if they be again intirely mix'd and blended together, they {107} will again compose that Colour, which they did before separation. And for the same reason, Transmutations made by the convening of divers Colours are not real; for when the differm Rays are again severed, they will exhibit the very same Colours, which they did before they entered the Composition; as you see, *Blue* and *Yellow* Powders, when finely mixed, appear to the naked Eye *Green*, and yet the Colours of the component Corpuscles are not thereby really transmuted, but only blended. For, when viewed with a good Microscope, they still appear *Blue* and *Yellow* interspersedly.

5. There are therefore two sorts of Colours. The one Original and Simple, the other compounded of these. The Original or Primary Colours are, *Red*, *Yellow*, *Green*, *Blue*, and a *Violet-purple*, together with Orange, Indico, and an indefinite variety of intermediate Gradations.

6. The same Colours in *Specie* with these primary Ones, may be also produced by Composition: For, a mixture of *Yellow* and *Blue* makes *Green*; of *Red* and *Yellow*, makes *Orange*; of *Orange* and *Yellowish Green*, makes *Yellow*. And in general, if any two Colours be mix'd, which in the Series of those, generated by the Prism, are not too far distant one from another, they by their mutual Alloy compound that Colour, which in the said Series appeareth in the mid-way between them. But those, which are situated at too great a distance, do not so. *Orange* and *Indico* produce not the intermediate *Green*, nor *Scarlet* and *Green* the intermediate *Yellow*.

7. But the most surprizing and wonderful Composition was that of *Whiteness*. There is no one sort of Rays which alone can exhibit this. 'Tis ever compounded, and to its Composition are {108} requisite all the aforesaid primary Colours, mix'd in a due proportion. I have often with admiration beheld, that all the Colours of the Prism being made to converge, and thereby to be again mixed as they were in the light before it was incident upon the Prism, reproduced light, intirely and perfectly white, and not at all sensibly differing from a *direct* light of the Sun, unless when the Glasses, I used, were not sufficiently clear; for then they would a little incline it to *their* Colour.

8. Hence therefore it comes to pass, that *Whiteness* is the usual Colour of *Light*; for Light is a confused aggregate of Rays, indued with all sorts of Colours, as they are promiscuously darted from the various parts of luminous Bodies. And of such a confused aggregate, as I said, is generated Whiteness, if there be a due proportion of the Ingredients; but if any one predominate, the Light must incline to that Colour; as it happens in the blue Flame of Brimstone, the yellow Flame of a Candle, and the various Colours of the fixed Stars.

9. These things consider'd, the *manner*, how Colours are produced by the Prism, is evident. For, of the Rays, constituting the incident Light, since those which differ in Colour proportionally differ in Refrangibility, *they* by their unequal Refractions must be severed and dispersed into an oblong Form, in an orderly succession, from the least refracted Scarlet to the most refracted Violet. And for the same reason it is, that Objects, when look'd upon through a Prism, appear coloured. For the differm Rays, by their unequal Refractions, are made to diverge towards several parts of the *Retina*, and there express the Images of things coloured, as in the former {109} case they did the Sun's Image upon a Wall. And by this inequality of Refractions, they become not only coloured, but also very confused and indistinct.

10. Why the Colours of the *Rainbow* appear in falling drops of Rain, is also from hence evident. For those drops, which refract the Rays, disposed to appear Purple, in greatest quantity to the

Spectator's Eye, refract the Rays of other sorts so much less, as to make them pass beside it; and such are the drops on the inside of the *Primary* Bow, and on the outside of the *Secondary* or Exteriour one. So those drops, which refract in greatest plenty the Rays, apt to appear red, toward the Spectator's Eye, refract those of other sorts so much more, as to make them pass beside it; and such are the drops on the Exteriour part of the *Primary*, and Interiour part of the *Secondary* Bow.

11. The odd Phænomena of an infusion of *Lignum Nephriticum*, *Leaf-gold*, *Fragments of colour'd Glass*, and some other transparently coloured Bodies, appearing in one Position of one Colour, and of another in another, are on these grounds no longer Riddles. For those are Substances apt to reflect one sort of Light, and transmit another; as may be seen in a dark Room, by illuminating them with similar or uncompounded Light. For then they appear of that Colour only, with which they are illuminated; but yet in one Position more vivid and luminous than in another, accordingly as they are disposed more or less to reflect or transmit the incident Colour.

12. From hence also is manifest the reason of an unexpected Experiment, which Mr. *Hook*, somewhere in his *Micrography*, relates to have made with two wedge-like transparent Vessels {110}
fill'd, the one with a red, the other with a blue Liquor; namely, that though they were severally transparent enough, yet both together became opake: For, if one transmitted only red, and the other only blue, no Rays could pass through both.

13. I might add more Instances of this Nature; but I shall conclude with this general one, that the Colours of all natural Bodies have no other Origin than this, that they are variously qualified to reflect one sort of Light in greater plenty than another. And this I have experimented in a dark Room, by illuminating those Bodies with uncompounded Light of divers Colours. For by that means any body may be made to appear of any Colour. They have there no appropriate Colour, but ever appear of the Colour of the Light cast upon them; but yet with this difference, that they are most brisk and vivid in the Light of their own day-light-colour. *Minium* appeareth there of any Colour indifferently, with which 'tis illustrated, but yet most luminous in red; and so *Bise* appeareth indifferently of any Colour with which 'tis illustrated, but yet most luminous in blue. And therefore *Minium* reflecteth Rays of any Colour, but most copiously those endu'd with red, and consequently when illustrated with day-light, that is, with all sorts of Rays promiscuously blended, those qualified with red, shall abound most in the reflected Light, and by their prevalence cause it to appear of that Colour. And for the same reason *Bise*, reflecting blue most copiously, shall appear blue by the excess of those Rays in its reflected Light; and the like of other Bodies. And that this is the intire and adequate cause of their Colours, is manifest, because {111}
they have no power to change or alter the Colours of any sort of Rays incident apart, but put on all Colours indifferently, with which they are enlightned.

These things being so, it can be no longer disputed, whether there be Colours in the dark, nor whether they be the Qualities of the Objects we see, no nor perhaps, whether Light be a Body. For, since Colours are the *Qualities* of Light, having its Rays for their intire and immediate Subject, how can we think those Rays *Qualities* also, unless one Quality may be the Subject of and sustain another; which in effect is to call it *Substance*? We should not know Bodies for Substances, were it not for their sensible Qualities; and the principal of those being now found due to something else, we have as good reason to believe that to be a Substance also.

Besides, whoever thought any Quality to be a *heterogeneous* Aggregate, such as Light is discovered to be? But to determine more absolutely, what Light is, after what manner refracted, and by what Modes or Actions it produceth in our Minds the Phantasms of Colours, is not so easie. And I shall not mingle Conjectures with Certainties.

Reviewing what I have written, I see the Discourse it self will lead to divers Experiments sufficient for its Examination; and therefore I shall not trouble you farther, than to describe one of those, which I have already insinuated.

In a darkned Room, make a hole in the shut of a Window, whose Diameter may conveniently be about a third part of an Inch, to admit a convenient quantity of the Sun's Light. And there place a clear and colourless Prism, to refract the entring Light towards the farther part of the Room; {112}
which, as I said, will thereby be diffused into an oblong coloured Image. Then place a *Lens* of about three Foot Radius (suppose a broad Object-glass of a three Foot Telescope,) at the distance of about four or five Foot from thence, through which all those Colours may at once be transmitted, and made by its Refraction to convene at a farther distance of about ten or twelve Feet. If at that distance you intercept this Light with a Sheet of white Paper, you will see the Colours converted into whiteness again by being mingled. But it is requisite, that the *Prism* and *Lens* be placed steady, and that the Paper, on which the Colours are cast, be moved to and fro; for, by such motion, you will not only find at what distance the whiteness is most perfect, but also see how the Colours gradually convene, and vanish into whiteness; and afterwards, having crossed one another in that place where they compound whiteness, are again dissipated and severed, and in an inverted order retain the same Colours, which they had before they entred the Composition. You may also see, that, if any of the Colours at the *Lens* be intercepted, the whiteness will be changed into the other Colours. And therefore, that the Composition of

whiteness be perfect, care must be taken that none of the Colours fall besides the *Lens*.

In the annexed Design, *Tab. 3. Fig. 2.* of this Experiment, *ABC* expresseth the Prism set endwise to sight, close by the hole *F* of the Window *EG*. Its vertical Angle *ABC* may conveniently be about 60 Degrees: *MN* designeth the *Lens*. Its breadth 2½ or 3 Inches. *SF* one of the streight Lines, in which difform Rays may be conceived to flow successively from the Sun. *FP*, and *FR* two {113}
of those Rays unequally refracted, which the *Lens* makes to converge towards *Q*, and after decussation to diverge again. And *HI* the Paper, at divers distances, on which the Colours are projected, which in *Q* constitute *Whiteness*, but are *Red* and *Yellow* in *R*, *r*, and ρ, and *Blue* and *Purple* in *P*, *p*, and π.

If you proceed further to try the impossibility of changing any uncompounded Colour (which I have asserted in the third and thirteenth Propositions,) 'tis requisite that the Room may be very dark, lest any scattering light, mixing with the Colour, disturb and allay it, and render it compound, contrary to the design of the Experiment. 'Tis also requisite, that there be a perfecter separation of the Colours, than, after the manner above described, can be made by the Refraction of one single Prism; and how to make such farther separations, will scarce be difficult to them, that consider the discovered Laws of Refractions. But if trial shall be made with Colours not throughly separated, there must be allowed changes proportionable to the mixture. Thus if compound Yellow Light fall upon blue *Bise*, the Bise will not appear perfectly yellow, but rather green, because there are in the yellow mixture many Rays indued with green, and green being less remote from the usual blue Colour of Bise than yellow, is the more copiously reflected by it.

In like manner, if any one of the Prismatick Colours, suppose red, be intercepted, on design to try the asserted impossibility of reproducing that Colour out of the others which are pretermitted; 'tis necessary, either that the Colours be very well parted before the red be intercepted; or that, together with the red, the neighbouring Colours, into which any red is {114}
secretly dispersed, (that is, the yellow, and perhaps green too) be intercepted; or else, that allowance be made for the emerging of so much red out of the yellow green, as may possibly have been diffused, and scatteringly blended in those Colours. And if these things be observed, the new Production of red, or any intercepted Colour, will be found impossible.

This, I conceive, is enough for an Introduction to Experiments of this kind; which if any of the *Royal Society* shall be so curious as to prosecute, I should be very glad to be informed with what success: That, if any thing seem to be defective, or to thwart this Relation, I may have an opportunity of giving farther Direction about it, or of acknowledging my Errors, if I have committed any.

Since the Publication of this Theory, some Misunderstandings happening between a French *Philosopher at* Paris *and Mr.* Newton*, he has endeavour'd to explain himself a little further in these Things, according to the following Method.*

A farther Explanation of the same Theory*.*

DEFINITIONS.

1. I call that Light Homogeneal, Similar, or Uniform, whose Rays are equally refrangible.

2. And that Heterogeneal, whose Rays are unequally refrangible.

Note, There are but three Affections of Light in which I have observ'd its Rays to differ; *viz.* Refrangibility, Reflexibility, and Colour; and those Rays which agree in Refrangibility, agree also {115}
in the other two, and therefore may well be defined Homogeneal; especially since Men usually call those things Homogeneal, which are so in all Qualities that come under their Knowledge, tho' in other Qualities, that their Knowledge extends not to, there may possibly be some Heterogeneity.

3. Those Colours I call Simple or Homogeneal, which are exhibited by Homogeneal Light.

4. And those Compound or Heterogeneal, which are exhibited by Heterogeneal Light.

5. Different Colours, I call, not only the more eminent Species, Red, Yellow, Green, Blue, Purple, but all other the minutest Gradations; much after the same manner, that not only the more eminent Degrees in Musick, but all the lead Gradations, are esteem'd different Sounds.

PROPOSITIONS.

1. The Sun's Light consists of Rays differing by indefinite Degrees of Refrangibility.

2. Rays which differ in Refrangibility, when parted from one another, do proportionally differ in the Colours which they exhibit. These Two Propositions are Matter of Fact.

3. There are as many Simple or Homogeneal Colours, as Degrees of Refrangibility. For to every Degree of Refrangibility belongs a different Colour, by *Prop.* 2. and that Colour is Simple, by *Def.* 1, and 3.

4. Whiteness, in all respects like that of the Sun's immediate Light, and of all the usual Objects

of our Senses, cannot be compounded of two Simple Colours alone. For such a Composition must {116}
be made by Rays that have only two Degrees of Refrangibility, by *Def.* 1 and 3. and therefore it cannot be like that of the Sun's Light. by *Prop.* 1. nor, for the same Reason, like that of ordinary white Objects.

5. Whiteness, in all respects, like that of the Sun's immediate Light, cannot be compounded of Simple Colours without an indefinite Variety of them. For to such a Composition, there are requisite Rays endu'd with all the indefinite Degrees of Refrangibility, by *Prop.* 1. And those infer as many Simple Colours, by *Def.* 1 and 3. and *Prop.* 2 and 3.

To make these a little plainer, I have added also the Propositions that follow.

6. The Rays of Light do not act on one another, in passing through the same Medium.

7. The Rays of Light suffer not any change of their Qualities from Refraction.

8. Nor afterwards from the adjacent quiet *Medium*: These two Propositions are manifest *de Facto* in Homogeneal Light, whose Colour and Refrangibility is not at all changeable, either by Refraction, or by the Contermination of a quiet *Medium*. And as for Heterogeneal Light, it is but an Aggregate of several sorts of Homogeneal Light, no one sort of which suffers any more alteration than if it were alone; because the Rays act not on one another, by *Prop.* 6. and therefore the Aggregate can suffer none. These two Propositions also might be further proved apart, by Experiments too long to be here described.

9. There can no Homogeneal Colours be reduced out of Light by Refraction, which were not commixt in it before. Because by *Prop.* 7. and 8. Refraction changeth not the Qualities of the Rays, but only separates those which have divers Qualities, by means of their different {117}
Refrangibility.

10. The Sun's Light is an Aggregate of an indefinite variety of Homogeneal Colours, by *Prop.* 1, 3, and 9. And hence it is, that I call Homogeneal Colours also Primitive or Original. And thus much concerning Colours.

For a further Illustration of this Doctrine, Mr. Newton*, in his Book of Opticks lately published, has by undeniable Experiments explained most of the Principal Phænomena of Light and Colours: To which we refer the Reader.*

{118}

A Demonstration concerning the Motion of Light, communicated from Paris.

PHilosophers have been labouring for many Years to decide by some Experiment, whether the Action of Light be conveyed in an instant to distant Places, or whether it requireth time. M. *Romer*, of the *Royal Academy* of Sciences, hath devised a way taken from the Observations of the first Satellit of *Jupiter*, by which he demonstrates, that for the distance of about 3000 Leagues, such as is very near the bigness of the Diameter of the Earth, Light needs not one Second of Time.

Let (in *Fig. 3. Plate 3.*) *A* be the *Sun*, *B Jupiter*, *C* the first Satellit of *Jupiter*, which enters into the shadow of *Jupiter*, to come out at *D*, and let *EFGHKL* be the *Earth*, placed at divers distances from *Jupiter*.

Now suppose the *Earth*, being in *L*, towards the second Quadrature of *Jupiter*, hath seen the first Satellit, at the time of its emersion, or issuing out of the shadow at *D*, and that about 42½ Hours after (*viz.* after one Revolution of this *Satellit*) the *Earth* being in *K*, do see it return'd in *D*: It is manifest, that if the Light require time to traverse the Interval *LK*, the *Satellit* will be seen return'd later in *D*, than it would have been if the *Earth* had remained in *L*. So that the Revolution of the *Satellit* being thus observ'd by the Emersions, will be retarded by so much time, as the {119}
Light shall have taken in passing from *L* to *K*; and that on the contrary, in the other Quadrature *FG*, where the *Earth* by approaching goes to meet the Light, the Revolutions of the Emersions will appear to be shortned, by so much as those of the Emersions had appear'd to be lengthned. And because 42½ Hours, which this *Satellit* very near takes to make one Revolution, the distance between the *Earth* and *Jupiter*, in both the Quadratures, varies at least 210 Diameters of the *Earth*: It follows, that if for the Account of every Diameter of the *Earth* there were required a Second of Time, the Light would take 3½ Minutes for each of the Intervals *GF*, *KL*; which would cause near half a quarter of an Hour between two Revolutions of the first *Satellit*, one observ'd in *FG*, and the other in *KL*, whereas there is not observed any sensible difference.

Yet doth it not follow hence, that Light demands no time. For after M. *Romer* had examin'd the thing more nearly, he found that what was not sensible in two Revolutions, became very considerable in many being taken together; and that, for Example, forty Revolutions observed on the side *F*, might be sensibly shorter, than forty others observ'd in any place of the *Zodiack* where *Jupiter* may be met with; and that in proportion of Twenty two for the whole Interval of *HE*, which is the double of the Interval that is from hence to the Sun.

The necessity of this new Equation of the Retardment of Light, is establish'd by all the

Observations that have been made in the *Royal Academy*, and in the *Observatory*, for the space of eight Years; and it hath been lately confirmed by the Emersion of the first *Satellit* observ'd at {120}
Paris, the *9th* of *November* last, at 5 a-clock 35' 45" at Night, 10 Minutes later than it was to be expected, by deducting it from those that had been observ'd in the Month of *August*, when the *Earth* was much nearer to *Jupiter*; which M. *Romer* had predicted to the said Academy from the beginning of *September*.

But to remove all doubt, that this Inequality is caused by the Retardment of the Light, he demonstrates, that it cannot come from any Excentricity, or other Cause of those that are commonly alledged to explicate the Irregularities of the *Moon*, and the other Planets; though he be well aware, that the first *Satellit* of *Jupiter* was Excentrick; and that, besides his Revolutions were advanced or retarded, according as *Jupiter* did approach to or recede from the Sun; as also, that the Revolutions of the *Primum Mobile* were unequal: Yet, saith he, these three last Causes of Inequality do not hinder the first from being manifest.

{121}

An introductory Essay *to the Doctrine of* Sounds*, containing some Proposals for the improvement of* Acousticks*; As it was presented to the* Dublin Society*, Nov. 12. 1683, by the Right Reverend Father in God* Narcissus *Lord Bishop of* Ferns *and* Leighlin*.*

BEing to treat of the Doctrine of *Sounds*, I hold it convenient to premise something in the general, concerning this Theory; which may serve at once to ingage your Attention, and excuse my Pains, when I shall have recommended them, as bestow'd on a Subject not altogether useless and unfruitful.

And for this purpose I shall omit to speak any thing of the *Excellency* of the Matter in Hand; though it might be celebrated by Arguments drawn from several Topicks, and particularly from this, that new Discoveries and Improvements may be made, both as to the *Generation*, *Propagation* and *Reception* of Sounds into the Sense; which, in a peculiar manner agrees to this, above the Object of any other Sense whatsoever. I shall, I say, omit these things, and apply my self wholly to the *Usefulness* of the Theory, that we are now falling upon, which I think cannot better be discovered, than by making a comparison 'twixt the Senses of *Seeing* and *Hearing*, as to {122}
their Improvements. I mean, by shewing, that this latter of *Hearing* is capable of all those improvements which the Sense of *Seeing* has receiv'd from Art, besides many more advantages that the *Ear* may enjoy, by the help of our Doctrine, above the *Eye*; all which moreover will be of as great benefit to Mankind, as any thing that *Opticks* have yet discover'd, if not of greater; which, with some other pre-eminencies that it has upon another Score, will happily render *Acousticks* the nobler Science of the two.

In order to the making good what I but now premised of the Comparison of these two Faculties of *Seeing* and *Hearing*, as to their Improvements, I observe;

That *Vision* is threefold, *Direct*, *Refracted*, and *Reflex'd*; answerable whereunto we have *Opticks*, *Dioptricks*, and *Catoptricks*.

In like manner *Hearing* may be divided into *Direct*, *Refracted* and *Reflex'd*; whereto answer three parts of our Doctrine of *Acousticks*, which are yet nameless, unless we call them *Acousticks*, *Diacousticks*, and *Catacousticks*, or (in another Sense, but to as good Purpose) *Phonicks*, *Diaphonicks*, and *Cataphonicks*.

I. Direct Vision has been improv'd two ways, *ex parte* Objecti, and *ex parte* Organi *vel* Medii.

1. *Ex parte Objecti*, Direct Vision has receiv'd advantages by the Arts of *Producing*, *Conserving* and *Imitating Light* and *Colours*, which are the Objects of Vision.

1. For the Art of *Producing Light*, we have the Frication of all hard Bodies that beget Fire; especially of the Flint and Steel; and instead of the Flint, most hard Stones (as well as the Cane) {123}
may be us'd to the same effect, as upon trial I have found. Add hereto the lately invented *Phosphorus*, which is a new and admirable way of producing a *Lucid Substance* by Art, out of a Body in itself not *Lucid*; and therefore may not unfitly be term'd an *Artificial production* of *Light*.

And then of the Art of *Conserving Light*, the *Lapis Bononiensis* is a notable Instance; and so happily were the *Sepulchral Lamps* of the Ancients.

2. As to *Colours*, 'tis the greatest part of the Art of *Dying* to be able to make and fix (that is preserve) them; and the *Painters* and *Limners* will own it to be no small part of their Skill to be able well to *Mix* (that is, in effect, to *Generate*) *Colours*.

3. For *Imitation of Light* and *Colours*, 'tis well known how far *Perspective* with the Art of *Limning* and *Shadowing* have gone therein, which all tend some way to the Advance or Improvement of *Direct Vision*.

Add to all these, That *a due Application of Light to the Object* renders it Visible, if it were not

so before; as appears from a dark Room illuminated; or else makes it better and more truly discernable by the Sense of *Seeing*, if before it might have been discern'd.

Hence the same *Colour*, in a diverse Light, will appear different, and no *Picture* can well be discern'd or judg'd of but by its true Light. Besides, the *Limner* will assure you, that he can hardly make true Work, or hit the Air of a Face exactly, unless he draw by a *North-Light*, by reason of the steadiness of that, and the uncertainty of all other Lights whatsoever. Which things {124}
shew, that the *Art of duly applying Light to the Object* does very much help and improve Vision. So also does the due placing of the *Object*, as to *Height* and *Distance*. But to enumerate all things that help *Direct Vision*, would be infinite.

2. *Ex parte Organi vel Medii*, Direct Vision has been improv'd by making use of a *Tube*, without Glasses, or a Man's clos'd Hand, to look thro'; which admitting into the *Eye* only the principal Rays, that come directly from the Object, do very much strengthen and clear the Sight, by excluding all the Collateral Rays, that crouding into the Eye, together with the direct ones, would confound and disturb it, partly by mixing and interfering with the direct Rays, and partly (or rather chiefly) by too much enlightning the fund of the Eye, wherein Vision is truly (tho' then imperfectly) made.

On this is founded the Art of making *Spectacles* without Glasses; (as well as *Tubes*) which is done by putting into the Glass-holes (instead of Glasses) two short *Tubes* of between three and four Inches long (for their length is to be vary'd according to the Age or Eye of the Beholder, and so also is the Diameter of the extream ends) which *Tubes* being made of *Spanish Leather* (or Past-board, or some such like Matter) and black'd on the inside, are so to be placed, as that the visual Rays, receiv'd thro' them, may meet in one point (or rather issue out from one Point) of the Object standing at such a due distance, as the Person may clearly and distinctly see it, or according to his length of Sight (as ABC, in the 4th *Fig. Tab.* 3.)

And these *Spectacles* may be suppos'd better for preserving the Sight, than the ordinary ones {125}
with Glasses, because they represent the Object more naturally, and withal more clearly and distinctly to the Eye, than the other, whose refracted Rays being collected together with the right ones in the Glasses, do somewhat confound good Vision, as before: Especially if the visive Power be strong enough to be sufficiently determin'd by the right Rays alone.

For I speak now of preserving a good Eye by these Spectacles, which holds in proportion true also of a bad one. Because those Rays (both right and refracted) being collected and brought so near the Eye (whether good or bad) as the Spectacles are usually plac'd, do too much affect it, both by their own brightness, and also by the brightness of the Colours of the Object (when they are bright) which is brought very near also; whereby the Eye is dazl'd and confounded, unless there be a strong attention and *conatus* of the Spirits, whereto the bright Rays do certainly engage them, which of necessity weakens Vision, especially if these Glass-spectacles be much us'd.

Wherefore the now describ'd new Tube-spectacles, contributing so much to the help and preservation of Sight, may well be counted an improvement of *Direct Vision*, because they convey the Rays to the Eye without any kind of Refraction whatsoever. Seeing the same Object also through various holes, plac'd at certain distances, does somewhat alter Vision; but of this perhaps more hereafter.

Now as *Direct Vision* has thus been improved, so likewise *Direct Hearing* partly has already receiv'd, and partly may by the Doctrine whereof we are treating, (if well cultivated) farther {126}
receive as great and notable Improvements, both *ex parte* Objecti, and *ex parte* Organi *vel* Medii.

1. As to the *Object* of Hearing, which is Sound, improvement has been and may be made, both as to the *Begetting*, and as to the *Conveying* and *Propagating* (which is a kind of *Conserving*) of Sounds.

1. As to the *Begetting* of Sounds. The Art of imitating any Sound, whether by *Speaking* (that is pronouncing) any kind of Language, (which really is an Art, and the *Art of Speaking*, perhaps one of the greatest) or by *Whistling*, or by *Singing* (which are allow'd Arts) or by *Hollowing* or *Luring* (which the Huntsman or Faulkner would have to be an Art also) or by imitating with the Mouth (or otherwise) the Voice of any Animal, as of *Quails*, *Cats*, and the like; or by *representing* any Sound begotten by the Collision of Solid Bodies, or after any other manner; these are all *Improvements* of *Direct Hearing*, and may be improv'd.

Moreover the Skill to make all sorts of *Musical Instruments*, both Ancient and Modern, whether *Wind* Instruments or *String'd*, or of any other sort, whereof there are very many (as *Drums*, *Bells*, the *Systrum* of the *Egyptians*, and the like) that beget (and not only propagate) Sounds; the Skill of making these, I say, is an Art, that has as much improv'd *Direct Hearing*, as an Harmonious Sound exceeds a single and rude one, that is, an immusical *Tone*; which Art is yet capable of farther improvement. And I do hope, that by the Rules, which may happily be laid down concerning the *Nature*, *Propagation* and *Proportion*, or *Adapting* of Sounds, a way may be found {127}
out, both to improve *Musical Instruments* already in use, and to invent new ones, that shall be more sweet and luscious, than any yet known. Besides that, by the same means *Instruments* may

be made, that shall imitate any Sound in Nature, that is not Articulate, be it of Bird, Beast, or what thing else soever.

2. The *Conveying* and *Propagating* (which is a kind of *Conserving*) of Sounds, is much help'd by *duly placing the Sonorous Body*, and also by the *Medium*.

For if the Medium be *Thin* and *Quiescent*, and the Sounding Body *plac'd conveniently*, the Sound will be easily and regularly propagated, and mightily conserv'd. I say,

1. If the *Medium be Thin and Quiescent*, because it otherwise causes a *Refracted Sound*, of which afterwards. Hence in a *still Evening*, or the *dead of the Night* (when the Wind ceases) a Sound is better sent out, and to a greater distance than otherwise, tho' much of this may be ascrib'd to its *Refraction* also.

2. I say, that the *Sonorous Body must be plac'd conveniently*, near a *Smooth Wall*, near *Water*, or *a Plain*, whose Surface is even.

1. Near a *Smooth Wall*, either Plain or Arch'd (Cycloidically or Elliptically, rather than otherwise, tho' a Circular or any Arch will do, but not so well.)

Hence in a Church, the nearer the Preacher stands to the Wall (and certainly 'tis much the best way to place Pulpits near the Wall) the better is he heard, especially by those who stand near the Wall also, though at a greater distance from the Pulpit; those at the remotest end of the Church, by laying their Ears somewhat close to the Wall, may hear him easier than those in the middle. {128}

Hence also do arise *Whispering Places*. For the Voice being apply'd to one end of an Arch, easily rowls to the other. And indeed were the *Motion* and *Propagation* of Sounds but rightly understood, 'twould be no hard matter to contrive *Whispering Places* of infinite variety and use. And perhaps there could be no better or more pleasant hearing a *Consort of Musick* than at such a place as this, where the Sounds rowling along together, before they come to the Ear, must needs consolidate and imbody into one; which becomes a true composition of Sounds, and is the very Life and Soul of Consort.

2. If the Sonorous Body be plac'd near *Water*, the Sound will easily be convey'd, yet mollified; as Experience teacheth us from a Ring of *Bells* near a River, and a great *Gun* shot off at Sea, which yet differ much in the strength, and softness and continuance, or propagation of their Sounds, from the same at Land, where the Sound is more harsh and more perishing, or much sooner decays.

3. In a *Plain* a Voice may be heard at a far greater distance than in uneven Ground.

The *Reason* of all which last nam'd *Phænomena* is the same; because the Sonorous Air meeting with little or no resistance upon a *Plane* (much less upon an Arch'd) smooth Superficies, easily rowls along it, without being let or hinder'd in its Motion, and consequently without having its parts disfigured, and put into another kind of Revolution, than what they had at the first begetting of the Sound. Which is the true cause of its *Preservation* or *Progression*, and fails much when the Air passes over an uneven Surface, according to the degrees of its inequality, and {129} somewhat also, when it passes over the plain Superficies of a Body that is hard and resisting.

Wherefore the smooth Top of the Water (by reason of its yielding to the Arch'd Air, and gently arising again with a kind of Resurge, like to *Elasticity*, tho' it be not so, by which Resurge it quickens and hastens the motion of the Air rowling over it, and by its yielding preserves it in its Arch'd Cycloidical or Elliptical Figure) the smooth Top of the Water, I say, for these Reasons, and by these Means, conveys a Sound more entire, and to a greater distance than the plain Surface of a piece of Ground, a Wall, or any other Solid Body whatever, can do.

As for the *Speaking Trumpet*, by which a Voice may be convey'd to a considerable distance, I refer its consideration to that of *Refracted Sounds*, or *Refracted Audition*.

Thus much of the Improvements of Hearing, that respect its *Object*, which is *Sound*.

2. The *Organ* and *Medium* are to be consider'd. And, 1. The *Organ*, which is the *Ear*, is helpt much by placing it near a Wall (especially at one end of an Arch, the Sound being begotten at the other) or near the Surface of Water, or of the Earth, along which the Sounds are most easily and naturally convey'd, as was before declar'd. And 'tis incredible how far a Sound made upon the Earth (by the trampling of a Troop of Horses, for Example) may be heard in a still Night, if a Man lays his Ear close to the Ground in a large Plain.

Otacousticks here come in for helping the *Ear*; which may be so contriv'd (by a right {130} understanding the *Progression of Sounds*, which is the principal thing to be known for the due regulating all such kinds of Instruments) as that the Sound might enter the Ear without any Refraction, but as now they are generally made I refer them to *Refracted Audition*.

2. As to the *Medium*, I know not how that, by any contrivance of Art, can advantage *Direct Hearing*, otherwise than I have declar'd already in the propagation or conveyance of Sounds, though to the Refracting or Reflecting of them it may very much conduce; of which presently.

And so I have done with the first part of my present undertaking, which is the *Comparison of*

Direct Vision and Audition, as to their Improvements from Art. The rest follow. Wherefore,

II. Concerning *Refracted Vision* and its Comparison, I observe, That *Refracted Vision* is always made *Ex parte Medii*, as *Reflected* is *ex parte Objecti*. And therefore, though *Direct Vision* may be help'd *ex parte Objecti, Medii vel Organi*, yet *Refracted* can be improv'd only *ex parte Medii*, and *Reflected ex parte Corporis oppositi* alone. Unless it be in a mixt or compound Vision, that is *Refracto-Reflext*, when the reflext Rays pass to the Eye through a refracting Medium, such as the *Medium Internum*, contain'd in the Body of the Eye, always is. So that in truth, all Vision is *Refracted* by an internal Refraction made in *ipso Oculo*.

And all that I have spoken of *Vision* holds true of *Hearing* also, both *Refracted* and *Reflext*, and therefore need not be repeated. {131}

Refracted Vision arises from the different *Density*, *Figure*, and *Magnitude* of the Medium, which is somewhat alter'd also by the diverse incidence of the visible Rays. And so it is in *Refracted Hearing*, all these Causes concur to its Production, and some others to be hereafter consider'd.

Now as any Object (a Man for example) seen through a thicken'd Air, by *Refraction* appears greater than really he is: So likewise a *Sound*, heard through the same thicken'd part of the *Atmosphere*, will be considerably vary'd from what it would seem to be, if heard through a thinner Medium.

And this I call a *Refracted Sound*: But what this Refraction of Sound is, and how caus'd, may hereafter be discuss'd, when the Nature, and Motion, or Progression of Sounds are well stated.

For the Improvement of *Refracted Vision* artificial Instruments have been made, by grinding or blowing Glasses, into a certain Figure, and placing them at due distances, whereby the Object may be (as 'twere) enabled to send forth its Rays more vigorously, and the Visive Faculty impower'd the better to receive them. And thus also Instruments may be contriv'd for the assisting both the *Sonorous Body*, to send forth its Sound more strongly, and the *Acoustick Faculty*, to receive and discern it more easily and clearly. *For*,

1. As a fine *Glass Bubble*, fill'd with clear Water, and placed before a burning Candle or Lamp, does help it to dart forth its Rays to a prodigious Length and Brightness: So an *Instrument* may be invented, that apply'd to the Mouth (or any Sonorous Body) shall send forth the Voice distinctly to as prodigious a Distance and Loudness. {132}

For if the *Stentoro-phonecon* (which is but a rude and unartificial Instrument) does such great feats, what might be done with one compos'd according to the Rules of Art? whose make should comply with the Laws of *Sonorous Motion* (which that does not) and therefore not so much *Refract*, as to alter and confound the *Tone* of the *Voice* and Words (as that somewhat does.)

Now of what use such an Instrument might be for speaking clearly and articulately at a distance (and that without altering the Tone of the Voice) whether it be at Sea or at Land (but especially at Sea in tempestuous Weather and in the Night) is obvious to any Man to conceive.

2. As Instruments have been invented to help the Eye, So likewise are there some, and more such there may be, for the Ear.

For,

1. As *Spectacles* and other *Glasses* are made to help the *Purblind* and weak *Eyes*, to see at any competent distance: So there are *Otacousticks* (and better may be made) to help weak *Ears* to hear at a reasonable distance also. Which would be as great a help to the infirmity of Old Age, as the other invention of Spectacles is, and perhaps greater; forasmuch as the Hearing what's spoken is of more daily use and concern to such Men, then to be able to *read Books* or to *view Pictures*.

2. As *Perspective-Glasses* and Telescopes help the Eye to see Objects at a very great distance, which otherwise would not be discernable; in like manner may a sort of *Otacousticks* be so contriv'd, as that they shall receive in *Sounds* made at a very great distance also, but with so much advantage, that the Ear shall be able to hear them, which otherwise would have been *inaudible*. {133}

And these *Otacousticks* in some respects would be of greater use than *Perspectives*. For whereas at Land *Perspectives* are many times render'd almost useless, by the interposition of Woods and Mountains, which hinder the Sight from reaching very far: Our *Otacousticks* would, notwithstanding these Obstacles, take in a Sound made some Leagues off. Which might be of notable use in the time of War, for discovering the Enemy at a good distance, when he marches or lyes incamp'd behind a Mountain or Wood, or any such place of shelter.

Yea, even at Sea also, where *Perspectives* are of most use, by reason of the plainess of the Surface of the Water; yet sometimes there *Otacousticks* may be of more benefit, when in dark hazy Weather the Air is too thick, or in Stormy Tempestuous Weather the Waves arise too high for the *Perspective* to be made use of.

But, whether at Sea or Land, *Perspectives* become altogether insignificant in the Night-time (unless it be for viewing the Stars) which is the chief time for using *Otacousticks*; as it is generally, for Soldiers to take their March, when they would surprise their Enemies.

And therefore this sort of *Otacousticks* have then their chief use, when *Perspectives* are of no {134}
use at all; besides that they may be imploy'd in the Day-time, as well as *Perspectives*, whence they may (not unfitly) be term'd *the most useful Instrument* of the two.

3. As *Microscopes* or *Magnifying-Glasses* help the Eye to see near Objects, that by reason of their smallness were *Invisible* before; which Objects they Magnify to a strange greatness: So *Microphones* or *Micracousticks*, that is Magnifying Ear Instruments, may be contriv'd after that manner, that they shall render the most minute Sound in nature distinctly audible, by Magnifying it to an unconceivable loudness.

By the help hereof we may hear the different Cries and Tones, as well as by *Microscopes* see the divers Shapes and Figures of the smallest Animals.

4. As by *Polyscopes* or *Multiplying-Glasses*, one thing is represented to the Eye as many, whether in the same or different Shapes (for so Multiplying-Glasses may be contriv'd:) So by a *Polyphone* or *Polyacoustick* well order'd, one *Sound* may be heard as many, either of the same or a different Note. Insomuch, that who uses this Instrument, he shall, at the Sound of a single Viol, seem to hear a whole Consort and all true Harmony. By which means this Instrument has much the advantage of the *Polyscope*.

And thus much may suffice for comparing the Improvements made upon *Refracted Seeing and Hearing*; I call it *Refracted Hearing*, because made through a *Medium*, viz. thick Air, or an Instrument, through which the Sound passing is broken or refracted.

III. *Reflected Vision* has been improv'd by the Invention of *Looking-glasses* and *Polished* {135}
Metals, whether *Plane*, *Concave*, or *Convex*; and these two last, either *Spherical*, *Oval*, *Cylindrical*, *Conical*, *Hyperbolical*, or of several other shapes; all which cause a different Reflection, and vary the *Phænomena*.

Thus also *Reflext Audition*, made by *Ecchoes*, may be improv'd, by contriving several sorts of *Artificial Ecchoes*; as 'tis no hard matter to do in almost any place.

For (speaking in the general) *Any Sound, falling directly or obliquely upon any dense Body, of a smooth (whether Plane or Arch'd) Superficies, is beat back again and reflected, or does eccho more or less*.

I say (1.) *falling directly or obliquely*; because, if the Sound be sent out and propagated parallel to the Surface of the *Dense Body*, or be made so *far off* and so *weak*, that it cannot reach it, there will be no Reflection of Sound, no *Eccho*.

I say (2.) *upon a Body of a smooth Superficies*; because if the Surface of the *Corpus Obstans* be uneven, the Air by reverberation will be put out of its regular Motion, and the Sound thereby broken and extinguish'd: So that tho' in this case also the Air be beaten back again, yet Sound is not reflected, nor is there any Eccho.

I say (3.) *it does eccho more or less*, to shew, that when all things are, as is before describ'd, there is still an Ecchoing, though it be not always heard; either because the *direct Sound* is too weak to be beaten quite back again to him that made it; or that it does return home to him, but so weak, that without the help of a good *Otacoustick*, it cannot be discern'd; or that he stands in a {136}
wrong place, to receive the reflected Sound, which passes over his head, under his Feet, or to one side of him; which therefore may be heard by a Man standing in that place, where the reflected Sound will come, provided no interpos'd Body does intercept it; but not by him, that first made it.

I shall further make out the comparison 'twixt *Reflex'd Vision* and *Audition*, by these following *Propositions*.

1. As a *Plain Speculum* reflects the *Object* in its due *Dimensions* and *Colours*; allowing for their difference of appearance, according to their distance: So a *Plane Corpus Obstans* reflects the *Sound* back in its due *Tone* and *Loudness*; if allowance be likewise made for the proportionable decrease of the Sound, according to its distance.

2. As a *Convex Speculum* reflects the *Object less*, but somewhat *brighter* or clearer: So a *Convex Corpus Obstans* repels the Sound (insensibly) *smaller*; but somewhat *quicker* (though *weaker*) than otherwise it would be.

3. As a *Concave Speculum* reflects the Object *bigger*, more obscure and *Inverted*: So a *Concave Corpus Obstans* ecchoes back the Sound (insensibly) *bigger*, *slower* (though *stronger*) and also *inverted*; but never according to the order of Words. Nor do I think it possible for the Art of Man to contrive a *Single Eccho*, that shall invert the Sound, and repeat backwards; because then the Words last spoken, that is, which do last occur to the *Corpus Obstans*, must first be repell'd; which cannot be: For where, in the mean time, should the first Words hang, and be conceal'd, or

lie dormant? Or how, after such a pause, be reviv'd and animated again into Motion? Yet in complicated or *Compound Ecchoes*, where many receive from one another, I know not whether something that way may not be done. {137}

From the determinate *Concavity* or *Archedness* of these reflecting Bodies, it comes to pass, that some of them, from a certain distance or posture, will eccho back but one determinate Note, and from no other place will they reverberate any; because of the undue Position of the sounding Body. Such an one (as I remember) is the Vault in *Merton* College in *Oxford*.

4. As a *Speculum* takes in and reflects more of its Object, when plac'd at a great distance from it, than when nearer; because it reflects according to the apparent Magnitude of the Body at such a distance, which is less: So also the *Ecchoing Body*, being remov'd farther off, reflects more of the Sound, than when nearer. And this is the reason, why some Ecchoes repeat but one Syllable, some one Word, and some many.

5. As *Specula's* may be so plac'd, that reflecting one upon or into the other, either directly or obliquely, one Object shall appear many; as in Sir *Samuel Moreland*'s Glass-room: After the same manner *Ecchoing Bodies* may be so contriv'd and plac'd, as that reflecting the Sound from one to the other, either directly and mutually, or obliquely and by Succession, out of one Sound shall many Ecchoes be begotten; which in the first case will be all together, and somewhat involv'd or swallow'd up of each other, and thereby confus'd (as a Face in Looking-glasses obverted) in the other they will be distinct, separate, and succeeding one another; as most *multiple Ecchoes* do.

Moreover a *Multiple-Eccho* may be made, by so placing the *Ecchoing Bodies*, at unequal distances, that they reflect all one way, and not one on the other; by which means a manifold successive Sound will be heard (not without astonishment) one Clap of the hands like many, one Ha, like a laughter, one single Word like many of the same Tone and Accent, and so one Viol like many of the same kind imitating each other. {138}

Furthermore, as *Specula's* may be so order'd, that by Reflection they shall make one single thing appear many different things; as one single Man to seem many Men, differing as to Shape and Complexion (or a company of Men) which I think Sir *Samuel Moreland*'s Contrivance does not: So may *Ecchoing Bodies* also be order'd, that from any one Sound given, they shall produce many Ecchoes, different both as to their *Tone* and *Intension*. (The ground whereof has elsewhere been laid down in a Treatise concerning the *Sympathy of Lute-strings*.)

By this means a *Musical Room* may be so contriv'd, that not only one Instrument, play'd on in it shall seem many of the same *sort* and *size*; but even a Consort of (somewhat) different ones; only by placing certain *Ecchoing Bodies* so, as that any Note (play'd) shall be return'd by them in 3*ds*, 5*ths*, and 8*ths*, which is possible to be done otherwise than was mention'd before in *Refracted Audition*.

I have now done with my *Comparison* of the two Noblest *Senses*, and *Sciences*, as to their *Improvements*; wherein I have been thus large, that I might give you a little prospect into the *Excellency* and *Usefulness* of *Acousticks*; and that thereby I might excite all that hear me, to bend their Thoughts towards the making of Experiments for the compleating this (yet very imperfect, tho' noble) Science; a *Specimen* whereof I will give you in three *Problems*, and then present you with the *Semiplane* of an *Acoustick or Phonical Sphere*, as an Attempt to explicate the great *Principle* in this Science, which is *The Progression of Sounds*. {139}

The Problems are these:

1. *Sonum intendere quousque velis*; or, *Datum sonum ad datum gradum intendere*.

2. *Sonum extendere quousque velis*; or, *Datum sonum ad datum distantiam extendere seu propagare*.

3. *Sonum transire ab extremo ad extremum* & *non per Medium*.

1. The first is, *To make the least Sound* (by the help of Instruments) *as loud as the greatest*; a whisper to become as loud as the shot of a Cannon.

By the help of this *Problem*, the most minute Sounds in Nature may be clearly and distinctly heard.

2. The second is, *To propagate any* (the least) *Sound to the greatest distance*.

By the help hereof any Sound may be convey'd to any, and therefore heard at any distance, (I must add, within a certain, tho' very large Sphere.)

Moreover, by this means, a *Weather-cock* may be so contriv'd, as that with an ordinary blast of Wind it shall cry (or whistle) loud enough to be heard many Leagues: Which happily may be found of some use, not only for *Pilots* in mighty tempestuous Weather, when *light Houses* are render'd almost useless, but also for the measuring the strength of Winds, if allowance be made for their different moisture. For I conceive, that the more dry any Wind is, the louder it will whistle *cæteris paribus*; I say, *cæteris paribus*, because, besides the strength and dryness of {140}

Winds or Breath, there are a great many other things (hereafter to be considered) that concur to the increase or magnifying of Sounds, begotten by them in an Instrument exposed to their Violence, or blown into.

3. The third *Problem*, is, *That a Sound may be convey'd from one extreme to the other* (or from one distant place to another) *so as not to be heard in the middle*.

By the help of this *Problem* a Man may talk to his Friend at a very considerable distance, so that those in the middle space shall hear nothing of what passed betwixt them.

FIG. V. TAB. III.

Semiplanum Sphæræ Phonicæ seu Acousticæ.

You are to conceive that (rude) *Semiplane*, as parallel to the *Horizon*: For if it be perpendicular thereunto, I suppose the upper extremity will be no longer *Circular*, but *Hyperbolical*, and the lower part of it suited to a greater Circle of the Earth. So that the whole *Phonical* Sphere (if I may so call it) will be a solid *Hyperbola*, standing upon a *Concave Spherical* Base. I speak this concerning *Sounds* made (as usually they are) nigh the Earth, and whose Sonorous *Medium* has a {141} free passage every way. For if they are generated high in the Air, or directed one way, the case will be different; which is partly design'd in the inequality of that Draught.

{142}

A Discourse concerning the Modern Theory *of* Generation*, by Dr.* George Garden *of* Aberdeen*, being part of a Letter to Dr.* William Musgrave*, L. L. D. Reg. Soc. S. and by him communicated the Royal Society.*

THE Subject I pitch upon, is that of the Formation of Animals. You know how wide and unsatisfying Men's Conjectures were upon this Head, until this Age, in which first the deservedly Famous Dr. *Harvey* discovered the proper place of the Formation of the Chick in the *Cicatricula* of the Egg, and the Formation of the Parts so far as was discernable by the naked Eye; and after him *Malpighius*, by the help of exact Glasses, observ'd the first Rudiments of it there, both before and after Incubation: And *R. de Graef*, and others, having upon many Observations concluded, that the *Testes Fœminei* were the Ovaries of Females, and consequently that all Animals were *ex ovo*; they began from hence to infer, that the Rudiments of each Animal were originally in the respective Females, and that the Male contributed only to give a new Ferment to the Mass of the Blood and Spirits, by which means a spirituous Liquor (which the Blood in its ordinary Ferment could not produce) did insinuate it self into the same Ducts and {143} Pores of the Rudiments of those Animals, which were in greatest forwardness in the Ovary, and so extend and enlarge all their Parts, and at last bring them to perfection, as Mr. *Perrault* does ingeniously discourse in the third Part of his *Essais de Physique*; till now at last *Leowenhoek* has discover'd an infinite number of *Animalcula in semine marium* of all kinds, which has made him condemn the former Opinions about the Propagation of all Animals *ex Ovo*.

Now upon comparing the Observations and Discoveries which have been made with one another, these three things seem to me very probable. 1. That Animals are *ex Animalculo*. 2. That these Animalcles are originally *in semine Marium* & *non in Fœminis*. 3. That they can never come forward, nor be formed into Animals of the respective kind, without the *Ova in Fœminis*.

The first of these seems probable from these three Observations. 1. That some such thing has been so often observ'd by *Malpighius*, in the *Cicatricula* of an Egg before Incubation, as the Rudiments of an Animal in the shape of a Tadpole, as may be seen in his first, and in his repeated Observations *de formatione Pulli in Ovo*. 2. The sudden appearance and displaying of all the Parts after Incubation, makes it probable, that they are not then actually formed out of a fluid, but that the *Stamina* of them have been formerly there existent, and are now expanded. The first Part of the Chick which is discovered with the naked Eye, is, you know, the *Punctum saliens*, and that not till three days and nights of Incubation be past; and then, on the fifth day, the Rudiments of {144} the Head and Body do appear. This made Dr. *Harvey* conclude, that the Blood had a being before any other Part of the Body; and that from it, all the Organs of the *Fœtus* were both form'd and nourished: But by *Malpighius*'s Observations we find that the Parts are then only so far extended, as to be made visible to the naked Eye, and that they were actually existent before, and discernable by Glasses. After an Incubation of thirty hours, are to be seen the Head, the Eyes, and the *Carina* with the *Vertebræ*, distinct, and the Heart. After forty hours its Pulse is visible, and all the other Parts more distinct, which cannot be discerned by the naked Eye before the beginning of the fifth day; from whence it seems probable, that even the so early discovery of those Parts of the *Fœtus* by the Microscope, is not the discerning of Parts newly formed, but only more dilated and extended by receiving of Nutriment from the *Colliquamentum*; so that they seem all to have been actually existent before the Incubation of the Hen. And what *Swammerdam* has discovered in the transformation of Insects, gives no small light to this; whilst he makes appear in the Explanation of the 13th Table of the General History of Insects, that in those large *Eruca's* which feed upon Cabbage, if they be taken about the time they retire to be transformed

into *Aurelia's*, and plung'd often in warm Water to make a Rupture of the outer Skin, you will discern through the transparency of their second Membrane, all the Parts of the Butterfly, the Trunk, Wings, Feelers, *&c.* folded up. But that after the *Eruca* is chang'd into an *Aurelia*, none of these Parts can be discern'd, they are so drencht with moisture, tho' they be there actually {145} form'd. Another Consideration is from the Analogy, which we may suppose between Plants and Animals. All Vegetables we do see proceed *ex Plantula*, the Seeds of Vegetables being nothing else but little Plants of the same kind folded up in Coats and Membranes; and from hence we may probably conjecture, that so curiously an organized Creature as an Animal, is not the sudden Product of a Fluid or *Colliquamentum*, but does much rather proceed from an Animalcle of the same kind, and has all its little Members folded up according to their several Joints and Plicatures, which are afterwards enlarged and distended, as we see in Plants. Now tho' this Consideration alone may seem not to bear much weight; yet being join'd to the two former, they do mutually strengthen each other. And indeed all the Laws of Motion, which are as yet discovered, can give but a very lame account of the forming of a Plant or Animal. We see how wretchedly *Des Cartes* came off when he began to apply them to this Subject; they are formed by Laws yet unknown to Mankind; and it seems most probable, that the *Stamina* of all the Plants and Animals that have been, or ever shall be in the World, have been form'd, *ab Origine Mundi*, by the Almighty Creator within the first of each respective kind. And he who considers the Nature of Vision, that it does not give us the true magnitude, but the proportion of things; and that what seems to our naked Eye but a Point, may truly be made up of as many Parts as seem to us to be in the whole visible World, will not think this an absurd or impossible thing.

But the second thing which later Discoveries have made probable, is, that these Animalcles are {146} originally *in Semine Marium* & *non in Fœminis*. And this I collect from these Considerations: 1. That there are innumerable *Animalcula* discover'd *in Semine Masculo omnium Animalium*. Mr. *Leewenhoeck* has made this so evident by so many Observations, that I do not in the least question the truth of the thing. The reason of their Multitude, and some of the Difficulties which arise thereupon, he has cleared to very good Purpose, so that I shall not repeat them. 2. The observing the Rudiments of the *Fœtus* in Eggs, which have been fecundated by the Male, and the seeing no such thing in those which are not fecundated, as appears from *Malpighius* his Observations, make it very probable that these Rudiments proceed originally from the Male, and not from the Female. 3. The resemblance between the Rudiments of the *Fœtus in Ovo*, both before and after Incubation, and the *Animalcle*, makes it very probable, that they are one and the same. The same Shape and Figure which Mr. *Leewenhoeck* gives us of the *Animalcle*, *Malpighius* likewise gives of the Rudiments of the *Fœtus*, both before and after Incubation; yea, and even the *Fœtus's* of Animals do appear so at first to the naked Eye, so that Dr. *Harvey* does acknowledge that all Animals, even the most perfect, are begotten of a Worm, *De Gen. Anim. Ex.* 18. 4. This gives a rational account of many *Fœtus's* at one Birth, especially that of the Countess of *Holland*, and how at least a whole Cluster of Eggs in a Hen are fecundated by one Coition of the Male. 5. This gives a new light, as it were, to the first Prophecy concerning the *Messiah*, that the Seed {147} of the Woman shall bruise the Head of the Serpent, all the rest of Mankind being thus most properly and truly the Seed of the Man. 6. The Analogy I have already mentioned, which we may rationally suppose between the manner of the propagation of Plants and Animals, does likewise make this probable. Every Herb and Tree bears its Seed after its kind; which Seed is nothing else but a little Plant of the same kind, which being thrown into the Earth, as into its *Uterus*, spreads forth its Roots, and receives its Nourishment, but has its form within its self, and we may rationally conjecture some such Analogy in the Propagation of Animals.

The third Particular which later Discoveries make probable, is, that Animals cannot be formed of these *Animalcula* without the *Ova in fœminis*, which are necessary for supplying of them with proper Nutriment: And this these Considerations seem to evince. 1. It is probable that an *Animalcle* cannot come forward, if it do not fall into a proper *Nidus*. This we see is the *Cicatricula* in Eggs; and tho' a Million of them should fall into an Egg, none of them would come forward, but what were in the Center of the *Cicatricula*; and perhaps the *Nidus* necessary for their formation is so proportion'd to their bulk, that it can hardly contain more than one *Animalcle*; and this may be the reason why there are so few Monsters. This we see is absolutely necessary in *Oviparis*; and the only difference which seems to be between them and the *Vivipara*, in this matter, is in this, that in the latter the *Ova* are properly nothing more but the *Cicatricula*, with its *Colliquamentum*, so that the *Fœtus* must spread forth its Roots into the *Uterus* to receive its {148} nourishment; but the Eggs in *Oviparis* may be properly term'd an *Uterus*, in relation to the *Fœtus*; for they contain not only the *Cicatricula*, with its *Amnion* and the *Colliquamentum*, which is the immediate nourishment of the *Fœtus*, but also the materials which are to be converted into that *Colliquamentum*; so that the *Fœtus* spreads forth its Roots no farther than into the White and Yolk of the Egg, from whence it derives all its nourishment. Now that an Animalcle cannot come forward without some such proper *Nidus*, Mr. *Leewenhoeck* will not readily deny; for if there were nothing needful, but their being thrown into the *Uterus*, I do not see why many hundreds of them should not come forward at once; for as to what Mr. *Leewenhoeck* says, that one of them would be-dwarf and choak the rest; this might fall out in process of time: But at first I do not see why many of them should not grow together, whilst scatter'd in so large a Field (and

yet no such thing is observed) if there were not an absolute necessity of a *Cicatricula* for their growth and thriving. Now, 2. That this *Cicatricula* is not originally in *Utero*, seems evident from the frequent Conceptions which have been found *extra Uterum*: Such as the Child which continued Twenty six Years in the Woman of *Tholouse*'s Belly, mention'd *Numb.* 139. of the *Philos. Trans.* And the little *Fœtus* found in the *Abdomen de St. Mere*, together with the Testicle torn and full of clotted Blood, recorded *Numb.* 150. both taken out of the Journals *des Savans*: Such also seem to be the *Fœtus* in the *Abdomen* of the Woman of *Copenhagen*, mention'd in the *Nouvelles des Lettres*, for *Sept.* 85. *pag.* 996. all the Members of which were easily to be felt {149}
through the Skin of the Belly, and which she had carried in her Belly for four Years; and the seven Years Gravidation, related by Dr. *Cole*, *Numb.* 172. of the *Transact.* That these two were undoubtedly *extra Uterum*, is uncertain, because the last was not open'd after her death, and the former may be yet still alive. Now granting once the necessity of a proper *Nidus*, for the formation of an Animalcle into the Animal of its respective kind; these Observations make it probable, that the *Testes* are the *Ovaria* appropriated for this use; for tho' the Animalcles coming thither in such Cases may seem to be extraordinary, and that usually the Impregnation is in *Utero*; yet it may be collected from hence, that the *Cicatriculæ* or *Ova* to be impregnated, are in *Testibus fœmineis*; for if it were not so, the accidental coming of Animalcles thither could not make them come forward more than in any other part of the Body, since they cannot be formed and nourished without a proper *Nidus*. But 3. It is acknowledg'd by all, that the *Fœtus in Utero*, for some considerable time after Conception, has no connexion with the Womb, that it sits wholly loose to it, and is perfectly a little round Egg with the *Fœtus* in the midst, which sends forth its Umbilical Vessels by degrees, and at last lays hold on the *Uterus*. Now from hence it seems evident, that the *Cicatricula*, which is the Fountain of the Animalcles nourishment, does not sprout from the *Uterus*, but has its *Origin* elsewhere, and falls in thither as into a fit Soil, from whence it may draw Nutriment for the growth of the *Fœtus*, else it cannot be easily imagin'd, how it should not have an immediate Connexion with the *Uterus* from the time of Conception. If {150}
you join all these three Considerations together, *viz.* that an *Animalcle* cannot come forward without a proper *Nidus* or *Cicatricula*; that there have been frequent *Fœtus's extra Uterum*; and that they have no *Adhæsion* to the *Uterus*, for a considerable time after Conception, they seem to make it evident, that Animals cannot be form'd *ex Animalculis* without the *Ova in Fœminis*. To all these I shall subjoin the Proposal of an *Experimentum Crucis*, which may seem to determine, whether the *Testes Fœmineæ* be truly the *Ovaria*, *viz.* Open the *Abdomen* of the Females of some kinds, and cut out these Testicles, and this will determine, whether they be absolutely necessary for the formation of Animals.

There are some Difficulties proposed against this Conjecture, which I think may be easily resolved. Some object the distance between the *Tubæ* or *Cornua Uteri*, and the Testicles; but to this is opposed by *Swammerdam*, and others, the like distance between the *Infundibulum*, in Hens and Frogs, and the Ovary; and yet it cannot be denied that the Eggs are transmitted thro' this into the *Uterus*: And besides *R. de Graef*, and others, have by repeated Observations found that the *Cornua Uteri* do at certain times after Conception, embrace the *Testes* on both sides the *Uterus*. They object in the second place the great disproportion between the pretended Eggs in the *Ovary*, and the Aperture of the *Tubæ* or *Cornua Uteri*, the former being a great deal bigger than the latter: But both *R. de Graef* and *Malpighius* have clear'd that Matter, by making appear, that these Bladders in the Ovary are not the *Ova*, but serve to form the *Glandules* within which {151}
the *Ova* are formed, which break through a small *Papilla* opening in the *Glandule*, which bears a proportion to the Aperture of the Tube. They object 3, The difficulty to conceive how these Eggs should be impregnated *per semen Maris*, both because there is no Connexion between the *Tubæ* and the *Ovary* for its transmission, and for that Dr. *Harvey* could never discover any thing of it *in Utero*. As to the last, Mr. *Leewenhoeck* has cleared that difficulty, by the discovery of innumerable *Animalcula Seminis Maris in Cornubus Uteri*, and those living a considerable time after Coition. *Numb.* 174. of the *Transact.* And as to the former, we may either suppose that there is such an Inflation of the *Tubæ* or *Cornua Uteri tempore Coitionis*, as makes them embrace the *Ovaria*, and such an approach of the *Uterus* and its *Cornua*, as that I may easily transmit the Seed into the *Ovary*; or else, that the *Ova* are impregnated by the Animalcles after they descend into the *Uterus*, and not in the *Ovary*; the former seems probable for this Reason, that at least a whole Cluster of Eggs in a Hen will be fecundated by one Tread of the Cock: Now this Fecundation seems to be in the Vitellary, and not in the *Uterus*, as the Eggs pass along from day to day; for it can hardly be supposed that the Animalcles should subsist so long, being scattered loosely in the *Uterus*, as to wait there for many days for the Fecundation of the Eggs as they pass along. The latter Conjecture has this to strengthen it, that the Animalcles are found to live a considerable time in the *Uterus*; and that if they should impregnate the *Ova* in the Ovary it self, the *Fœtus* would increase so fast, that the *Ova* could not pass through the *Tubæ Uteri*, but would {152}
either burst the Ovary, or fall down into the Abdomen from the Orifices of the *Tubæ*; and that from hence proceed those extraordinary Conceptions in *Abdomine extra Uterum*. But, 4. Mr. *Leewehoeck*, *Numb.* 147. of the *Transact.* to weaken the third Consideration about the Conceptions, being like unto an *Ovum* in the Womb, proposes a Parallel between these Animalcles and Insects; and insinuates, that as the latter cast their Skins, and appear of another

Shape, so the other which at first seem like Tadpoles, may cast their outer Skin, and then be round; and that this may be the occasion of the round Figure of the Conception in the Womb. To this it may be replied, that according to Mr. *Leewenhoeck*'s own Sentiment, the Animalcles cannot come forward, if they do not find the *Punctum* or proper place for their Nourishment, to which it seems they must have some *Adhæsion*. Now the Conception in *Viviparis* is not fastned unto the Womb for many days, nor does adhere to any point of it; so that it seems this roundish Body is not the Animalcle thus chang'd after having cast an outer Skin, but is rather the *Cicatricula* or little Egg, into which the Animalcle has entred as its *Punctum* or place of nourishment; else I do not see why they should not be adhering to the Womb from the first Conception, or why (as I have said) many hundreds of them are not conceiv'd and formed together, *&c.*

{153}

A short Discourse concerning Concoction: Read at a Meeting of the Royal Society, May ... 1699*, by* Clopton Havers*, M. D. Fellow of the Royal Society.*

THE manner in which the Digestion of the Aliment is performed, is a thing not very easie to be understood and explained. However, it has not escap'd the Conjectures of some Philosophical Men, who having curiously observ'd the *Phænomena* of Nature, and enquired into their Causes, have, amongst other things, endeavour'd to account for this. But their Sentiments about it have been various, and the Hypothesis, by which they have studied to explain it, very different. Some have thought the Concoction of the Food to be a kind of Elixation; and that the grosser and more solid Parts being, as it were, boil'd in the Liquid by the Heat of the Stomach, and the Parts adjacent to it, as the Liver, Spleen, and Omentum, are by a long and continued Elixation, first render'd more tender, and then colliquated, and dissolved into minuter Particles, so as to mix more equally with the Fluid, and with that to make one Pulpament, or chylous Mass. And *Hippocrates*, tho' he does not plainly call it an Elixation, yet seems to attribute the Concoction of the Food to the Heat of the Stomach, as the Cause of it, *Sect. 4. Libro de salubri victus ratione*. {154} So where he takes notice of the voiding of such Fæces, as appear to be like the Food that has been eaten; he adds, *Constat enim, sane ventriculum, ciborum copiam, ut concoquat, calefacere non posse*. And there are other Passages in the same Book, from which we may conclude, that he suppos'd the Heat of the Stomach to be the great Cause of the Digestion of the Food.

There are others that make the Stomach itself to be the great Instrument of Digestion, but in a different manner: And they suppose it to be perform'd by an Attrition, as if the Stomach, by those repeated Motions, which are the necessary Effects of Respiration, when it is distended by the Aliment, did both rub or grind off some minuter Particles from the grosser Parts; and by continually agitating the Mass of Food, make those Parts, which are not contiguous to the Stomach, strike one against another, and break one another in pieces, until they are all attenuated. It is evident enough, that the sides of the Stomach do in Expiration press upon the *Contenta*, so as to oblige, at least some Parts of them, every time the Muscles of the Abdomen are contracted, to move and shift their places. So in Inspiration, when the Diaphragm and Liver press upon the upper part of the Stomach, the Aliment must be moved again. So that by these reciprocal Motions, that part of the Food which is contiguous to the Stomach, and moves in a Line parallel to it, must rub against it; and all the other Parts being moved by such a Compression, as gives them a different Tendency, it is certain they must be continually striking one against another. And for Bread, and such things as are made of Flower, that will be softned {155} and dissolv'd with any common Liquid, that Agitation of the Stomach which moves them in Respiration, might seem sufficient to break and dissolve them, when they are sufficiently moisten'd with a Fluid. Yet this cannot be thought enough to break and digest Flesh-meat, Fruits, or any other thing that will not be softned and dissolv'd in Water, or some such Liquid. But although this Motion of the Aliment, caused by Respiration, does not actually digest it, yet it has a great and necessary Use in Concoction, and makes all the grosser Parts, as they are attenuated, mix equally with the Fluid.

Some think that the Bilious Juice; others, that the Spirits are chiefly concern'd in this Affair. *Galen*, in his Book *de Neutralibus Facultatibus*, makes it to be the Effect, not of one, but of several Causes; as a pituitous Juice in the Stomach, the Bile, *&c.* which appears from what he has said, and the Translator thus render'd: '*Verum quanto ii (cibi) qui mansi sunt, iis, qui inhæserunt, magis sunt alterati; tanto etiam his magis ii, qui devorati sunt. Siquidem incomparabilis erit horum alterationis excessus, si & quæ in ventre est Pituita & Bilis, & Spiritus, & Calor, & tota Ventris substantia, æstimentur.*'

Some there are that will have the Food to be dissolv'd by a Menstruum, which is supply'd from the Glands of the Stomach, or some other way: But those that do so far agree in the General, as to think Concoction is perform'd by a Dissolvent, do differ in their Notions of the Nature of the Menstruum: For there are some that suppose it to be an Acid, which does erode the grosser parts of the Food, and dissolves them in the same manner as Vinegar, Spirit of Vitriol, or any such-like {156} Acid, will dissolve even so solid a Body as Iron. And it cannot be deny'd, but that Oil of Vitriol will

dissolve Flesh-meat, and reduce it to a Pulp; but it is not to be suppos'd, that the Fibres of the Stomach can admit any such strong and corroding Acid, without something to correct it, but it must be injur'd in its Tone, and labour under great and extraordinary Pains. Neither does such a Menstruum, tho' it will digest some things, seem capable of dissolving so great a Variety of Things as we eat, especially when a great many of them are of a contrary Nature. Some will have the Menstruum to be a *nitro-aerius* Spirit, that is, quick, and very penetrating, and included in its proper Vehicle; which, being in its own Nature apt to penetrate the Mass of the Aliment, does diffuse it self through the Whole, and breaking the Vinculum of the more solid Parts, does dissolve their Compages. By others, it is thought to be some saline Juice in the Stomach, by which the Parts of the Aliment are divided and dissolved, and those which are fit for Nourishment, are volatiliz'd.

Lastly, There are some others who reject the Opinions I have already mention'd, and suppose the Digestion of the Food to be perform'd by the Benefit of a Ferment; which, when it is mixed with the Aliment, excites in the Mass an intestine motion; and the different and contrary motions and tendency of the Parts, making some kind of Collision, gradually break off Particles from the grosser, and more solid Parts, till they are so attenuated as to be apt to mix more equally with the Fluid, and with them to make one soft or chylous Substance. But yet there is not amongst them an universal Consent, either about the Nature of this Ferment, or the manner how it is supply'd. {157}
For first, some think it to be the Remains of the Food that was last digested; which having lain some time in the Stomach, after the rest is carried down into the Intestines, contracts an Acid, or some other Quality, and is so alter'd, as to partake of the Nature of a Leaven. And this Leaven being a part of the Food, which has been already digested, is so soft and liquid as to be capable of mixing with the Aliment, which is next taken into the Stomach; and being agitated with it by the repeated Pressures of the Diaphragm, Liver, and Abdominal Muscles upon the Stomach in Respiration, does diffuse it self through the whole Mass; and being mixed with it, like Leaven, or Yest added to new Wort, *&c.* puts it into a State of Fermentation; and by this Fermentation, or the Expansion of the Ferment, and the more tenuious Parts, which are first put into motion by it, those which are more solid, and with which they are intermixed, are rent, and divided, and so attenuated, as to become a soft and pulpous matter. And altho' the greatest part of the Food, that is thus broken and concocted, is by the Contraction of the Fibres of the Stomach press'd into the Duodenum; yet they do not contract themselves so as to force out all the Aliment, but leave between the *Rugæ* or Folds, on the inside of the Stomach, a sufficient Quantity to be a Leaven to the next Meal; and so from time to time.

Some have a Notion, That this Ferment, or Principle of Fermentation, is in the Aliment it self; which being a Congeries of Matter, consisting of various Parts of a different Nature, is no sooner {158}
enclosed in the Stomach, and digested in the Heat of that, and the adjacent Parts, but the more spirituous and subtil Particles are put into motion both from that Warmth, and the difference of their Natures, and enter upon a Fermentation. And so by their intestine Commotion, and the Violence they offer to those Parts which oppose the tendency of any of them, they break and dissolve what is more solid.

Again: Some suppose, that this Ferment is supply'd from the Glands of the Stomach.

And Lastly, Others, and perhaps with much better Reason, contend for the Saliva, and make that to be the Ferment, which serves principally for the Digestion of the Food; which in Mastication being mix'd with our Aliment, is with that carried down into the Stomach, where the Parts of it being put into motion by a kindly and agreeable Heat, they do ferment with, and exagitate first those Parts of the Food which are most apt to ferment with it, and then both conspire to break and dissolve the grosser and more stubborn Parts. And *Galen*, in the Book I have before-mention'd, plainly allows that the *Saliva* is concern'd in the business of Concoction, tho' he supposes the Alteration, which is produc'd by this Juice, to be made in the Mouth, as appears from these Words: *Quæ (alteratio) in ore agitur mutat quidem id (nutrimentum) in alteram speciem manifestè, non tamen ad perfectionem transmutat--Qui mansi sunt cibi primum quidem hac Pituita (oris) imbuunter, & cum ea miscentur----Itaque majorem mutationem consecuti sunt, quam ii, qui in vacuis dentium intervallis fuere impacti*.

Now I have given this short Account of the various Opinions of some Ingenious Men, {159}
concerning the manner how Concoction is perform'd; I come now to propose my own Hypothesis, by which I shall endeavour to explain it.

In order to the more easie and effectual Digestion of the Food, Nature has appointed some Parts for the breaking our Aliment, and reducing whatever is gross into smaller Parts, before it is put upon Digestion: Others to supply the Ferment, by which it is to be dissolv'd and concocted, and which, before it comes to be included in the Stomach, does moisten, and make it more soft, that it may more easily be penetrated, and broken by those Parts which serve to divide every Morsel into smaller Pieces, and prevents the Inconvenience and Trouble which would arise from the Nourishment sticking about or between them, when it is dry or viscous.

For the breaking of that part of our Food, which is not liquid, Nature has furnish'd us with

Teeth, and those of two sorts: For some are ordain'd to divide and break off smaller Morsels from a larger Mass; others are made for the grinding those Morsels into much smaller parts. The Teeth, which serve to break off Pieces of a convenient Magnitude from a larger Mass, are of two sorts, accommodated to the Nature of the Substance which we eat. These are the *Incisores*, and the *Dentes Canini*. If the Substance, which we have to eat, be not hard, but more easily penetrated and divided, then the *Incisores* are capable of making an Impression upon it, and fix'd firmly enough in the Jaws to break off that part which they take hold of. But if it be more solid, {160} and not easily penetrated, nor any Piece without difficulty to be separated from that Body, whereof it is a part; then we apply the *Dentes Canini*, or Eye-Teeth, to it, which are not spread, nor have such an edge as the *Incisores*, but are sharp and pointed like an Awl, and so do more readily penetrate a Substance that is hard, and which the *Incisores* can scarcely make any Impression upon. And as the Parts of a more solid Body are commonly with more difficulty separated, and there must be a greater stress put upon those Teeth which pull it into pieces; so these Teeth are much more firmly fixed in the Jaws than the *Incisores*, tho' they have but one single Root. Besides, the Position of all these Teeth is accommodated to their use, as being planted opposite to the Aperture of the Mouth; so that they may be conveniently apply'd to the Substance which we have to eat, before it is broken, and when it is too large to be admitted within the Mouth.

The Teeth which do by a Compression and Attrition reduce the little Morsels to smaller Parts, are from the manner in which they break the Aliment, called *Dentes Molares*, because they do, like so many Mill-stones, grind the Food between them. And that they might be render'd fit for this purpose, they are made broad at that Extremity, which stands out of the Gums, by which means they retain some Quantity of the Food between them every time the lower Jaw is pulled up and forc'd against the *Maxilla superior*. And as they are broad, so they are formed with Inequalities and Protuberances; and by the motion of the lower Jaw, from one side towards the {161} other, they grind what they have between them into pieces. The Position of these Teeth too is as convenient as that of the *Incisores*, and the *Dentes Canini*: For being design'd to break those pieces of our solid Food, which are taken into the Mouth, and these pieces, when they are compress'd, and mov'd by the *Dentes Molares*, being apt to fly out of the Mouth, if there were no Contrivance to prevent it, they are placed beyond the Aperture of the Mouth, and opposite to the Cheeks, which keep the Food within that Cavity, and not only so, but press it in between the *Dentes Molares* on one side, as the Tongue does on the other, until they have sufficiently broken and divided it.

At the same time, whilst the *Dentes Molares* are breaking the Food, there flows into the Mouth a Salival Juice, which mixes with it, and not only serves to moisten it, and to render it more apt and easie to be divided, but seems to be the Ferment, by the Benefit of which the Food is dissolved and digested. And therefore it is intimately mixed with it, by the Teeth agitating or stirring them together in Mastication.

This Liquor, which we commonly call the *Saliva*, or Spittle, seems to be a Composition made of two several Juices, very different in their Nature: And therefore the several Parts of it are separated by their proper Glands, and Nature has planted no fewer than four Pair about the Mouth, which supply the Juices that make the *Saliva*; to wit, the *Parotides*, and the *Glandulæ Nuckianæ*, the *Glandulæ Maxillares internæ*, and *Sublinguales*. Whereas if the *Saliva* were but {162} one more simple Liquor, a less number of Glands might have been sufficient. At least there appears no Reason why one of every Pair should disembogue itself into the Mouth so very near to the Orifice, by which a Gland of some other Pair throws in its Juice; and they are not rather all planted at more equal distances from one another, so to flow in upon every part of the Aliment at the same time.

Not that I suppose, as there are four Pair of salivatory Glands, so there are four sorts of Juices supply'd from them, to make the *Saliva*; but, as I hinted before, that there are only two different Juices that constitute it. And these are not only sufficient, but more proper to excite and secure that Fermentation, which is necessary to Concoction. For we find that most of those Fermentations, which arise upon Mixtures made for Experiments, are produced from the mixture of two things; and it is not so easie to find out three or four such Liquors of a different Nature, as will, upon the mixtion of them all, produce a Fermentation, and from the omission of any one of them discover no Discord or Disposition to ferment: Besides, it is certain that two do better secure the End, which Nature designs. For, if there were three or four different Juices, of which the *Saliva* naturally consists, these must all have their proper Qualities preserved to them, or else the Fermentation, which should arise between them, will not necessarily follow upon their mixture; and it is certain, that there would be more Danger, that one of three or four should be {163} deprived of its Natural Quality, than one of two.

What Nature these two Juices are of, I do not pretend positively to determine; but so far as I have been able to make my Conjectures about it from Experiments, I do think one of them to be an acid Juice; the other an oleaginous Liquor, something like Oil of Turpentine. For amongst the many Experiments I have made, there was no one that gave me so much Satisfaction, as that which I made with Oil of Turpentine, and Oil of Vitriol, though I try'd several other things, that

will produce a Fermentation upon their Mixture. And it was for this Reason, that I made the Experiment with Oil of Turpentine and the other Oil.

I took a piece of raw Flesh, and having cut it into pieces, but much larger than what our more solid Food is reduc'd to by due Mastication, I mix'd some Crums of Bread with it, then I pour'd in the Oil of Turpentine to them, and upon that the Oil of Vitriol; and having shak'd them together, I digested them about four Hours in *Balneo Mariæ*, and then shaking them again in the Glass, I found the Meat dissolv'd, and they all became a thickish Pulp. I could not but take notice, that Oil of Camphire (though it does not otherwise seem much different in its Nature from Oil of Turpentine) and Oil of Vitriol, which upon mixture will produce an Effervescence as well as the Oil of Turpentine and Oil of Vitriol, yet did not touch the Meat, upon which I poured them, so as in the least to dissolve them. I cannot deny but that an Acid, and a Solution of Salt of Tartar, did {164} dissolve some part of the Flesh-meat, which I mix'd them with, but yet neither so soon, nor so perfectly as the two forementioned Oils. And I do the rather think one of those Juices, which constitute the *Saliva*, to be of the Nature of Oil of Turpentine, than of a fix'd Salt, because it will correct and temper even Oil of Vitriol, so as to render it more tolerable to the Fibres of the Stomach. Not that I suppose the acid part of the *Saliva* to come near to the Acidity of Oil of Vitriol. For though, when they are mix'd, they will make a Liquor that may not be injurious to the Stomach; yet the acid Juice, if it were so corrosive as Oil of Vitriol, would certainly be injurious and painful to the Salivatory Ducts, which convey it to the Mouth before it is mix'd with the oleaginous Liquor. But I only say it is an Acid, and in some degree approaches to the Nature of that Oil. And Nature, which can much better adapt several Causes for the Production of such an Effect than Art, may attain her End by a more temperate Acid; though, at the same time, we may be able to make some probable and true Conjectures about the Nature of those Causes from Experiments.

It being most reasonable to suppose, that there are but two sorts of Juices, of a different Quality, that make the *Saliva*, I do conceive, that four of the eight Salivatory Glands, or two Pair of the four, do supply one of these Juices, and the other four Glands the other. And this seems to be a very good Reason, why they are so planted, and the Orifice of their Ducts so order'd, that {165} the Juice, which is supply'd by one Gland, is discharg'd into the Mouth, very near to the Orifice, by which the Juice of a different Nature is transmitted from another, so that they must necessarily meet and mix together. Thus the *Glandulæ Nuckianæ*, and *Parotides*, throw in two different Juices by Orifices, which open into the Mouth very near to one another; and the *Glandulæ Maxillares internæ*, and *Sublinguales*, do below supply the same kind of Juices by Orifices, that open so near to one another as to secure the mixture of the two different Juices.

These Glands, I say, do between them afford two divers sorts of Liquors, of such a Nature as are apt to ferment upon their first Mixture, but perhaps more considerably when they come to be digested by the Heat of the Stomach. So that the Colluctation, or Fermentation, which attenuates and concocts the Food in the Stomach, does not ordinarily arise between the Aliment and the *Saliva*, but between the several Parts of the *Saliva* it self. And indeed, if the *Saliva* did not consist of two Juices, whose Nature is in such a manner different, as to render them apt to ferment upon their mixture, it would be very hard to conceive how it should so readily and indifferently serve for the Digestion of all Eatables; how it should ferment with, and dissolve so great a variety of Things, not only of a different, but of a contrary Nature; how it should ferment with Acids as well as Alkalies, digest things that are cold, as well as hot or temperate; some things that are salt, others that are insipid, bitter and sweet, mucilaginous, oily, *&c.* But if we suppose, that the {166} Fermentation, which serves for the Digestion of the Food, arises from a peculiar difference in the Nature of two Juices, which constitute the *Saliva*, it will be easie to give a rational Account of our Concoction of innumerable things of a different Nature. And this seems to be as effectual, and a more certain way to attenuate and dissolve the grosser Parts of our Food, than if the Fermentation were made only between the *Saliva* and the Aliment: Besides, the *Saliva* seems to discover a Fermentation upon the mixture of its constituent Juices, even at those times when we do not actually eat; for it is always attended with Bubbles, and a Froth, when it has not been at all agitated in the Mouth, and many of those Bubbles will remain for some considerable time after we have spit it out.

Nature therefore having appointed the *Saliva* for the digestion of the Food, has taken care that it shall be thrown in upon the Aliment on every side. Thus the *Glandulæ Nuckianæ*, and the *Parotides*, supply their Juices to that part of the Food, which lies on the outside of the Gums, between the Cheeks and the Teeth, and the *Glandulæ Maxillares internæ*, and *Sublinguales*, do bestow their Liquor upon the Meat, which is within the Teeth and Gums. Neither has she had a Regard only to that Supply, which is due to all the parts of our Food, but likewise to the mixture of the two different Juices of the *Saliva*, which is necessary to its Fermentation. And therefore, as I have already observ'd, the Orifices of the Ducts, which belong to one sort of Glands, are placed {167} near the Aperture of a Duct, which conveys a Juice from one of the other Glands. So the Ducts of the *Glandulæ Nuckianæ*, and the *Ductus Stenoniani*, do on each side open into the Mouth, near one another; and the salivatory Ducts of the *Glandulæ Sublinguales*, and the *Maxillares internæ*, though they have distinct Orifices, empty themselves under the same *Papillæ*, and the Juices,

which are supply'd by them, meet there, and flow into the Mouth together.

The several Parts of the *Saliva* being discharg'd into the Mouth in such a manner as to meet and begin a Fermentation, the *Saliva* does, partly as it is agitated, with the Food by the Teeth, and some other parts of the Mouth; partly by its own Fluidity, insinuate it self into, and mixes with the Food, and not only moistens and softens it, but excites the Fermentation, which is to dissolve it. And when the Aliment is thus mix'd with the *Saliva*, which serves to ferment the whole Mass, it is then to be convey'd into the Stomach, that great digestive Vessel of the Body, where the Fermentation is not only continued, but improved.

The Nourishment being convey'd into the Cavity of the Stomach, is there kept for some time in a digestive Heat, all which time it is under a Fermentation, produc'd by the different Parts or Juices of the *Saliva*, which are mix'd with it; which Fermentation does first agitate the more tenuious or subtil parts of the Food, and puts them into motion, and so with the Fermentation of its own, and those Alimentary Parts, which it first communicates a Motion to, improved by the {168}
Heat of the Stomach, the *Saliva* must necessarily act upon the grosser Parts. For the intestine Motion, which is excited in the Mass, does not give the Particles, which are fermented, the same Tendency, but what is so various and confus'd, that they must inevitably strike not only one against another, but against those which are more gross, so as to attenuate them, sometimes by a Collision, which strikes off smaller Particles from the larger Parts; sometimes by a Compression, when the Particles which are in Motion, happen to strike directly against any grosser Part, on every side of it, sometimes by a kind of Explosion. For without doubt the *Saliva*, which is fluid, insinuates it self into the Interstices of the more crass Parts of the Aliment, and whatever is agitated and expanded in those Interstices, requiring a larger space for the Freedom of its Motion, and offering a Violence to every thing that opposes its Tendency, will, like Gun-powder included in a Shell, force its way out, and tear to pieces that Matter, which does endeavour to confine it.

Thus the grosser Parts are broken and divided, until they are at last so far attenuated as to mix more equally with the Fluid, and with them to make one Pulp or Chylous Mass. And although I do not apprehend how the Stomach should by its reciprocal Motions in Inspiration and Expiration, be able to break and attenuate any Matter, that will not be softned and dissolved by Agitation in a Liquid; yet it is certain that these Motions, caused by the Diaphragm and Abdominal Muscles in {169}
Respiration, do make those Parts, which are broken off, as they are dissolv'd, mix intimately with the more Liquid; as the Meat which I digested with Oil of Turpentine, and Oil of Vitriol, did by Agitation mix more equally with the Oils, and became a Pulpament.

As the Juices, which constitute the *Saliva*, do ferment upon their mixture, so it is probable, that from their Mixture and Fermentation there results such a *Tertium quid*, as is apt to ferment with the Bile. And therefore, when the Aliment has been under the Fermentation, excited by the *Saliva*, a sufficient time, it is then thrown into the *Duodenum*, where it meets with the bilious Juice, which flows into that Intestine from the Liver, from which a new Fermentation seems to begin; and the Commotion of the Parts of the Aliment being still continued, does carry on the Business of Digestion until the Food is perfectly concocted: Though it is probable, that this new Fermentation serves not only for the more perfect Digestion of the Food, but likewise for the Separation of the Chyle from the feculent Parts.

Neither do I by a random Guess, and an ungrounded Conjecture, suppose that from the Mixture and Fermentation of the two Juices, which constitute the *Saliva*, there results a Matter, which is apt to ferment with the Bile. But to me the Notion seem'd to be confirmed by an Experiment that I made. For considering with my self, that the Bile is generally allow'd to have much of a saponary Nature, I made a Solution of Soap in fair Water, and mix'd it with the Oils of Turpentine and Vitriol first put together, and from their Mixture I observ'd a very easie and gentle {170}
Fermentation, which continued for a considerable time.

{171}

A Discourse concerning some Influence of Respiration *on the* Motion *of the* Heart*, hitherto unobserved. By* J. Drake*, M. D. F. R. S.*

THO' divers accurate Treatises of the *Heart*, and its Action, have been written by Learned Men of several Nations, especially by two of our own Country; the Great Dr. *Harvey*, to whose happy Sagacity this Nation owes the Glory of the Invention of the *Circulation* of the *Blood*; and the incomparable Dr. *Lower*, to whom we are beholden for a compleat Display of the *Mechanical Structure* of the *Heart*, and a most ingenious Rationale of its Action. Yet there remain several Doubts and Difficulties about it (in my Opinion) not sufficiently accounted for; towards the resolving some of which, I shall offer what my own Thoughts have suggested to me, and leave it to the Consideration of the Reader.

The Learned Dr. *Lower* (whose accurate Piece on this Argument will insure his Reputation so long as Physical Knowledge shall last in esteem) has so well accounted for the *Systole*, or Contraction of the Heart, from the *Mechanical* Structure of it, that he seems almost to have

exhausted the Subject; and had he been as happy in discovering the true cause of the *Diastole*, he had left little room for the Industry and Sagacity of others about this *Viscus*. {172}

But having judiciously and solidly explain'd the *Systole*, he contents himself to ascribe the *Diastole* to a motion of *Restitution*, which account gives me no Satisfaction: Because the *Systole* being the proper, and (as himself confesses) the only motion of the Heart, a State of *Contraction* seems to be the natural State, and consequently without External Violence, it shou'd have no *Diastole* at all.

This will appear more plain, if we consider the Circumstances of it, and its Motion, as a Muscle, with respect to other Muscles. That Contraction is the proper Action, and State of all Muscles, is evident from Experience of Fact, as well as Reason. For, if any Muscle be freed from the power of its *Antagonist*, it is immediately *contracted*, and is not by any Action of the Will, or Spirits, to be reduced to a State of *Dilatation*. Thus, if the *Musculi Flexores* of any Joint be divided, the *Extensores* of that Joint being by that means free'd from the contrary Action of their *Antagonists*, that Joint is immediately extended without any consent of the Will, and in that State it remains; and so *Vice versa*, if the *Extensores* be divided. From whence it is plain, that the Muscles have no restitutive Motion, but what they derive from the Action of their *Antagonists*, by which they are balanc'd. Thus likewise the *Sphincters* of the *Gula*, *Anus* and *Vesica*, having no proper *Antagonists*, are always in a State of Contraction, and suffer nothing to pass them, but what is {173} forced through them by the contrary Action of some stronger Muscles, which, though not properly to be call'd *Antagonists*, yet on all necessary Occasions perform the Office of such.

That the Heart is a Muscle, furnish'd and instructed for Motion like other Muscles, is (in my Opinion at least) demonstrated beyond Contradiction by Dr. *Lower* and others. And, as it is a *Solitary* Muscle without any proper *Antagonist*, and not directly under the power of the Will, nor exercising *Voluntary* Motion, it approaches nearest to the *Sphincter* kind, which only has these Conditions in common with it. But in constant and regular Alternations of Contraction and Dilatation, it differs exceedingly from all the Muscles of the Body.

This *reciprocal Æstus* of the Heart has given the Learned abundance of trouble; who, finding nothing peculiar in the Structure, which shou'd necessarily occasion it, nor any *Antagonist*, whose re-action should produce it, have been extreamly perplex'd to find out the cause of it.

But passing over the various Opinions of Authors, to avoid being tedious, I shall take notice here only of the very Learned Dr. *Lower*'s, in whose Account of the *Systole*, however solid and ingenious, I observe something deficient, and whose *Hypothesis* of the *Diastole* I think to be precarious and false.

This Excellent Author, having by sound Arguments drawn from the Structure and Mechanism of the Heart, establish'd the Certainty of its *Muscular Motion*, rests satisfied, without taking notice {174} of any Assistance, that the Heart receives from any other Part, except from the Brain, by the means of the eight pair of Nerves.

Part 2 *d. Prop.* 67. *Prop.* 73. *Prop.* 76.

The Accurate *Borellus*, in his *Oeconomia Animalis*, computes the *Motive* Power of the *Machine* of the Heart to be equal to, or to surmount that of a Weight of 3000*l.* The *Obstacles* to the Motion of the Blood thro' the *Arteries* he esteems equivalent to 180,000*l.* which is 60 times as much as he rates the Force of the Heart at. Then deducting 45,000*l.* for the adventitious Help of the *Muscular Elastic Coat* of the *Arteries*, he leaves the Heart with a Force of 3,000*l.* to overcome a resistance of 135,000*l.* that is, with 1, to remove 45.

This stupendous Effect he contents himself to ascribe to the *Energy* of *Percussion*. But, had he proceeded in his Calculation to the Veins, which he allows to contain constantly a quantity of Blood, quadruple to the Contents of the Arteries, and to which this *Energy* of *Percussion* does either not reach at all, or but very languidly, he might probably have seen a necessity for some other Expedient to remove so insuperable a Difficulty.

But not to insist rigorously on the Exactness of this Calculation, (though the great Abilities of the Author in this way, and his Ingenuity and Modesty, are a sufficient Warrant for the Accuracy of his Computations, and the Fidelity of his Accounts) we may allow a much greater Deduction, than would be justifiable, without lessening the Difficulty. But this Account I have taken notice of {175} purely for the sake of the Calculation, which may be of use in the Sequel; the account it self being in other respects more defective than Dr. *Lower*'s, to which we will return.

The Doctor, notwithstanding his great Sagacity, appears (to me) to have overlook'd something of very great moment, and importance in the explication of the Action of the Heart. For, tho' it should be granted, that the *Muscular Fibres* of the Heart acted by the Nerves, are the immediate Instruments of its *Constriction* or *Systole*, yet it must not be denied, that the *Intercostal* Muscles and *Diaphragm* are of great service to aid and facilitate this Contraction, by opening a Passage for the Blood through the Lungs, which denied would be an invincible Obstacle.

Neither do they promote it that way only. The manner how they farther assist the Heart in its Contraction, will appear manifestly, if we consider the different Posture, Situation, and Capacity

of the Blood-Vessels of the Lungs in the several times of *Elevation* and *Depression* of the *Costæ*.

The *Pulmonary* Artery rises from the *right* Ventricle of the Heart, and runs in one Trunk, till it comes to the *Aspera Arteria*, where it is divided, and sends a Branch along with each Division of the *Aspera Arteria*, according to all the minutest Subdivisions, of which it is likewise subdivided, accompanying all the *Bronchi*, in their whole progress through the Lungs.

The *Pulmonary* Vein, which empties itself into the *Left* Ventricle of the Heart, spreads it self on {176}
the *Aspera Arteria* and *Bronchi*, in the same manner that the Artery does.

The necessary confluence of this Disposition if, that this Artery and Vein being co-extended with, and fasten'd to the *Bronchi*, must needs suffer such alteration of *Superficial* Dimensions, as the *Bronchi* do in the *Elevation* or *Depression* of the *Costæ*.

While the Ribs are in a State of *Depression* (whether before Commerce with the External Air or after) the *Annular Cartilages* of the *Bronchi* shrink one into another, and by that means their *Dimensions* are exceedingly contracted. In conformity to this condition of the *Bronchi*, the *Pulmonary* Artery and Vein must likewise, either by means of their *Muscular* Coats, contract themselves to the same *Dimensions*, or lye in *Folds* or *Corrugations*, which is less probable.

On the other hand, when the Ribs are elevated, and the *Diaphragm* bears downward, the Air rushing into the Lungs, shoots out the *Cartilaginous* Rings, and *divaricates* the Branches of the *Trachea*, and by them extends and divaricates the several Divisions of the *Pulmonary* Artery and Veins, and thereby lengthens and enlarges their Cavities.

This enlargement of their Cavities is very considerable, not only upon the score of the addition, which they receive in length thereby, but also upon the account of their *Divarication*. For whereas, when the Ribs are depress'd, and the Lungs subside, the Blood-vessels are not only contracted, (as I have already observ'd) but their Branches, which are exceeding numerous, approach one another, and lie in *juxta-position*, by which their Cavities are very much compress'd {177}
and streighten'd: When the Ribs are elevated, and the Lungs turgid with Air, not only the Fibres, by which their Coats in the opposite state were contracted, are extended; but those innumerable Vessels, which lying before in lines almost parallel upon one another, compress'd one another, making an *acute* Angle at their Junctures, are divaricated and separated from each other, and make an *obtuse*, whereby their Channels are widened.

Thus a passage is open'd to the Blood, from the *Right* Ventricle of the Heart to the *Left*, through the Lungs, to which it could not otherwise pass; and the opposition, which the Blood contain'd in that Ventricle, must otherwise necessarily have made to its Constriction, is taken off, and the *Systole* thereby facilitated.

Nor is that all. For the *Diastole* being caus'd (as I shall in the Sequel shew) by the force of the Blood rushing into the Ventricles, this Ampliation and Extension of the *Pulmonary* Artery is a sort of *Check* or *Counterpoise* to it, and prevents an endeavour towards two contrary Actions at once, which must necessarily frustrate both. For the Heart being a *Springy*, *Compressible* Body, whose proper Action, which is Contraction, depends on the influx of certain Fluids into its Fibers, or Substance; and containing besides a Fluid in its *Ventricles*, or great Cavities, in one of which is the Mouth of this Artery, the action of this Vessel must in great measure resemble that of a *Syringe*, whose extremity is immers'd in Water, the Enlargement or Expansion of the Chanels of {178}
the Artery answering the drawing of the *Embolum*, as the constrictive motion of the Muscle of the Heart does the pressure of the *Atmosphere* upon the *Surface* of the Water, the one making way for the fluid, and the other forcing it to follow, where the resistance is least. In this Sense we may allow a sort of Attraction to the *Pulmonary*-Artery, depending wholly upon the Action of the *Intercostal* Muscles and *Diaphragm*, which we must therefore confess to be very serviceable and instrumental in promoting the *Systole* of the Heart.

But if the Learned Author be deficient in his Account of the *Systole*; that is, if he has not observ'd all the Mechanism and Contrivance of Nature for the Contraction of the Heart; much less sufficiently has he accounted for the *Diastole*, or Dilatation of it, which he ascribes to a motion of *Restitution* of the over-strain'd Fibres, which yet he confesses are made for *Constriction* only. 'Tis true, he immediately after joins the *Influx* of the *Blood* as a concurrent Cause; but from the slight notice that he takes of it, 'tis plain, that he did not so much as dream of any great share it had in that Action. His Words are these:

De Corde, Pag. 75.

Quin & (ut obiter hoc moneam) omnis motus contractione perficiatur, & Cordis Fibræ ad constrictionem solum factæ sint, apparet quoque Cordis motum totum *in* Systole *positum esse; cumque Fibræ ultra tonum suum in omni constrictione eius tendantur, idcirco ubi nixus iste absolvitur, motu quasi* restitutionis *Cor iterum relaxatur, & sanguine à Venis* influente *rursus distenditur; à* nullo *enim cordis motu, nisi* tensionem suam {179}
remittente*, & ab* irruente *sanguine* Diastole *ejus libratis adeo viribus succedit.*

I have transcrib'd the intire Paragraph, because it contains his whole *Hypothesis* of the *Diastole*, and all the notice that he takes of it through his whole Work. But how slender soever this may prove, it is the most substantial that I have any where met with, except a late one of Mr.

Cowper, which is properly an Improvement of this, and shall be consider'd in the Sequel.

But if Contraction be the sole Action of these Fibres (as this Great Man confesses it to be) and as indeed it is of all *Muscular* Fibres, I wonder how so judicious a Writer came to slip into such an Absurdity, as to call their Distention (vulgarly but improperly call'd Relaxation) a Motion of *Restitution*. For from the Nature of those Fibres, and their disposition in the Structure of the Heart, the natural State of the Heart appears manifestly to be *Tonical*, and its Dilatation a State of Violence; and consequently, the Constriction is the *true* motion of *Restitution*, and the State to which it will *spontaneously* return, when the Force is taken off, which is the work of the *Intercostal* Muscles and *Diaphragm*.

Thus we are left still to seek for the true Cause of the *Diastole*, which seems to me to be the main and most difficult *Phænomenon*, relating to the Heart and the Circulation of the Blood. But in Mr. *Cowper*'s ingenious *Introduction* to his *Anatomy of Humane Bodies*, I find the Share which {180}
Dr. *Lower* hints the Blood to have in that Action, further prosecuted, and improved into the main Instrument of the Dilatation of the Heart, wherein I agree intirely with him. But as to the manner, and reasons of its being so very instrumental, I can't be so perfectly of his mind.

*The Heart (*says this accurate Anatomist*) of an Animal bears a great Analogy to the Pendulums of those Artificial Automata, Clocks and Watches, whilst its motion is performed like that of other Muscles, the Blood doing the Office of a* Pondus*.*

This Explication, being but a Simile without a distinct application to Particulars, is beside so very short, that I can at best but give a conjecture at the meaning; which if I mistake, I shall deserve to be excused, and expect to be better inform'd.

By the *Bloods* doing the Office of a *Pondus*, I suppose he means, that the Blood contributes in the same manner to the motion of the Heart, as the *Weights* do to that of the *Pendulum* of a *Clock*. If so, the Blood, according to him, must be the Instrument of *Constriction*; and *Dilatation* must be the *Natural* State, or *Spontaneous* Motion, to which it wou'd, when under no violence, return; the contrary of which, I presume, will appear e're I have done.

But if he means, that the *Blood* in its reflux, by *gravitating* on the *Auricles* and *Ventricles*, dilates and expands 'em, acting therein as a *Counterpoise* to its contractions as a Muscle, I cou'd wish his Design had not bound him up to so narrow a compass, and that he had given us an {181}
explication at large of so abstruse and so important a *Phænomenon*: Because the *Specifick Gravity* of the Blood seems to me a cause by no means alone adequate to the effect, which it is here suppos'd to produce.

For, if the Blood acts only as a *weight* by meer *gravitation*, then that part of it only which descends from the Parts above the Heart can be employ'd in that Action. This at the largest computation can't amount to Five pound weight, and must, according to the computation of *Borellus*, force a Machine, that is able to overcome a resistance of 135,000*l.* I leave every Man to deduct what he shall upon examination find reasonably to be deducted, and yet shall rest secure, that it is not to be effected in the least with so small a Weight.

But neither does the *Refluent* Blood gravitate in any such proportion, as I have here assign'd. For to make a true estimate of its *Gravitation*, we must consider the Circumstances of the Liquor suppos'd to gravitate; in which it very much resembles Water inclos'd in a recurve Tube, of which, if the length of the two Legs be equal, it may be suspended in the Air full of Water, with the Extremities downwards, without losing a drop, although the *Diameter* of those Legs should be very unequal. The Case of the Arteries and Veins is pretty near a parallel to a Tube, so fill'd and inverted. For, if the Arteries and Veins be continued Tubes, (as by the Microscope they are made to appear) then supposing their contents to have no other determination of motion, than their {182}
own weight wou'd give them, the contain'd Fluids must be Counterpoises to each other. For the Veins and Arteries being join'd at the smaller Extremities, and the larger of both terminating in the same parallel Line, it is impossible, according to the Laws of *Hydrostaticks*, that the contents of either shou'd overbalance t'other. How far then must it fall short of forcing the natural Power and Resistance of so strong a Muscle as the Heart, by meer Gravitation?

The Blood indeed has a *Progressive* Motion through its Vessels, wherein it differs from Water, in a recurve Tube, in the Experiment above-stated. But, if the natural Gravitation of the Blood contributes nothing to the Dilatation of the Heart, this progressive Motion will not be found much more sufficient. For, as this Motion is deriv'd intirely from the Heart's Constriction (as all Accounts hitherto derive it) cou'd the Blood be suppos'd to re-act upon it by the Heart, with all the force first impress'd upon it by the Heart, it would be insufficient, unless we will suppose the *Force communicated* to be superiour to the *Power Communicant*, which is absurd.

But when the just and necessary Deductions for the Impediments, which the Blood meets with in its Progress through the Vessels, shall be made, the remaining Force will be found so exceeding weak, that to prop the Blood through the Veins may be a task alone too great for so small a Power, without charging it with the additional difficulty of forcing the Muscle of the Heart.

Alphonsus Borellus, after a great deal of solemn pains taken to shew his Care and Exactness, {183}
and to possess his Reader of the Truth of his Calculations, casts up the force of the Heart, and the *Muscular* Coat of the Arteries, to be together equal to a weight of 3,750*l.* and allots them a Resistance equal to 180,000*l.* to overcome which is 45 to 1. To make up for a disproportion, by his own confession, incredible to those who have not consider'd the Matter as he had done, he flings into the Scale the additional *Force of Percussion*, which he leaves *indefinite*, and thinks sufficient to *force any quiescent finite Resistance whatsoever*.

But as this Account and *Hypothesis* are part of a Posthumous Work (if a liberty of Conjecture may be allow'd in so uncertain a Matter,) I shou'd suspect, that these Papers were left unfinish'd by *Borellus*; or at least, that in many places the last Hand was never put to them. For neither in this Place, nor any other of this Work, does he account for any more than the *Systole* of the Heart, and the resistance which is made to the progressive motion of the Blood in the Arteries only. This alone he found to exceed the Power of the Heart so prodigiously, that he seems to shuffle it off his Hands with a general and precarious Solution, as a difficulty that he was desirous to be rid of. For, having ascrib'd this *stupendous* (as he himself calls it) effect to the *Energy of Percussion*, he takes no care to satisfie his Reader any farther about it, or to refer him, or give him the expectation of Satisfaction any where else; although he has an express Treatise on the *Force of Percussion*, which was written preparatory to this, and to which he frequently {184}
refers in other Places of this Work. But what confirms my suspicion, that this part was intended for a farther Revise by the Author, is, that he has left the Progress of the Blood through the Veins, and the *Diastole* of the Heart, absolutely untouch'd, tho' they are Difficulties of a much greater magnitude than this, which he has attempted to account so slightly for: For, in these he is excluded the benefit of *Percussion*, and has yet a greater resistance to overcome without it. Omissions of this kind are so unusual with this Author, where-ever he knows himself to go upon sure grounds, that it is to me an Argument, that he doubted the sufficience of his *Percussion*, and reserv'd these important *Phænomena* for farther Consideration, without plunging himself into such an Absurdity, as to ascribe to *Percussion* any such *Energy* as to be able (so broken as it returns to the Heart) by its re-action to force that Power, from whence only it was at first deriv'd.

Dr. *Lower*, and Mr. *Cowper*, deliver their Opinions of the Cause of the Dilatation of the Heart so very short, and without any Arguments to support them, that by exposing them naked, they seem rather to discourse of it transiently, as Men oblig'd by the Nature of their Subjects to say something of it, than solicitous to give any full or satisfactory Account; and therefore I shall proceed no farther upon them here.

But though the *Hypothesis* of *Borellus* may, in this Case, be found precarious or insufficient (a {185}
Misfortune that has befallen him in divers other Particulars) his *Theory* holds still good. At least it ought to be allow'd, in justice to his great Abilities and Exactness, till some Body convicts him of some material Error in his Calculations, which has not as yet been done by any Body, that I know of.

Supposing then the force of the Heart, and of the *Muscular* Coat of the Arteries, as likewise of the resistance, which they must overcome, to be computed with any degree of accuracy, there remains yet such a prodigious disproportion to be accounted for, as requires some more powerful Agent, than any yet assign'd, to make up the deficiency.

What assistance the Heart receives from the action of the *Thorax* towards the facilitating its Contraction, without which assistance there cou'd have been no *Systole*, has been already shewn. But neither the *Intercostal* Muscles, or *Diaphragm*, which are so instrumental in that part of its action, can contribute any thing to the *Diastole*; because they serve only to enlarge the Cavity of the *Thorax*, and thereby to open a passage to the Blood from the Heart, and promote its Constriction.

Whatever therefore the force is, that dilates the Heart, and is the cause of the *Diastole*, it must be equal to that of the Heart, the *Intercostal* Muscles and *Diaphragm*; to all which it acts as an Antagonist. I take no notice of the *Serratus Major Anticus*, and other Muscles; which have an obscure share in the *Elevation* of the *Costæ*, because as much may reasonably be deducted upon the account of the *Obliquus externus Abdominis*, and other Muscles; which having their Insertions on some of the lower *Ribs* are as instrumental towards the *Depression* of them, and so {186}
balance the Account. But the chief use of these is in violent Respiration: In ordinary Respiration their share is small.

Such a real Power (which may in the least be suspected of any share in this Action) is hard, perhaps impossible to be found in the *Machine* of any *Animal* Body; and yet without some such Antagonist, it is as impossible the Circulation of the Blood should be maintain'd. All the Engines yet discover'd within the Body, conspire towards the *Constriction* of the Heart, which is the *State* of *Quiescence*, to which it naturally tends. Yet we find it alternately in a *State* of *Violence*, that is, of *Dilatation*; and this upon necessity, because upon this *Alternation* depends all Animal Life.

Some sufficient Cause External must therefore be found, to produce this great *Phænomenon*; which Cause must be either in the *Air*, or *Atmosphere*, because we have no constant and

immediate Commerce with any other *Mediums*.

Some great Physicians observing this, and that depriv'd by whatsoever means of Communication with the *external* Air, we became instantly extinct, have imagin'd, that in the Act of Inspiration certain purer parts of the Air, mixed with the Blood in the Lungs, and was convey'd with it to the Heart, where it nourish'd a sort of *Vital Flame*, which was the Cause of this reciprocal *Æstus* of the Heart. Others not quite so gross, rejecting an *Actual Flame*, have fancied, that these fine Parts of Air mixing with the Blood in the Ventricles of the Heart, produc'd an *Effervescence* which dilated it. But these Fancies have been long since exploded and condemn'd upon ample Conviction; and 'tis a Point yet undetermin'd, whether any Air does mix with the Blood at all in the Lungs, or not. {187}

But supposing, that some Air may insinuate it self into the *Pulmonary* Vein, it can no other way dilate the Heart than by an Effervescence in the Left Ventricle, which wou'd not dilate the Right. But this Opinion is contradicted by *Autopsie*, and too laboriously confuted by others, to be brought upon the Stage again here.

There remains therefore only the *gross Body* of the *Atmosphere* to be considered, which is undoubtedly the *true Antagonist* to all those Muscles, which serve for ordinary Inspiration, and the Constriction of the Heart. This will appear more evidently, if we consider not only the Power, but the Necessity of its Action upon *Animal* Bodies, as well as the want of other sufficient Agents.

The Heart is a *Solitary* Muscle of very great strength, and the *Intercostal* Muscles and Diaphragm, which likewise have no *Antagonists*, are a vast additional Force, which must be balanc'd by the contrary Action of some equivalent Power or other. For, tho' the Action of the *Intercostal* Muscles be voluntary, that does not exempt them from the condition of all other Muscles serving for *voluntary* motion, which wou'd be in a State of perpetual Contraction, notwithstanding any Influence of the Will, were it not for the Libration of *Antagonist* Muscles. This Libration between other Muscles, is answer'd by the *Weight* of the incumbent *Atmosphere*, which presses upon the *Thorax* and other parts of the Body. And, as in all other voluntary Motions the influence of the Will only gives a prevalence to one of its two Powers before equilibrated, so here it serves to enable those Muscles to lift up a weight too ponderous for their strength not so assisted; and therefore as soon as that assistance is withdrawn, the *Costæ* are again depress'd by the meer *Gravitation* of the *Atmosphere*, which wou'd otherwise remain elevated through the natural Tendency of those Muscles to Contraction. {188}

This is evidently prov'd from the *Torricellian* Experiments, and those made upon Animals in Mr. *Boyle*'s Engine; where, as soon as the Air is withdrawn, and the *pressure* thereby taken off, the Intercostal Muscles and Diaphragm are contracted, and the Ribs elevated in an instant, and can't by any Power of the Will be made to subside, till the Air is again let in to bear them forcibly down.

It were scarce worth while to take notice here of a Mistake of the Learned Dr. *Willis*, were it not for the great Authority of the Man, which is almost sufficient to keep Error in countenance.

De Respirationis Organis & Usu.

The Doctor having observ'd, that the Fibres of the *External* and *Internal Intercostal* Muscles ran in a contrary order, as it were, decussating each other, takes occasion from thence to fansie, that there was an opposition in their Office; and that as the *External* serv'd to raise up the Ribs, the *Internal* drew them down again, forgetting at that time, That, when a contractile Body is fasten'd at the several ends to Points unequally moveable, let the Contraction happen in what part or manner soever, the more moveable Point must be drawn towards the less moveable: By which Rule, whether *External* or *Internal Intercostals* be contracted, the lower Ribs will be forc'd to approach the upper, that is, be rais'd up. {189}

As in the Elevation of the *Costæ*, the Blood, by the passage that is open'd for it, is in a manner solicited into the Lungs; so in the Depression of them, by the subsidence of the Lungs, and the Contraction of the Blood-Vessels, both which are consequent thereof, the Blood is forcibly driven, as it were with an *Embolum*, through the Pulmonary Vein into the Left Ventricle of the Heart. And this, together with the *general Compression* of the *Body* by the *weight* of the *Atmosphere*, which surrounds and presses upon the whole Surface of it, is that Power which causes the Blood to mount in the Veins, after the force impress'd upon it by the Heart is broken and spent, and which is sufficient to force the Heart from its natural State to Dilatation.

He that is able to compute the weight of a Column of Air, equal to the Surface of the whole Body, will readily grant it a power sufficient for the Effects, which are here ascrib'd to it. And when he considers, that the Bodies of Animals are compressible Machines, he will find that it must of necessity affect them in the manner here laid down. But though our Bodies be entirely compos'd of *Tubuli*, or Vessels fill'd with Fluids; yet this pressure, how great soever, being equal, cou'd have no effect upon them, if the superficial Dimensions were not easily variable; because being compress'd on all parts with the same degree of Force, the contain'd Fluids cou'd not any where begin to recede, and make way for the rest to follow, but wou'd remain as fix'd and immoveable as if they were actually solid. But by the Dilatation of the *Thorax*, room is made for {190}

the Fluids to move, and by the Coarctation of it, fresh motion is imprest, which is the main Spring whereby the Circulation is set and kept going.

This reciprocal Dilatation and Contraction of the superficial Dimensions of the Body, seems so necessary to Animal Life, that there is not any Animal so imperfect as to want it, at least none to the inward Structure, of which our Anatomical Discoveries have yet reach'd. For, tho' most kinds of *Fish* and *Insects*, want both *moveable* Ribs and Lungs, and consequently have no dilatable *Thorax*, yet that want is made up to 'em by an *Analogous* Mechanism, answering sufficiently the Necessities of their Life.

Those Fishes which have no Lungs, have *Gills*, which do the *Office* of Lungs, receiving and expelling alternately the Water, whereby the *Blood-Vessels* suffer the same alteration of Dimensions, that they do in the Lungs of more perfect Animals.

The Lungs or *Air-Vessels* of Insects, are yet exceedingly more different in Structure, Distribution, and Situation from those of perfect Animals, than those of Fishes are, and yet in their Use and Action agree perfectly with both; that is, *receiving* and *expelling* the Air, and *varying* the *Dimensions* and *Capacities* of the *Blood-Vessels*. These having no *Thorax*, or separate Cavity for the Heart and Air-Vessels, have the latter distributed through the whole Trunk of their Bodies, by which they communicate with the *External* Air through several *Spiracula* or *Vent-holes*, to which are fasten'd so many little *Tracheæ*, or Wind-pipes, which thence send their Branches to all the Muscles and *Viscera*, and seem to accompany the Blood-Vessels all over the Body, as they do in the Lungs only of perfect Animals. By this disposition in every *Inspiration*, the whole Body of these little Animals is inflated, and in every *Expiration* compress'd; and consequently the Blood-Vessels must suffer a *Vicissitude* of Extension and Contraction, and a greater motion must thereby be impress'd upon the Fluids contain'd in them, than the Heart, which does not in those Creatures appear to be Muscular, seems capable of giving. {191}

The only Animal that is exempted from this necessary condition of *Breathing*, or *receiving* and *expelling alternately some Fluid* into and out of the Body, is a *Fœtus*. But this, while included in the Womb, has little more than a *vegetative* Life, and ought scarce to be reckon'd among the number of *Animals*. For, were it not for that small share of *Muscular* Motion, which it exercises in the Womb, it might without absurdity be accounted for as a Graft upon, or Branch of the Mother.

Concerning the immediate Matter, and Means of Life, and Nutrition, Authors are not agreed, nor is it the business of this place to reconcile, or decide their Differences, but to account for the Motion of the Blood through the Vessels only. In order to this, it will be necessary to observe, that the Pulsation of the Heart in a *Fœtus* is so very weak and obscure, and the Motion of the Blood so extream slow and languid, as to be scarce, if at all perceivable, as has been experienced in the Dissection of Puppies before Respiration had. To produce such a feeble Palpitation, and creeping Motion, no greater force seems to be required, than may be deriv'd from the Communication between the Vessels of the Mother and *Fœtus* in the *Placenta*. I am not ignorant, that divers very Learned Anatomists (whom the Crowd have implicitly follow'd) have absolutely rejected all Communication between these Vessels. But, with submission to Great Authorities, I think they have acted arbitrarily, and without sufficient Warrant from Reason or Experiment: For neither are the Arguments which they bring against it conclusive, nor the Office which they assign to the Umbilical Vessels in lieu of it, proper, or natural to those Vessels, or the reality of the Fact made out by any substantial Reasons. Those that reject this Communication usually do it in favour of one or both of these Opinions, that the Arteries of the *Uterus* do deposite a Nutritive Juice, or a Juice impregnate *with Air* in the *Placenta*, which is suck'd in by the *Umbilical* Vein, and convey'd to the *Fœtus*, for the necessary Uses of Nutrition and Life. Now those that patronize either of these Opinions, lead Nature an unnecessary Dance. For if the *Maternal* Blood does really contain any such *Nutritious*, or any such necessary *Aerial Particles*, why shou'd they be separated and extravasated, to be with difficulty receiv'd into the *Umbilical* Vein, and again mixt with the Blood, when they might more easily have been imparted by the plain simple way of Transfusion from the Arteries of the *Mother* to the Veins of the *Fœtus*. And, that this is the course which Nature takes in this Case, I am perswaded from the easiness and simplicity of the Method, which readily performs what might be perhaps in vain expected from the other, and wou'd over and above find them, what they seem to grope so blindly about for, a first Mover of the Blood in a *Fœtus*. {192} {193}

Boyle *of the Elasticity of Air. Pechlinus de Aeris & Alimenti defectu.*

Those that contend for the conveyance of the *Nutricious* Juice, through the *Umbilical* Vein from the *Placenta*, are forc'd upon two Difficulties next to Absurdities. For first they are oblig'd to make this Vein, which, as all other Veins, seems dedicated to the Re-conveyance of Blood only, the proper and immediate Chanel, thro' which a very different Liquour is to be carried; and next, to give a Power of Attraction or Suction to it; because the *Nutricious* Juice, which it is thus destin'd to carry, is both viscous and stagnant, and has neither force to drive, nor subtilty to penetrate, or insinuate it self into the Capillary Veins; and therefore must be drawn or suck'd as *Milk* is from the *Breast*, to which the *Placenta* and its *Nutricious* Juice are by the Favourers of them expresly compar'd. But if this were the sole use of the *Placenta*, and *Umbilical Vessels*, why

were the Umbilical *Arteries* sent along with the Vein? Their business is not to bring any thing back to the *Fœtus*, nor can they contribute any thing to the benefit of the *Mother*; for the *Uterine* Arteries bring all to the *Placenta*, the Umbilical Vein carries it to the *Fœtus*, and the *Uterine* Veins convey back again the Surcharge of the *Mother*'s Blood; the Umbilical *Arteries* only, have {194} nothing to do, and are superfluous and impertinent, which is contrary to the constant Practice of Nature. Yet if *Autopsie* did in the least countenance this Hypothesis, some Defence might still be made; but we find in the Umbilical *Vein* of a *Fœtus* nothing but *Florid* Blood, such as in all probability it received immediately from the *Arteries* of the *Mother* without any mixture. And therefore I can't help concluding, that this Opinion engages its Favourers in some Absurdity, without Necessity and without Proof.

They that from the *Placenta* supply the Body of the *Fœtus* with *Air*, are as much distress'd as t'other; for they are forc'd to beg the Question twice, which, even when granted, will not answer their Ends. First, they suppose, that an intimate mixture or confusion of *Air* with the *Blood*, is necessary for the support of Animal Life, a *Postulatum*, which perhaps the former part of this Discourse may have render'd unnecessary; and next, that the *Fœtus* is supply'd with *Air* from, and its *Blood* mix'd with it in the *Placenta*.

But here again they fetch a Compass without necessity or proof. For if a mixture of *Air* were necessary to a *Fœtus*, why should it be separated from the *Mother*'s Blood, and not rather both communicated together, since it is so much more easie and commodious? But neither does the *Placenta* seem to be instructed and provided for the separation of *Air*, but of a much *grosser Fluid*, destin'd to some other use, which *Autopsie* confirms: Yet, were both these Opinions true, {195} they are however defective, and the Circular Motion of the Blood unprovided for.

By the way of *Transfusion*, this great Phænomenon is naturally accounted for, and the Ends, for which the other two Hypotheses were devis'd, might both be answer'd with more ease. For the *Hysterick* Arteries transmitting their Blood immediately to the *Umbilical* Vein, may very easily transmit such *Nutricious* Juices or *Aerìal* Particles, as are contain'd in the Blood, along with it, without depositing them by the way. By this means so much of the Impulse of the Mother's Blood is preserv'd, as suffices to maintain that languid Circulation which a *Fœtus* enjoys. For the Blood being driven through the *Arteries* of the *Uterus* into the *Umbilical Vein*, is convey'd directly to the *Sinus* of the *Porta*, and thence by a short and direct Passage through the *Cava* to the Heart; where passing through the *Foramen Ovale* to the *Left* Ventricle, and through the *Canalis Arteriosus* from the *Right* and *Pulmonary* Artery, it is all deliver'd without coming at the *Lungs* to the *Aorta*, and from thence again by the *Umbilical Arteries* to the *Veins* of the *Uterus*, making a sort of *Epicycle* to the main Circulation in the Mother.

As this Opinion is Favour'd by the Structure and Disposition of the Blood-Vessels on both Parts, so there is nothing in it difficult to be conceiv'd, or repugnant to Experience. Late Discoveries have made it appear, that the Arteries and Veins are continu'd Tubes, and that the latter contain nothing but what they receive from the former, and no Reason appears why we shou'd think this {196} Method to be varied in the *Placenta*. On the other hand, if the Arteries of the *Uterus* were continued to the Veins of the *same* part, and those of the *Fœtus* in like manner, without communicating with each other, their Confluence in the *Placenta* seems to be altogether impertinent, and of no use, and the *Umbilical* Arteries and Vein fram'd for no other Service or Purpose, than to give the Blood room for an idle Sally.

Thus the Reasonableness of this old Opinion may be vindicated, but the Certainty of it rests upon stronger Proof. Mr. *Cowper*, to whose happy Industry we owe the Confirmation of many ancient Discoveries, and the Benefit of some new ones, has the Honour to re-establish this old, but long exploded Truth. For by pouring *Mercury* into a Branch of the *Uterine Arterie* of a *Cow*, that went into one of the *Cotyledones* of the *Uterus*, he fill'd those Branches of the *Umbilical* Veins, which went from that *Cotyledon* to the *Navel* of the *Fœtus*; which, with a part of the *Uterus*, he keeps prepared by him.

It would be a weak Objection, to alledge, That the Observation and Experiment being made on the *Uterus* of a *Cow*, the Inference would not hold from thence to a *Woman*, the one being *Glanduliferous*, and the other *Placentiferous*; since every one of these *Cotyledones*, or *Uterine Glandules*, is in all respects a little *Placenta*, and all the difference between them is in number, name, and magnitude. Why *Ruminants* differ in this Particular from other *Viviparous* Animals, is beside the Subject of our present Enquiry. But the great Flux of Blood, which constantly follows upon drawing the *Placenta* from Women (which is frequently so great as to cost them their Lives) {197} is as plain a demonstration to Reason of the *Continuity* of the Vessels, as Mr. *Cowper*'s Experiments is to the Eye.

I have heard it objected by very Learned Men, that if there were such a *Continuity* of Vessels, and such *Transfusion* of Blood, the *Fœtus* must necessarily perish through loss of Blood, upon the separation of the *Placenta* from the *Uterus*; but that, on the contrary, no visible Flux of Blood does follow while the *Fœtus* continues wrapt in the Membrane, in which Condition it may be kept alive some Hours. To this it may be answer'd, that the Circulation in the *Fœtus*, being deriv'd from the Mother, may be suppos'd wholly to cease upon the cutting off the Communication

between them, till it is again renew'd more forcibly by *Respiration*. But if we allow the motion already impress'd upon the Blood to be sufficient to keep it going a little while; yet it must needs be so exceeding languid, that the meer resistance of the External Air must be more than enough to hinder any Efflux of Blood from a *Fœtus* before Respiration. How long Life may be preserv'd without an *actual* Circulation of the Blood, is a Question not of this place. But we have been convinc'd by many and notorious Observations and Experiments, that Life has been recover'd a long time after all tokens of Respiration, Circulation, or even Life it self, have disappear'd; so that we can't think the first Solution either impossible or improbable.

I expect to be told, that in the early Days of *Gestation* in *Viviparous* Animals, there is no {198}
Placenta, or any Adhesion of the *Umbilical* Vessels to any part of the *Mother*, and consequently no such *Transfusion*; and that in *Oviparous* there is no *continuity*, or *communication* of Vessels of any kind, during the whole time of *Incubation*.

But these Objections carry neither the Weight nor Difficulty along with them, that they may be suppos'd to do; for in those Days there is neither *Blood* or *Blood-Vessels*, and consequently there can be no *Circulation* of the *Blood*; and the *Embryo*, of what Species soever, is no more than a *Vegetable* at that time; nor does the *Fœtus* of any *Viviparous* Creature enjoy any *Circulation*, or shew any signs of Animal Life, till after those Vessels, as well as others requisite to the Circulation, are compleated.

It must be confess'd, that *Oviparous* Animals are denied the benefit of this Communication; but that want is sufficiently compensated by a peculiar Mechanism, which directly answers the ends of *Respiration*, and the *pressure* of the *Atmosphere* upon the *Fœtus*. There is at the *obtuse* end of an Egg a small Cavity fill'd with Air, which is the succedaneous Instrument to the *Respiratory* Organs. For as soon as the Contents begin to be warm'd by the *Incubation* of the Hen, or *any analogous* Heat of *Furnace* or *Dunghill*, the several Humours of the Egg require a *fermentative* motion, and the *Air* contain'd in the *Cavity* or *Vesicle*, at the *obtuse* end of the Egg, is rarefied, and the Vesicle extended and enlarg'd, and consequently the other Contents are comprest; to {199}
which the *fermentative* motion naturally resists. But both Bodies being as well *compressible* as *dilatable*, and both having an *expansive* motion imprest upon them by *Incubation*, the Compression and Renitency will be mutual, but varied in degree, according as either, through the variation of Circumstances, shall prevail. By this means, an Alternation of Compression and Dilatation will be produc'd in both, answering the *respiratory* motion, by which a motion will be communicated, which, as soon as the Organs by which it should be regulated are compleated, will in the Body of the *Pullus* be *regular* and *circulatory*.

Fabricius ab *Aquapendente*, and after him, our Great Dr. *Harvey*, have assign'd divers Uses to this Cavity or Air Vesicle, the Extravagance of which have perhaps deterr'd others from enquiring so much into the Use, as the Importance of it requir'd. But though I can't agree to that *Perspiration*, *Refrigeration*, and *Respiration*, which they make it the Instrument of; yet perhaps the *Air*, that was inclos'd in that *Cavity*, may through the Augmentation of the Body of the *Pullus*, and its own *Rarefaction* (which is at last so great as to occupy half the Shell) break the *Membrane*, which separated it from the *Pullus*, and thereby give so much *Respiration* as to form the *chirping Voice*, which is often heard before the breaking of the Shell, and with it give an addition of Strength to enable it to break the Shell. But how it should respire sooner, is to me inconceivable.

There are many Problems of great seeming Difficulty, the Solutions of which flow naturally {200}
from what has been laid down here: But intending to prosecute this Subject farther, and to treat of the Impediments of Respiration, and the Consequences of Respiration obstructed or intermitted, I shall reserve them for that Opportunity, and content my self here to attempt the *Harveyan* Problem only, which has given abundance of Authors so much perplexity.

That incomparable Philosopher enquires, *Why a* Fœtus*, taken out of the* Uterus *with the* Membranes *intire, shall live in Water some Hours without communication with the* External Air*; whereas if it be taken out and suffer'd once to breath, it can't afterwards survive a Moment without the benefit of* Respiration*.*

Granting the Fact to be as he has deliver'd it, which yet is not so in all Cases, the main Difficulty is grounded on a Mistake, which from the stating of the Question I find this Great Man to have slipt into. For he thinks, that a *Fœtus* is sooner suffocated after having once breath'd, than if it had not breath'd at all, and that by breathing it had contracted something which render'd it more perishable. *Idem tamen secundis exutus, (*says he*) si semel* aerem *intra* Pulmones *attraxerit, postea ne momentum quidem temporis absque eo durare possit, sed confestim moriatur.* And presently after, *Siquidem constat, fœtum, postquam* eum semel *hauserit,* citius *suffocari; quam cum ab* illo prorsus *accebatur*. The Doctor observing a *Fœtus* to live longer without Respiration, and to dispence better with the want of Air while included in the Membranes intire, than it cou'd afterwards; infers thence, that the Air does in the first Act of Inspiration {201}
impress upon the Lungs some quality, which renders it ever after more indispensably necessary. But allowing his Observation, I must yet deny his Inference to be good: For deprive a *Fœtus* of means of respiring, and then take it out of the Membranes, and it shall be as soon suffocated, as

if it had respired before. This proves, that this necessity of intercourse with the Air, by way of the Lungs, is not the Offspring, but the Parent of Respiration, and that, that Learned Man was drawn into a Fallacy of *Non causa pro causa*.

The Reason of this Necessity is the pressure of the External Air upon the Surface of the Body, from which it was defended by the Interposition of the Membranes, and the Humours contain'd, which are not so compressible as the Body of the *Fœtus* it self. So soon therefore as the *Fœtus* is excluded, and expos'd to the immediate contact of the ambient Atmosphere, the Vessels and all the Cavities of the Body must necessarily be so compress'd, that the Fluids can't have room for motion, and consequently the *Fœtus* could have no Life, if Nature had not contriv'd by the motion of the *Thorax* to remove and admit that pressure alternately, and thereby to impress a motion on the Fluids, which is the Spring of Life. But this motion of the *Thorax* being any way suppress'd, the equal pressure of the Atmosphere on all parts, occasions a total Cessation of motion, which is Death.

I shall prosecute this Subject no farther now, nor trouble the Reader with any Apology, for dissenting from those Great Men herein named; because, I hope, I have done it with Modesty, {202}
and all the Respect due to so great Authorities, and have assign'd nothing which is not Matter of Fact uncontroverted, or deduc'd from it by plain Mechanical Necessity.

{203}

Some Thoughts and Experiments concerning Vegetation*. By* John Woodward*, M. D. of the College of Physicians, and R. S. and Professor of Physick in* Gresham College*.*

THE *Ancients* generally intitled the *Earth* to the Production of the *Animals*, *Vegetables*, and *other Bodies* upon and about it; and that for that Reason 'twas, that they gave it so frequently the Epithets of *Parent* and *Mother*[1]. They were of opinion, that it furnished forth the *Matter* whereof *those Bodies* consist; and receiv'd it all back again at their Dissolution for the Composure of *others*. Even those who asserted *four Elements*, supposed that the *Earth* was the *Matter* that *constituted* those Bodies; and that *Water* and the *rest*, serv'd only for the *Conveyance* and *Distribution* of that *Matter*, in order to the *forming* and *composition* of them. 'Tis true, *Thales*, a Philosopher of the first Rank in those early Ages, has been thought to have Sentiments very different from these; but that without just Grounds, as I think I have sufficiently prov'd in another Paper, which I am ready to produce.

But though *Antiquity* thus gave its *Vote* for *Terrestrial Matter*, several of the *Moderns*, and {204}
some of very *great Name* too, both *here* and *abroad*, have gone quite counter, and given *theirs* in behalf of *Water*. The *Dignity* of the *Persons* that have espoused it, as well as their *Numbers*, renders this Doctrine very considerable, and well worth our enquiring into. The great Restorer of *Philosophy* in this last Age, my Lord *Bacon*, is of Opinion, *That for Nourishment of* Vegetables*, the Water is almost all in all; and that the Earth doth but keep the Plant upright, and save it from over-heat, and over-cold*[2]. Others there are who are still more express; and assert Water to be the only Principle or Ingredient of all Natural Things. They suppose that, I cannot tell by what Process of Nature, Water is *transmuted* into *Stones*, into *Plants*, and in brief, all other Substances whatever. *Helmont*,[3] particularly, and his *Followers*, are very positive in this; and offer some *Experiments* to render it credible. Nay, a very *Extraordinary Person* of our own *Nation*[4] tries those *Experiments* over again; and discovers a great Propensity to the same Thoughts and Opinion they had; declaring for this *Transmutation of Water* into *Plants* and *other Bodies*, though with great Modesty and Deference, which was his usual manner.

The *Experiments* they insist upon are chiefly *two*; the *first* is, that *Mint*, and several *other* {205}
Plants prosper and thrive very greatly in *Water*. The *other* is this; they take a certain quantity of *Earth*, and *bake* it in an *Oven*; then they weigh it, and put it into an *Earthen Pot*. Having well water'd this *Earth*, they make choice of some fit *Plant*, which, being first carefully *weigh'd*, they *set* in it. There they let it grow, continuing to *water it* for some time, till 'tis much advanced in *bigness*: Then they take it up; and though the *Bulk* and *Weight* of the *Plant* be much greater than when *first set*, yet upon *baking* the *Earth*, and *weighing* it, as at first, they find it little or not at all diminished in *weight*; and therefore conclude, 'tis not the *Earth* but *Water*, that nourishes and is *turn'd* into the Substance of the *Plant*.

I must confess I cannot see how *this Experiment* can ever be made with the *nicety* and *justness* that is requisite, in order to *build* upon it so *much* as *these Gentlemen* do. 'Tis hard to weigh *Earth* in that *quantity*, or *Plants* of the *size* of those they mention, with any great *exactness*; or to *bake* the Earth with that *accuracy*, as to reduce it *twice* to just the *same Driness*. But I may wave all this; for though the *Experiment* be never so easily practicable, and all the Accidents of it exactly as they set forth, yet nothing like what they *infer* can possibly be concluded from it; unless *Water*, which they so plentifully bestow upon the *Plant* in *this Experiment*, be *pure*, *homogeneous*, and not charged with any *terrestrial Mixture*; for if it be, the Plant after all may owe its *Growth* and *Encrease* intirely to *that*.

Some *Waters* are indeed so very *clear* and *transparent*, that one would not easily suspect any *terrestrial Matter* were latent in them; but they may be *highly saturated* with such *Matter*, though the Eye be not presently able to descry or discern it. 'Tis true, *Earth* is an *Opake Body*; but it may be so far dissolved, reduced to so extreme small Particles, and these so *diffused* through the *watry Mass*, as not sensibly to impede *Vision*, or render the Water much the less *diaphanous*. *Silver* is an *Opake*, and indeed a very *dense Body*; and yet, if perfectly *dissolved* in *Spirit* of *Nitre*, or *Aqua Fortis*, that is *rectified* and thorowly *fine*, it does not *darken* the *Menstruum*, or render it less *pellucid* than before[5]. And other Instances there are, that oftentimes *great quantities* of *Opake Matter* are sustain'd in *Fluids*, without considerably striking the *Eye*, or being perceiv'd by it. So that were there *Water* any where found so *pure*, that the quickest Eye could discover in it no *terrestrial Intermixture*; that would be far short of a *Proof*, that in reality there was *none*. {206}

But after all, even the *clearest Water* is very far from being *pure* and wholly *defecate*, in any part of the World that I can learn. For ours here, I have had an Opportunity of examining it over a good part of *England*; and cannot say I ever met with any, that, however fresh and newly taken out of the Spring, did not exhibit, even to the naked Eye, great numbers of exceeding small terrestrial Particles disseminated through all parts of it. Thicker and crasser Water exhibits them in still greater Plenty. {207}

These are of two general kinds. The one a vegetable terrestrial Matter, consisting of very different Corpuscles; some whereof are proper for the formation and increment of one sort of Plant, and some of another; as also some for the Nourishment of one part of the same Plant, and some of another. The other kind of Particles sustain'd in Water are of a Mineral Nature. These likewise are of different sorts. In some Springs we find common Salt, in others *Vitriol*, in others *Alum*, *Nitre*, *Sparr*, *Ochre*, &c. nay, frequently several of these, or other Minerals, all in the same Spring; the Water as it drains and passes thorough the *Strata* of Stone, Earth, and the like, taking up and bearing along such loose Mineral Corpuscles, as it meets with in the Pores and Interstices of those *Strata*, and bringing them on with it quite to the Spring. All Water whatever is much charg'd with the Vegetable Matter, this being fine, light, and easily moveable. For the Mineral, the Water of Springs contains more of it than that of Rivers, especially when at distance from their Sources; and that of Rivers more than the Water that falls in Rain. This I have learn'd from several Trials, which I must not give Account of here; my Drift in this place being only to evince the Existence of Terrestrial Matter in Water.

Any one who desires farther Satisfaction in this, may easily obtain it, if he only put Water into a clear Glass Viol, stopping it close, to keep Dust and other exterior Matter out, and letting it stand, without stirring it for some Days: He will then find a considerable Quantity of terrestrial Matter in the Water, however pure and free it might appear when first put into the Viol. He will in a very short time observe, as I have frequently done, the Corpuscles that were at first, while the Water was agitated and kept in motion, separate, and hardly visible[6], by degrees, as the Water permits, by its becoming more still and at rest, assembling and combining together; by that means forming somewhat larger and more conspicuous *Moleculæ*. Afterwards he may behold these joining and fixing each to other, by that means forming large thin Masses, appearing like *Nubeculæ*, or Clouds in the Water; which grow more thick and opake, by the continual appulse and accretion of fresh Matter. If the said Matter be chiefly of the Vegetable kind, it will be sustain'd in the Water; and discover at length a green Colour, becoming still more and more of that Colour, I mean an higher and more saturate Green, as the Matter thickens and encreases. That this *Matter* inclines so much to that *Colour*, is the less strange, since we see so large a share of it, when constituting Vegetables wearing the same Colour in them. But if there be any considerable quantity of meer Mineral Matter in the Water, this, being of a greater specifick Gravity than the Vegetable, as the Particles of it unite and combine in such Number, till they form a *Molecula*, the Impetus of whose Gravity surpasses that of the Resistance of the Water, subsides a great deal of it to the *bottom*. Nor does it only fall down it self, but frequently entangling with the *Vegetable Nubeculæ*, forces them down along with it. {208} {209}

The Reason why Bodies, when dissolved and reduced to extreme small Parts, are sustain'd in Liquors that are of less specifick Gravity than those Bodies are, hath been pointed at by a late ingenious Member of this Society[7]. He is indeed far from having adjusted all the *Momenta* of this Affair; however it must be admitted, that, in the *dividing* or *solution* of Bodies, their Surfaces do not decrease in the same Proportion that their Bulk does. Now the Gravity of a Body, which is the Cause of its sinking or tendency downwards, is commensurate to its Bulk; but the resistance that the Liquor makes, is proportion'd, not to the Bulk, but to the Extent of the Surface of the Body immersed in it. Whence 'tis plain, a Body may be so far divided, that its Parts may be sustain'd in a Fluid, whose specifick Gravity is less than that of the said Body. Nay, 'tis Matter of Fact, that they frequently are so; and we daily see *Menstrua* supporting the Parts of *Metals*, and other Bodies, that are of six, ten, nay, almost twenty times the specifick Gravity of those *Menstrua*. And as the Parts of Bodies when divided, are thus supported in a Fluid; so when they occur and unite again, they must sink of course, and fall to the Bottom. {210}

Upon the whole, 'tis palpable and beyond reasonable Contest, that *Water* contains in it a very considerable Quantity of terrestrial Matter. Now the Question is, to which of these, the Water, or the Earthly Matter sustain'd in it, Vegetables owe their Growth and Augment: For deciding of which, I conceive the following Experiments may afford some Light; and I can safely say, they were made with due Care and Exactness.

Anno 1691.

I chose several *Glass Vials*, that were all, as near as possible, of the same shape and bigness. After I had put what Water I thought fit into every one of them, and taken an Account of the weight of it, I strain'd and ty'd over the Orifice of each Vial, a Piece of Parchment, having an hole in the middle of it, large enough to admit the Stem of the Plant I design'd to set in the Vial, without confining or streightning it, so as to impede its *Growth*. My Intention in this, was to prevent the inclosed Water from evaporating, or ascending any other way than only through the Plant to be set therein. Then I made choice of several Sprigs of Mint, and other Plants, that were, as near as I could possibly judge, alike fresh, sound, and lively. Having taken the weight of each, I placed it in a Vial, order'd as above; and as the Plant imbib'd and drew off the Water, I took care to add more of the same from time to time, keeping an Account of the weight of all I added. Each {211}
of the Glasses were, for better distinction, and the more easie keeping a Register of all Circumstances, noted with a different Mark or *Letter*, *A*, *B*, *C*, *&c.* and all set in a Row in the same Window, in such manner that all might partake alike of *Air*, *Light*, and *Sun*. Thus they continued from *July* the Twentieth, to *October* the Fifth, which was just Seventy Seven Days. Then I took them out, weigh'd the Water in each Vial, and the Plant likewise, adding to its weight that of all the Leaves that had fallen off during the time it stood thus. And Lastly, I computed how much each Plant had gain'd; and how much Water was spent upon it. The Particulars are as follow.

(A.) *Common Spear-Mint*, set in *Spring-Water*. The Planted weighed when put in, *July* 20. just 27 Grains; when taken forth, *October* 5. 42 Grains: So that in this space of 77 Days, it had gained in weight 15 Grains.

The whole Quantity of Water expended, during these 77 Days, amounted to 2558 Grains. Consequently the weight of the Water taken up, was $170\frac{8}{15}$ times as much as the Plant had got in weight.

(B.) *Common Spear-Mint*, *Rain-Water*. The Mint weigh'd, when put in, Gr. 28¼; when taken out Gr. 45¾, having gain'd in 77 Days Gr. 17½.

The Dispendium of the Water Gr. 3004, which was $171\frac{22}{35}$ times as much as the {212}
Plant had received in weight.

(C.) *Common Spear-Mint*, *Thames-water*. The Plant when put in, Gr. 28, when taken forth, Gr. 54. So that in 77 Days it had gained Gr. 26.

The Water expended, amounted to Gr. 2493. which was $95\frac{23}{26}$ times as much as the additional weight of the Mint.

(D.) *Common Solanum*, or *Night-shade*: *Spring-water*. The Plant weigh'd, when put in, Gr. 49; when taken out, 106; having gain'd in 77 Days 57 Gr.

The Water expended during the said time, was 3708 Gr. which was $65\frac{3}{57}$ times as much as the Augment of the Plant.

This Specimen had several *Buds* upon it, when first set in the Water. *These* in some Days became fair *Flowers*, which were at length succeeded by *Berries*.

(E.) *Lathyris seu Cataputia Gerh. Spring-Water.* It weigh'd, when put in, Gr. 98. when taken forth, Gr. 101½. The additional weight for the whole 77 Days, being but Gr. 3½.

The Quantity of Water spent upon it during that time, Gr. 2501. which is $714\frac{4}{7}$ times as much as the Plant was augmented.

Several other Plants *were try'd, that did* not thrive *in* Water*, or succeed any better than the* Cataputia *foregoing: But 'tis besides my purpose to give a particular* Account *of them here.* {213}

(F, G.) *These Two Vials* were fill'd, the former (F) with *Rain*, the other with *Spring-water*, at the same time as those above-mention'd were; and stood as long as they did.

But they had neither of them any Plant; my Design in these being only to inform my self, whether any Water exhaled out of the Glasses, otherwise than *thorow* the Bodies of the Plants. The Orifices of these two Glasses were cover'd with Parchment; each piece of it being perforated with an hole of the same bigness with those of the Vials above. In this I suspended a bit of Stick, about the thickness of the Stem of one of the aforesaid Plants, but not reaching down to the Surface of the included Water. I put them in thus, that the Water in these might not have more Scope to evaporate than that in the other Vials. Thus they stood the whole 77 Days in the same Window with the rest; when, upon Examination, I found none of the Water in these wasted or gone off. Tho' I observed both in these, and the rest, especially after hot Weather, small Drops of Water, not unlike Dew, adhering to the Insides of the Glasses, that Part of them, I mean, that was above the Surface of the enclosed Water.

The Water in these two Glasses that had no Plants in them, at the end of the Experiment, exhibited a larger Quantity of Terrestrial Matter than that in any of those that had the Plants in them did. The Sediment at the bottom of the Vials was greater; and the *Nubeculæ*, diffus'd through the Body of the Water, thicker. And of that which {214}
was in the others, some of it proceeded from certain small Leaves that had fallen from that part of the Stems of the Plants that was within the Water, wherein they rotted and dissolved. The Terrestrial Matter in the Rain-water was finer than that in the Spring-water.

Anno 1692.

The Glasses made use of in this, were of the same sort with those in the former Experiment; and cover'd over with Parchment in like manner. The Plants here were all *Spear-Mint*; the most kindly, fresh, sprightly Shoots I could chuse. The Water, and the Plants were weigh'd as above; and the Vials set in a Line, in a South Window: where they stood from *June* the 2d to *July* 28. which was just 56 Days.

(H.) *Hyde-Park Conduit Water*, alone. The *Mint* weighed, when put in, 127 Gr. when taken out, 255 Gr. The whole Quantity of Water expended upon this Plant, amounted to 14190 Gr.

This was all along a very kindly Plant; and had run up to above two Foot in height. It had shot but one considerable collateral Branch; but had sent forth many and long Roots, from which sprung very numerous, though small and short, lesser Fibres. These lesser Roots came out of the larger on two opposite sides, for the most part; so that each Root, with its *Fibrillæ*, appear'd not unlike a small Feather. To these *Fibrillæ* {215}
adher'd pretty must Terrestrial Matter. In the Water, which was at last thick and turbid, was a green Substance, resembling a fine thin *Conserva*.

(I.) The *same Water*, alone. The *Mint* weigh'd, when put in, 110 Gr. when taken out, 249. Water expended, 13140 Gr.

This Plant was as kindly as the former, but had shot no collateral Branches. Its Roots, the Water, and the green Substance, all much as in the former.

(K.) *Hyde-Park Conduit-water*, in which was dissolved an Ounce and half of *Common Garden-earth*. The *Mint* weigh'd, when put in, 76 Gr. when taken out, 244 Gr. Water expended, Gr. 10731.

This Plant, though it had the Misfortune to be annoy'd with many small Insects that hapn'd to fix upon it; yet had shot very considerable collateral Branches; and at least as many Roots as either that in H or I; which had a much greater Quantity of Terrestrial Matter adhering to the Extremities of them. The same green Substance here, that was in the two preceding.

(L.) *Hyde-Park Water*, with the same Quantity of *Garden-mould* as in the former. The *Mint* weigh'd, when put in, 92 Gr. when taken out, 376 Gr. The Water expended 14950 Gr. {216}

This Plant was far more flourishing than any of the precedent; had several very considerable collateral Branches, and very numerous Roots, to which Terrestrial Matter adhered very copiously.

The Earth in both these Glasses was very sensibly and considerably wasted, and less than when first put in. The same sort of green Substance here as in those above.

(M.) *Hyde-Park Water*, distilled off with a gentle Still. The *Mint* weigh'd, when put in, 114 Gr. when taken out 155. The Water expended, 8803 Gr.

This Plant was pretty kindly; had two small collateral Branches, and several Roots, though not so many as that in H or I, but as much Terrestrial Matter adhering to them as those had. The Water was pretty thick; having very numerous small Terrestrial Particles swimming in it, and some Sediment at the bottom of the Glass. This Glass had none of the green Matter above mentioned, in it.

(N.) The Residue of the Water, which remain'd in the *Still* after that in M, was distill'd off. It was very turbid, and as high-colour'd (reddish) as ordinary Beer. The *Mint* weigh'd, when put in, 81 Gr. when taken out, 175 Gr. Water expended, 4344 Gr. This Plant was very lively; and had sent out six collateral Branches, and several Roots.

(O.) *Hyde-Park Conduit-water*, in which was dissolved a Drachm of Nitre. The Mint set in this suddenly began to wither and decay; and died in a few Days: As likewise did {217}
two more Sprigs, that were set in it, successively. In another Glass I dissolv'd an Ounce of good Garden-mould, and a Drachm of Nitre, and in a third, half an Ounce of Wood ashes, and a Drachm of Nitre; but the Plants in these succeeded no better than in the former. In other Glasses I dissolved several other sorts of Earths, Clays, Marles, and variety of Manures, *&c.* I set Mint in distill'd Mint-water; and other Experiments I made, of several kinds, in order to get Light and Information, what hastened or retarded, promoted or impeded Vegetation; but these do not belong to the Head I am now upon.

(P.) *Hyde-Park Conduit-water.* In this I fix'd a Glass-Tube about ten Inches long, the Bore about one sixth of an Inch in Diameter, fill'd with very fine and white Sand, which I kept from falling down out of the Tube into the Vial, by tying a thin piece of Silk over that end of the Tube that was downwards. Upon Immersion of the lower end of it into the Water, this by little and little ascended quite to the upper Orifice of the Tube. And yet, in all the fifty six Days which it stood thus, a very inconsiderable Quantity of Water had gone off, *viz.* scarce twenty Grains; though the Sand continued moist up to the top till the very last. The Water had imparted a green Tincture to the Sand, quite to the very top of the Tube. And, in the Vial, it had precipitated a greenish Sediment, mix'd with black. To the bottom and sides of the Tube, as far as 'twas immers'd in the Water, adher'd pretty much of the green Substance describ'd above. Other like Tubes I fill'd {218}
with Cotton, Lint, Pith of Elder, and several other porous Vegetable Substances; setting some of them in clear Water; others in Water tinged with Saffron, Cochinele, *&c.* And several other Trials were made, in order to give a mechanical Representation of the motion and distribution of the Juices in Plants; and of some other *Phænomena* observable in Vegetation, which I shall not give the Particulars of here, as being not of use to my present design.

(Q, R, S, *&c.*) Several Plants set in Vials, ordered in like manner as those above, in *October*, and the following colder Months. These throve not near so much; nor did the Water ascend in nigh the quantity it did in the better Seasons, in which the before recited Trials were made.

Some Reflections upon the foregoing Experiments.

1. *In Plants of the same kind, the less they are in Bulk, the smaller the Quantity of the fluid Mass, in which they are set, is drawn off; the Dispendium of it, where the Mass is of equal thickness, being pretty nearly proportion'd to the Bulk, of the Plant.* Thus that in the Glass mark'd A, which weigh'd only 27 Grains, drew off but 2558 Grains of the Fluid; and that in B, which weigh'd only 28¼, took up but 3004 Grains; whereas that in H, which weigh'd 127 Grains, spent {219}
14190 Grains of the Liquid Mass.

The Water seems to ascend up the *Vessels* of Plants, in much the same manner as up a Filtre; and 'tis no great wonder that a larger Filtre should draw off more Water than a lesser; or that a Plant that has more and larger Vessels, should take up a greater share of the Fluid in which it is set, than one that has fewer and smaller ones can. Nor do I note this as a thing very considerable in it self, but chiefly in regard to what I am about to offer beneath; and that it may be seen that, in my other Collations of Things, I made due Allowance for this Difference.

2. *The much greatest part of the fluid Mass, that is thus drawn off and convey'd into the Plants, does not settle or abide there; but passes through the pores of them, and exhales up into the Atmosphere.* That the Water in these Experiments ascended only through the Vessel of the

Plants, is certain. The *Glasses* F and G, that had no Plants in them, though disposed of in like manner as the rest, remain'd at the End of the Experiment, as at first; and none of the Water was gone off. And that the greatest part of it flies off from the Plant into the Atmosphere, is as certain. The least Proportion of the Water expended, was to the Augment of the Plant, as 46 or 50 to 1. And in some the weight of the Water drawn off, was 100, 200, nay, in one above 700 times as much as the Plant had received of Addition.

This so continual an Emission and Detachment of Water, in so great Plenty from the Parts of {220}
Plants, affords us a manifest Reason why Countries that abound with Trees, and the larger Vegetables especially, should be very obnoxious to Damps, great Humidity in the Air, and more frequent Rains, than others that are more open and free. The great Moisture in the Air, was a mighty inconvenience and annoyance to those who first settled in *America*; which at that time was much overgrown with Woods and Groves. But as these were burnt and destroy'd, to make way for Habitation and Culture of the Earth, the Air mended and clear'd up apace, changing into a Temper much more dry and serene than before.

Nor does this Humidity go off pure and alone; but usually bears forth with it many Parts of the same Nature with those whereof the Plant, through which it passes, consists. The *Crasser* indeed are not so easily born up into the Atmosphere; but are usually deposited on the Surface of the Flowers, Leaves, and other Parts of the Plants: Hence comes our Manna's, our Honeys, and other Gummous Exsudations of Vegetables. But the finer and lighter Parts are with greater ease sent up into the Atmosphere. Thence they are conveyed to our Organs of Smell, by the Air we draw in Respiration; and are pleasant or offensive, beneficent or injurious to us, according to the Nature of the Plants from whence they arise. And since these owe their Rise to the Water, that ascends out of the Earth through the Bodies of Plants, we cannot be far to seek for the Cause why they are more numerous in the Air, and we find a greater quantity of Odors exhaling from Vegetables, {221}
in warm, humid Seasons, than in any other whatever.

3. *A great part of the Terrestrial Matter that is mix'd with the Water, ascends up into the Plant as well as the Water*. There was much more Terrestrial Matter at the end of the Experiment, in the Water of the Glasses F and G, that had no Plants in them, than in those that had Plants. The *Garden-mould* dissolved in the Glasses K and L, was considerably diminished, and carried off. Nay, the Terrestrial and Vegetable Matter was born up in the Tubes fill'd with Sand, Cotton, *&c.* in that Quantity, as to be evident even to Sense. And the Bodies in the Cavities of the other Tubes, that had their lower Ends immers'd in Water, wherein Saffron, Cochinele, *&c.* had been infused, were tinged with Yellow, Purple, *&c.*

If I may be permitted to look abroad a while, towards our Shores and Parts within the Verge of the Sea, these will present us with a large Scene of Plants, that, along with the Vegetable, take up into them meer mineral Matter also in great abundance. Such are our Sea-Purslains, the several sorts of *Alga's*, of Sampires, and other marine Plants. These contain common Sea-salt, which is all one with the *Fossil*, in such plenty, as not only to be plainly distinguish'd on the Palate, but may be drawn forth of them in considerable Quantity. Nay, there want not those who affirm, there are Plants found that will yield *Nitre*, and other mineral Salts; of which indeed I am {222}
not so far satisfied, that I can depend on the Thing, and therefore give this only as an hint for Enquiry.

To go on with the Vegetable Matter, how apt and how much disposed this, being so very fine and light, is to attend Water in all its Motions, and follow it into each of its Recesses, is manifest, not only from the Instances above alledg'd, but many others. Percolate it withal the Care imaginable: Filter it with never so many Filtrations, yet some Terrestrial Matter will remain. 'Tis true, the Fluid will be thinner every time than other, and more disingaged of the said Matter; but never wholly free and clear. I have filtred Water thorough several wholly free and clear Sheets of thick Paper; and, after that, through very close fine Cloth twelve times doubled. Nay, I have done this over and over; and yet a considerable quantity of this Matter discover'd it self in the Water after all. Now if it thus pass Interstices, that are so very small and fine along with the Water, 'tis the less strange it should attend it in its passage through the Ducts and Vessels of Plants. 'Tis true, filtering and distilling of Water intercepts and makes it quit some of the Earthy Matter it was before impregnated withal: But then that which continues with the Water after this, is fine and light; and such consequently, as is in a peculiar manner fit for the Growth and Nourishment of Vegetables. And this is the Case of Rain-water. The Quantity of Terrestrial Matter it bears up into the Atmosphere, is not great. But that which it does bear up, is mainly of that light kind of {223}
Vegetable Matter; and that too perfectly dissolved, and reduced to single Corpuscles, all fit to enter the Tubules and Vessels of Plants: On which Account 'tis, that this Water is so very fertile and prolifick.

The Reason, why in this Proposition, I say, only a great part of the Terrestrial Matter that is mix'd with the Water, ascends up with it into the Plant, is, because all of it cannot. The Mineral Matter is a great deal of it, not only gross and ponderous, but scabrous and inflexible; and so not disposed to enter the Pores of the Roots. And a great many of the simple Vegetable Particles by

degrees unite, and form some of them small Clods or *Moleculæ*; such as those mention'd in H, K, and L, sticking to the Extremities of the Roots of those Plants. Others of them intangle in a looser manner; and form the *Nubeculæ*, and green Bodies, so commonly observ'd in stagnant Water. These, when thus conjoin'd, are too big to enter the Pores, or ascend up the Vessels of Plants, which singly they might have done. They who are conversant in Agriculture, will easily subscribe to this. They are well aware that, be their Earth never so rich, so good, and so fit for the production of Corn or other Vegetables, little will come of it, unless the Parts of it be separated and loose. 'Tis on this Account they bestow the Pains they do in Culture of it, in Digging, Plowing, Harrowing, and Breaking of the Clodded Lumps of Earth. 'Tis the same way that Sea-salt, Nitre, and other Salts, promote Vegetation. I am sorry I cannot subscribe to the Opinion of those {224}
Learned Gentlemen, who imagine Nitre to be essential to Plants; and that nothing in the Vegetable Kingdom is transacted without it. By all the Trials I have been able to make, the thing is quite otherwise; and when contiguous to the Plant, it rather destroys than nourishes it. But this Nitre and other Salts certainly do; they loosen the Earth, and separate the concreted Parts of it; by that means fitting and disposing them to be assumed by the Water, and carried up into the Seed or Plant, for its Formation and Augment. There's no Man but must observe, how apt all sorts of Salts are to be wrought upon by Moisture; how easily they liquate and run with it; and when these are drawn off, and have deserted the Lumps wherewith they were incorporated, those must moulder immediately, and fall asunder of Course. The hardest Stone we meet with, if it happen, as frequently it does, to have any sort of Salt intermix'd with the Sand, of which it consists, upon being expos'd to an humid Air, in a short time dissolves and crumbles all to pieces; and much more will clodded Earth or Clay, which is not of near so compact and solid a Constitution as Stone is. The same way likewise is Lime serviceable in this Affair. The Husbandmen say of it, that it does not fatten, but only mellows the Ground: By which they mean, that it does not contain any thing in it self that is of the same Nature with the Vegetable Mould, or afford any Matter fit for the Formation of Plants; but meerly softens and relaxes the Earth; by {225}
that means rendering it more capable of entering the Seeds and Vegetables set in it, in order to their Nourishment, than otherwise it would have been. The Properties of Lime are well known; and how apt 'tis to be put into Ferment and Commotion by Water. Nor can such Commotion ever happen when Lime is mix'd with Earth, however hard and clodded that may be, without opening and loosening of it.

4. *The Plant is more or less nourish'd and augmented, in Proportion as the Water, in which it stands, contains a greater or smaller Quantity of proper terrestrial Matter in it.* The Truth of this Proportion is so eminently discernable through the whole Process of these Trials, that I think no doubt can be made of it. The *Mint* in the Glass C, was of much the same Bulk and Weight with those in A and B. But the Water, in which that was, being River-water, which was apparently stored more copiously with terrestrial Matter, than the Spring or Rain-water, wherein they stood, were; it had thriven to almost double the Bulk that either of them had, and with a less Expence of Water too. So likewise the Mint in L, in whose Water was dissolved a small quantity of good Garden-mould, though it had the disadvantage[8] to be less, when first set, than either of the Mints in H or I, whose Water was the very same with this in L, but had none of that Earth mix'd with it; yet, in a short time the Plant not only overtook, but much out-strip'd those and at the end of the Experiment was very considerably bigger and heavier than either of them. In like manner {226}
the *Mint* in N, though less at the beginning than that in M, being set in that thick, turbid, feculent Water, that remained behind, after that wherein M was placed, was still'd off, had in fine more than double its original weight and bulk; and receiv'd above twice the additional Encrease, than that in M, which stood in the thinner distill'd Water, had done. And, which is not less considerable, had not drawn off half the Quantity of Water that that had.

Why, in the beginning of this Article, I limit the Proportion of the Augment of the Plant to the Quantity of proper Terrestrial Matter in the Water, is, because all, even the Vegetable Matter, to say nothing of the Mineral, is not proper for the Nourishment of every Plant. There may be, and doubtless are, some Parts in different Species of Plants, that may be much alike, and so owe their Supply to the same common Matter; but 'tis plain all cannot. And there are other Parts so differing, that 'tis no ways credible they should be formed all out of the same sort of Corpuscles. So far from it, that there want not good Indications, as we shall see by and by, that every kind of Vegetable requires a peculiar and specifick Matter for its Formation and Nourishment. Yea, each Part of the same Vegetable does so; and there are very many and different Ingredients go to the Composition of the same individual Plant. If therefore the Soil, wherein any Vegetable or Seed is planted, contains all or most of these ingredients, and those in due quantity, it will grow and thrive there; otherwise 'twill not. If there be not as many sorts of Corpuscles as are requisite for {227}
the Constitution of the main and more essential Parts of the Plant, 'twill not prosper at all. If there be these, and not in sufficient Plenty, 'twill starve, and never arrive to its natural Stature: Or if there be any the less necessary and essential Corpuscles wanting, there will be some failure in the Plant; 'twill be defective in Taste, in Smell, in Colour, or some other way. But though a Tract of Land may happen not to contain Matter proper for the Constitution of some one peculiar

kind of Plant; yet it may for several others, and those much differing among themselves. The Vegetative Particles are commix'd and blended in the Earth, with all the diversity and variety, as well as all the uncertainty, conceivable. I have given some intimations of this elsewhere[9], and shall not repeat them here, but hope in due time to put them into a much better Light than that they there stand in.

It is not possible to imagine, how one uniform, homogeneous Matter, having its Principles or Original Parts all of the same Substance, Constitution, Magnitude, Figure, and Gravity, should ever constitute Bodies so egregiously unlike, in all those respects, as Vegetables of different kinds are; nay, even as the different Parts of the same Vegetable. That one should carry a resinous, another a milky, a third a yellow, a fourth a red Juice, in its Veins; one afford a fragrant, another an offensive Smell; one be sweet to the Taste, another bitter, acid, acerbe, austere, &c. that one should be nourishing, another poisonous, one purging, another astringent: In brief, that {228} there should be that vast difference in them, in their several Constitutions, Makes, Properties, and Effects, and yet all arise from the very same sort of Matter, would be very strange. And, to note by the by, this Argument makes equally strong against those, who suppose meer Water the Matter, out of which all Bodies are form'd.

The *Cataputia* in the Glass E, received but very little Encrease, only three Grains and an half all the while it stood, though 2501 Grains of Water were spent upon it. I will not say the Reason was, because that Water did not contain in it Matter fit and proper for the Nourishment of that peculiar and remarkable Plant. No, it may be the Water was not a proper *Medium* for it to grow in; and we know there are very many Plants that will not thrive in it. Too much of that Liquor, in some Plants, may probably hurry the Terrestrial Matter thorough their Vessels too fast for them to arrest and lay hold of it. Be that as it will, 'tis most certain there are peculiar Soils that suit particular Plants. In *England*, Cherries are observ'd to succeed best in *Kent*; Apples in *Herefordshire*; Saffron in *Cambridgeshire*; Wood in two or three of our *Midland Counties*; and Teazles in *Somersetshire*. This is an Observation that hath held in all Parts, and indeed in all Ages of the World. The most ancient Writers of Husbandry[10] took notice of it; and are not wanting in their Rules for making choice of Soils suited to the Nature of each kind of Vegetable they thought valuable, or worth propagating.

But, which is a further Proof of what I am here endeavouring to advance, that Soil that is once {229} proper and fit for the Production of some one sort of Vegetable, does not ever continue to be so. No, in Tract of time it loses that Property; but sooner in some Lands, and later in others: This is what all who are conversant in these things know very well. If Wheat, for Example, be sown upon a Tract of Land that is proper for that Grain, the first Crop will succeed very well; and perhaps the second, and the third, as long as the Ground is in Heart, as the Farmers speak; but in a few Years 'twill produce no more, if sowed with that Corn: Some other Grain indeed it may, as Barley. And after this has been sown so often, that the Land can bring forth no more of the same, it may afterwards yield good Oats; and, perhaps, Pease after them. At length 'twill become barren; the Vegetative Matter, that at first it abounded withal, being educed forth of it by those successive Crops, and most of it born off. Each sort of Grain takes forth that peculiar Matter that is proper for its own Nourishment. First, the Wheat draws off those Particles that suit the Body of that Plant; the rest lying all quiet and undisturbed the while. And when the Earth has yielded up all them, those that are proper for Barley, a different Grain, remain still behind, till the successive Crops of that Corn fetch them forth too. And so the Oats and Pease, in their Turn; till in fine all is carried off, and the Earth in great measure drain'd of that sort of Matter.

After all which, that very Tract of Land may be brought to produce another Series of the same {230} Vegetables; but never till 'tis supplied with a new Fund of Matter, of like sort with that it at first contain'd. This Supply is made several ways: By the Grounds lying fallow for some time, till the Rain has pour'd down a fresh Stock upon it: *Or*, by the Tiller's Care in manuring of it. And for farther Evidence that this Supply is in reality of like sort, we need only reflect a while upon those Manures that are found by constant Experience best to promote Vegetation, and the Fruitfulness of the Earth. These are chiefly either parts of Vegetables, or of Animals; which indeed either derive their own Nourishment immediately from Vegetable Bodies, or from other Animals that do so. In particular, the Blood, Urine, and Excrements of Animals; Shavings of Horns, and of Hoofs; Hair, Wool, Feathers; calcin'd Shells; Lees of Wine, and of Beer; Ashes of all sorts of Vegetable Bodies; Leaves, Straw, Roots, and Stubble, turn'd into the Earth by Plowing or otherwise to rot and dissolve there: These, I say, are our best Manures; and, being Vegetable Substances, when refunded back again into the Earth, serve for the Formation of other like Bodies.

Not wholly to confine our Thoughts to the Fields, let us look a while into our Gardens; where we shall meet with still further Confirmations of the same thing. The Trees, Shrubs, and Herbs cultivated in these, after they have continued in one Station, till they have derived thence the greater part of the Matter fit for their Augment, will decay and degenerate, unless either fresh {231} Earth, or some fit Manure, be applied unto them. 'Tis true, they may maintain themselves there for some time, by sending forth Roots further and further to a great Extent all round, to fetch in more remote Provision; but at last all will fail; and they must either have a fresh Supply brought

to them, or they themselves be removed and transplanted to some Place better furnished with Matter for their Subsistence. And accordingly *Gardiners* observe, that Plants that have stood a great while in a Place, have longer Roots than usual; part of which they cut off, when they transplant them to a fresh Soil, as now not of any further use to them. All these Instances, to pass over a great many others that might be alledg'd, point forth a particular Terrestrial Matter, and not Water, for the Subject to which Plants owe their Increase. Were it Water only, there would be no need of Manures; or of transplanting them from place to place. The Rain falls in all Places alike; in this Field and in that indifferently; in one side of an Orchard or Garden, as well as another. Nor could there be any Reason, why a Tract of Land should yield Wheat one Year, and not the next; since the Rain showers down alike in each. But I am sensible I have carried on this Article to too great a length; which yet on so ample and extensive a Subject, 'twas not easie to avoid.

5. *Vegetables are not form'd of Water; but of a certain peculiar Terrestrial Matter*. It hath been shewn, that there is a considerable Quantity of this Matter contain'd both in Rain, Spring, and {232} River-water: That the much greatest part of the fluid Mass that ascends up into Plants, does not settle or abide there, but passes through the Pores of them, and *exhales* up into the Atmosphere; That a great part of the Terrestrial Matter, mix'd with the Water, passes up into the Plant along with it; and that the Plant is more or less augmented in proportion, as the Water contains a greater or smaller Quantity of that Matter. From all which we may very reasonably infer, that *Earth, and not Water, is the Matter that constitutes Vegetables*. The Plant in E, drew up into it 2501 Grains of the fluid Mass; and yet had received but Grains 3 and a half of Increase from all that. The Mint in L, though it had at first the disadvantage to be much less than that in I; yet being set in Water wherewith Earth was plentifully mix'd, and *that* in I, *only in Water* without any such additional Earth, it had vastly outgrown the other, weighing at last 145 Grains more than that did, and so having gain'd about twice as much as that had. In like manner that in K, though 'twas a great deal less when put in than that in I, and also was impair'd and offended by Insects; yet being planted in Water wherein Earth was dissolved, whereas the Water in which it stood had none, it not only over-took, but considerably surpass'd the other; weighing at last 29 Grains more than that in I, and yet had not expended so much Water as that, by above 2400 Grains. The Plant in N, tho' at first a great deal less than that in M; yet being set in the foul crass Water that was left in the Still, after that, in which M was set, was drawn off, in Conclusion had gain'd in weight {233} above double what that in the finer and thinner Water had. The Proportion of the Augment of that Plant that throve most was, to the fluid Mass spent upon it, but as 1 to 46. In others, 'twas but as 1 to 60, 100, 200; nay, in the *Cataputia*, 'twas but as 1 to 714. The Mint in B took up 39 Grains of Water a-day, one day with another; which was much more than the whole weight of the Plant originally; and yet, with all this, it gain'd not one fourth of a Grain a-day in weight. Nay, that in H took up 253 Grains a day of the Fluid: Which was near twice as much as its original Weight, it weighing, when first set in the Water, but 127 Grains. And, after all, the daily Encrease of the Plant was no more than Grains $2\frac{15}{56}$.

6. *Spring, and Rain-water, contain pretty near an equal Charge of Vegetable Matter*; *River-water more than either of them.* The Plants in the Glasses A, B, and C, were at first of much the same size and weight. At the End of the Experiment, the Mint in A had gain'd 15 Grains out of 2558 Grains of Spring-water; that in B, Grains 17 and an half, out of 3004 Grains of Rain-water; but that in C had got 26 Grains out of only 2493 Grains of River-water. I do not found this Proposition solely upon these Trials; having made some more, which I do not relate here, that agree well enough with these. So that the Proportions here deliver'd, will hold for the main; but a strict and just Comparison is hardly to be expected. So far from it, that I make no doubt, but the Water that falls in Rain, at some times, contains a greater share of Terrestrial Matter than that which falls at others. A more powerful and intense Heat must needs hurry up a larger quantity of {234} that Matter along with the humid Vapours that form Rain, than one more feeble and remiss ever possibly can. The Water of one Spring may flow forth with an higher Charge of this Matter, than that of another; this depending partly upon the quickness of the Ebullition of the Water, and partly upon the Quantity of that Matter latent in the *Strata*, through which the Fluid passes, and the greater or less laxity of those *Strata*. For the same Reason, the Water of one River may abound with it more than that of another. Nay, the same River, when much agitated, and in commotion, must bear up more of it, than when it moves with less rapidity and violence. That there is a great Quantity of this Matter in Rivers; and that it contributes vastly to the ordinary Fertility of the Earth, we have an illustrious Instance in the *Nile*, the *Ganges*, and other Rivers that yearly overflow the neighbouring Plains. Their Banks shew the fairest and largest Crops of any in the whole World. They are even loaded with the multitude of their Productions; and those who have not seen them, will hardly be induced to believe the mighty Returns those Tracts make in comparison of others, that have not the Benefit of like Inundations.

7. *Water serves only for a Vehicle to the Terrestrial Matter, which forms Vegetables; and does not it self make any addition unto them.* Where the proper Terrestrial Matter is wanting, the Plant is not augmented, though never so much Water ascend into it. The *Cataputia* in E, took up {235} more Water than the Mint in C, and yet had grown but very little, having received only three Grains and an half of additional weight; whereas the other had received no less than twenty six Grains. The Mint in I, was planted in the same sort of Water as that in K, was; only the latter had Earth dissolved in the Water; and yet that drew off 13140 Grains of the Water, gaining it self no more than 139 Grains in weight; whereas the other took up but 10731 Grains of the Water, and was augmented 168 Grains in weight. Consequently that spent 2409 Grains more of the Water than this in K, did, and yet was not so much encreased in weight as this by 29 Grains. The Mint in M, stood in the very same kind of Water as that in N, did. But the Water in M, having much less Terrestrial Matter in it than that in N had, the Plant bore up 8803 Grains of it, gaining it self only 41 Grains the while; whereas that in N drew off no more than 4344 Grains, and yet was augmented 94 Grains. So that it spent 4459 Grains of Water more than that did; and yet was not it self so much increased in weight, as that was, by 53 Grains. This is both a very fair, and a very conclusive Instance; on which Account 'tis that I make oftner use of it. Indeed they are all so; and to add any thing further on this Head, will not be needful.

'Tis evident therefore Water is not the Matter that composes Vegetable Bodies. 'Tis only the Agent that conveys that Matter to them; that introduces and distributes it to their several Parts for their Nourishment. That Matter is sluggish and unactive, and would lie eternally confin'd to {236} its Beds of Earth, without ever advancing up into Plants, did not Water, or some like Instrument, fetch it forth and carry it unto them. That therefore there is that plentiful Provision, and vast Abundance of it supplied to all Parts of the Earth, is a mark of a natural Providence superintending over the Globe we inhabit; and ordaining a due Dispensation of that Fluid, without the Ministry of which the Noble Succession of Bodies we behold, *Animals*, *Vegetables*, and *Minerals*, would be all at a stand[11]. But to keep to Plants, 'tis manifest Water, as well on this, as upon the other Hypothesis, is absolutely necessary in the Affair of Vegetation; and it will not succeed without it: Which indeed gave occasion to the Opinion, that Water it self nourished, and was changed into Vegetable Bodies. They saw, though these were planted in a Soil never so rich, so happy, so advantageous, nothing came of it unless there was Water too in a considerable quantity. And it must be allow'd Vegetables will not come on or prosper where that is wanting: But yet what those Gentlemen inferr'd thence, was not, we see, well grounded.

This Fluid is capacitated for the Office here assign'd it several ways: By the Figure of its Parts, which, as appears from many Experiments, is exactly and mathematically Spherical; their Surfaces being perfectly polite, and without any the least Inequalities. 'Tis evident, Corpuscles of such a Figure are easily susceptible of Motion, yea, far above any others whatever; and {237} consequently the most capable of moving and conveying other Matter, that is not so active and voluble. Then the Intervals of Bodies of that Figure are, with respect to their Bulk, of all others the largest; and so the most fitted to receive and entertain foreign Matter in them. Besides, as far as the Trials hitherto made inform us, the constituent Corpuscles of Water are, each singly consider'd, absolutely solid; and do not yield to the greatest External Force. This secures their Figure against any Alteration; and the Intervals of the Corpuscles must be always alike. By the latter, 'twill be ever disposed to receive Matter into it; and by the former, when once received, to bear it on along with it. Water is further capacitated to be a Vehicle to this Matter, by the tenuity and fineness of the Corpuscles of which it consists. We hardly know any Fluid in all Nature, except Fire, whose constituent Parts are so exceeding subtle and small as those of Water are. They'll pass Pores and Interstices, that neither Air nor any other Fluid will. This enables them to enter the finest Tubes and Vessels of Plants, and to introduce the Terrestrial Matter, conveying it to all Parts of them; whilst each, by means of Organs 'tis endowed with for the Purpose, intercepts and assumes into it self such Particles as are suitable to its own Nature, letting the rest pass on through the common Ducts. Nay, we have almost every where Mechanical Instances of much the same Tenor. 'Tis obvious to every one, how easily and suddenly Humidity, or the Corpuscles of Water sustained in the Air, pervade and insinuate themselves into Cords, however {238} tightly twisted, into Leather, Parchment, Vegetable Bodies, Wood, and the like. This it is that fits them for *Hygrometers*; and to measure and determine the different quantities of Moisture in the Air, in different Places and Seasons. How freely Water passes and carries with it Terrestrial Matter, through Filtres, Colatures, Distillations, *&c.* hath been intimated already.

8. *Water is not capable of performing this Office to Plants, unless assisted by a due Quantity of Heat; and this must concur, or Vegetation will not succeed.* The Plants that were set in the Glasses Q, R, S, *&c.* in *October*, and the following colder Months, had not near the quantity of Water sent up into them, or so great an additional Encrease by much, as those that were set in *June*, *July*, and the hotter. 'Tis plain Water has no power of moving it self; or rising to the vast height it does in the more tall and lofty Plants. So far from this, that it does not appear from any Discovery yet made, that even its own Fluidity consists in the intestine Motion of its Parts; whatever some, otherwise very learned and knowing, Persons may have thought. There is no

need of any thing more, for solving all the *Phænomena* of Fluidity, than such a Figure and Disposition of the Parts, as Water has. Corpuscles of that make, and that are all absolutely Spherical, must stand so very tickle and nicely upon each other, as to be susceptible of every Impression; and though not perpetually in Motion, yet must be ever ready and liable to be put {239} into it, by any the slightest Force imaginable. It is true, the Parts of Fire or Heat are not capable of moving themselves any more than those of Water; but they are more subtil, light, and active, than those are, and so more easily put into Motion. In fine, 'tis evident and matter of Fact, that Heat does operate upon, and move the Water, in order to its carrying on the Work of Vegetation: But how 'tis agitated it self, and where the Motion first begins, this is no fit Place to enquire.

That the Concourse of Heat in this Work is really necessary, appears, not only from the Experiments before us, but from all Nature; from our Fields and Forests, our Gardens and our Orchards. We see in *Autumn*, as the Sun's Power grows gradually less and less, so its Effects on Plants is remitted, and their Vegetation slackens by little and little. Its Failure is first discernible in Trees. These are raised highest above the Earth; and require a more intense Heat to elevate the Water, charged with their Nourishment, to the Tops and Extremities of them. So that for want of fresh Support and Nutriment, they shed their Leaves, unless secur'd by a very firm and hardy Constitution indeed, as our *ever-Greens* are. Next the Shrubs part with theirs; and then the Herbs and lower Tribes; the Heat being at length not sufficient to supply even these, though so near the Earth, the Fund of their Nourishment. As the Heat returns the succeeding Spring, they all recruit again; and are furnish'd with fresh Supplies and Verdure: But first, those which are lowest and nearest the Earth, Herbs, and they that require a lesser degree of Heat to raise the {240} Water with its Earthy Charge into them: Then the Shrubs and higher Vegetables in their Turns; and lastly, the Trees. As the Heat increases, it grows too powerful, and hurries the Matter with too great Rapidity thorough the finer and more tender Plants: These therefore go off, and decay; and others that are more hardy and vigorous, and require a greater share of Heat, succeed in their Order. By which Mechanism, provident Nature furnishes us with a very various and differing Entertainment; and what is best suited to each Season, all the Year round.

As the Heat of the several Seasons affords us a different Face of Things; so the several distant Climates shew different Scenes of Nature, and Productions of the Earth[12]. The Hotter Countries yield ordinarily the largest and tallest Trees; and those in too much greater variety than the colder ever do. Even those Plants which are common to both, attain to a much greater Bulk in the Southern than in the Northern Climes. Nay, there are some Regions so bleak and chill, that they raise no Vegetables at all to any considerable Size. This we learn from *Greenland*, from *Iseland*, and other Places of like cold Site and Condition. In these no Tree ever appears; and the very Shrubs they afford, are few, little, and low.

Again, in the warmer Climates, and such as do furnish forth Trees and the larger Vegetables, if there happen a remission or diminution of the usual Heat, their Productions will be impeded and diminished in proportion. Our late Colder Summers have given us proof enough of this. For {241} though the Heat we have had, was sufficient to raise the Vegetative Matter into the lower Plants, into our Corns, our Wheat, Barley, Pease and the like; and we have had plenty of Straw-berries, Ras-berries, Currans, Goosberries, and the Fruits of such other Vegetables as are low and near the Earth: Yea, and a moderate store of Cherries, Mulberries, Plumbs, Filberts, and some others that grow somewhat at a greater Height; yet our Apples, our Pears, Walnuts, and the Productions of the taller[13] Trees have been fewer, and those not so kindly, so thoroughly ripen'd, and brought to that Perfection they were in the former more benign and their warm Seasons. Nay, even the lower Fruits and Grains have had some share in the common Calamity; and fallen short both in Number and Goodness of what the hotter and kinder Seasons were wont to shew us. As to our Grapes, Abricots, Peaches, Nectarens, and Figs, being transplanted hither out of hotter Climes, 'tis the less wonder we have of late had so general a Failure of them.

Nor is it the Sun, or the ordinary emission of the Subterranean Heat only, that promotes Vegetation; but any other indifferently, according to its Power and Degree: This we are taught by our Stoves, hot Beds, and the like. All Heat is of like kind; and where-ever is the same Cause, {242} there will be constantly the same Effect. There's a Procedure in every part of Nature, that is perfectly regular and geometrical, if we can but find it out; and the further our Searches carry us, the more shall we have occasion to admire this, and the better 'twill compensate our Industry.

[1] *Terra Parens.* Γῆ μὴτηρ πάντων. *Terra Matter.*

[2] *Nat. History, Cent.* 5. §. 411.

[3] *Complexionum atque Mistion. Element. Figm.*

[4] Mr. *Boyle, Scept. Chym. par. 2.*

[5] *Provided the* Silver *be* pure *and absolutely* refin'd*: For the least admixture of* Copper *will produce* a blue Tincture *in the* Menstruum*; as* that *of some* other Bodies*, one* different.

[6] *To say nothing of those that were not discernible.*

[7] Mr. *W. Molineux, Philosophical Trans. No. 181.*

[8] *Confer. Prop. 1. supra.*

[9] *Nat. Hist. Earth*, p. 228. & seq.

[10] *Vid. Varronem, Columellam, & reliquos Rei Rusticæ Scriptores.*

[11] *Conf. Nat. Hist. Earth*, p. 47. & seq. uti & p. 128, *&c.*

[12] *Conf. Nat. Hist. Earth*, Pag. 267. & seq.

[13] *The Dwarf Apple and Pear trees have succeeded better. And indeed in Trees of the same kind, those that keep closest to the Earth always produce the most and best Fruit. For which Reason 'tis that the Gardiners check and restrain the Growth of better Fruit-trees, and prevent their running up to too great a Height.*

{243}

An Account of the Measure of the thickness of Gold upon Gilt Wire; together with Demonstration of the exceeding Minuteness of the Atoms or constituent Particles of Gold; as it was read before the Royal Society*, by* E. Halley*.*

WHAT are the constituent Parts of Matter, and how there comes to be so great a diversity in the weight of Bodies, to all appearance equally solid and dense, such as are Gold and Glass, (whose specifick Gravities are nearly as 7 to 1) seems a very hard Question to those that shall rightly consider it: For from undoubted Experiment, Gravity is in all Bodies proportionable to the Quantity of Matter in each; and there is no such thing as a Propension of some more, others less, towards the Earth's Center; since the Impediment of the Air being removed, all Bodies descend, be they never so loose or compact in Texture, with equal Velocity. It follows therefore, That there is 7 times as much Matter in Gold, as in a piece of Glass of the same Magnitude; and consequently, that at least six parts of seven in the Bulk of Glass, must be Pore or Vacuity: This some Favourers of the Atomical Philosophy have endeavoured to solve, by supposing the primary or constituent Atoms of Gold to be much larger than those of other Bodies, {244}
and consequently the Pores fewer; whereas in other Bodies, the great multitude of the interspersed Vacuities does diminish their Weights.

Being desirous to examine this Notion of the Magnitude of Atoms of Gold, I bethought my self of the extreme Ductility of that Metal, which is seen in the beating of it into Leaf, and above all in the drawing fine Gilt-wire, by means whereof, I believed I might most exactly obtain the true thickness of the Coat of Gold, that appears, even with the Microscope, so well to represent Gold it self, that not the least point of Silver appears through it. In order to this, I inform'd my self among the Wire-drawers, what Gold they us'd to their Silver; and they told me, That the very best double Gilt Wire was made out of Cylindrick Ingots, 4 Inches in Circumference, and 28 Inches long, which weigh 16 Pounds Troy; on these they bestow 4 Ounces of Gold, that is, to every 48 Ounces of Silver one of Gold; and that two Yards of the super-fine Wire weighs a Grain. Hence at first sight it appear'd, that the length of 98 Yards is in weight 49 Grains, and that a single Grain of Gold covers the said 98 Yards, and that the 10000th part of a Grain is above ⅓ of an Inch long; which yet may be actually divided into 10, and so the 100000th part of a Grain of Gold be visible without a Microscope. But being desirous to compute the thickness of the Skin of Gold, by means of the specifick Gravities of the Metals, viz. Silver 10⅓, and Gold 18⅔, I found the Diameter of such Wire the $^1/_{386}$ part of an Inch, and its Circumference the $^1/_{123}$ part; but the Gold in thickness {245}
not to exceed the $^1/_{134500}$ part of an Inch; whence it may be concluded, that the Cube of the hundredth part of an Inch would contain above 2433000000, (or the Cube of 1345) of such Atoms. And it may likewise be marvelled at, that Gold being stretcht to so great a degree, as is here demonstrated, should yet shew it self of so even and united a Texture, as not to let the white Colour of the Silver under it appear through any the least Pores; which argues, that even in this exceeding thinness very many of those Atoms may still lie one over the other: Which is a Consideration may merit the Thoughts of this Honourable Society, as tending to examine that renowned Atomical Doctrine, which has of late much obtain'd among the Learned.

{246}

An Account of the several Species of Infinite Quantity*, and of the Proportions they bear one to the other; as it was read before the* Royal Society*, by* E. Halley*.*

THAT all Magnitudes infinitely great, or such as exceed any assignable Quantity, are equal among themselves, though it be vulgarly received for a Maxim, is not yet so common as it is erroneous; and the Reason of the mistake seems to be, That the Mind of Man, coming to contemplate the Extensions of what exceeds the bounds of its Capacity, and of which the very Idea does include a Negation of Limits; it comes to pass that we acquiesce generally, and it suffices to say such a Quantity is infinite.

But if we come more nearly to examine this Notion, we shall find, that there are really besides infinite *Length* and infinite *Area*, no less than three several sorts of infinite Solidity; all of which are *Quantitates sui generis*, having no more relation or proportion the one to the other, than a Line to a Plane, or a Plane to a Solid, or a Finite to an Infinite. But that among themselves, each of those Species of Infinites are in given Proportions, is what I now intend to make plain, if possible.

But first, infinite Length, or a Line infinitely long, is to be considered either as beginning at a {247}

Point, and so infinitely extended one way, or else both ways from the same Point; in which case the one, which is a beginning infinity, is the one half of the whole, which is the Summ of the beginning and ceasing Infinity; or, as I may say, of Infinity, *à parte ante*, and *à parte post*: Which is analogous to Eternity in Time or Duration, in which there is always as much to follow as is past, from any point or moment of Time: Nor doth the Addition or Subduction of finite Length or Space of time alter the case either in Infinity or Eternity, since both the one or the other cannot be any part of the whole.

As to infinite *Surface* or *Area*, any right Line, infinitely extended both ways on an infinite Plane, does divide that infinite Plane into equal Parts; the one to the right, and the other to the left of the said Line: But if from any Point in such a Plane, two right Lines be infinitely extended, so as to make an Angle, the infinite Area, intercepted between those infinite right Lines, is to the whole infinite Plane, as the Arch of a Circle, on the Point of Concourse of those Lines, as a Centre, intercepted between the said Lines, is to the Circumference of the Circle; or as the Degrees of the Angle to the 360 Degrees of a Circle. For Example, two right Lines meeting at a right Angle do include, on an infinite Plane, a quarter part of the whole infinite Area of such a Plane.

But if so be, two parallel infinite Lines be supposed drawn on such an infinite Plane, the Area intercepted between them will be likewise infinite; but at the same time will be infinitely less, {248}
than that Space which is intercepted between two infinite Lines that are inclined, though with never so small an Angle; for that in the one Case, the given finite distance of the parallel Lines diminishes the Infinity in one Degree of Dimension; whereas in a Sector, there is Infinity in both Dimensions; and consequently, the Quantities are the one infinitely greater than the other, and there is no proportion between them.

From the same Consideration arise the Three several Species of infinite Space or Solidity, as has been said; for a Parallelepipede, or a Cylinder, infinitely long, is greater than any finite Magnitude how great soever; and all such Solids, supposed to be formed on given Bases, are as those Bases, in proportion to one another. But if two of these three Dimensions are wanting, as in the Space intercepted between two parallel Planes infinitely extended, and at a finite distance; or with infinite Length and Breadth, with a finite Thickness; All such Solids shall be as the given finite distances one to another: But these Quantities, though infinitely greater than the other, are yet infinitely less than any of those, wherein all the three Dimensions are infinite. Such are the Spaces intercepted between two inclined Planes infinitely extended; the Space intercepted by the Surface of a Cone, or the sides of a Pyramid likewise infinitely continued, *&c.* of all which notwithstanding, the Proportions one to another, and to the τὸ πᾶν, or vast Abyss of infinite Space (wherein is the *Locus* of all things that are or can be; or to the Solid of infinite Length, Breadth, and Thickness, taken all manner of ways) are easily assignable. For the Space between two Planes, is to the whole, as the Angle of those Planes to the 360 Degrees of the Circle. As for {249}
Cones and Pyramids, they are as the Spherical Surface, intercepted by them, is to the Surface of the Sphere; and therefore Cones are as the versed Sines of half their Angles, to the Diameter of the Circle: These three sorts of infinite Quantity are analogous to a Line, Surface and Solid, and after the same manner cannot be compared, or have any proportion the one to the other.

Besides these, there are several other Species of infinite Quantity, arising from the Contemplation of Curves, and their Asymptotes; which, by reason of the difficulty of the Subject, cannot be made so plain to most Readers: But what has been already said, may be sufficient to evince what we undertook to explain.

{250}

An Account of Dr. Robert Hook*'s Invention of the Marine Barometer, with its Description and Uses; published by order of the Royal Society, by* E. Halley*, R. S. S.*

SInce it was found that the *Torricellian Tube*, commonly call'd the *Mercurial Barometer*, by the rising and falling of the *Quick-silver* therein, doth presage the Changes of the Air, in relation to fair and foul Weather; upon several Years Observation of it, it has been proved and adjusted for that purpose by Dr. *Robert Hook*; and there have been by him many attempts to improve the Instrument, and render the Minute Divisions on the Scale thereof more sensible. He also judging that it might be of great use at Sea, contrived several ways to make it serviceable on Board of Ship; one of which he explain'd to the *Royal Society* at their Weekly Meeting in *Gresham College*, *January 2. 1667/8*. Since which time he hath further cultivated the Invention, and some Years ago produced before the said *Society*, the Instrument I am now to describe, which for its subtilty and usefulness, seemeth to surpass all other performances of the like Nature. {251}

'Till such time as the Author's present Indisposition will give him leave to bestow freely his Thoughts on this Subject upon the Publick, it is the Opinion of the Society, that such an Account be given of this Contrivance, as may render it known, and recommend it to the Mariners use, for which it was principally intended.

The *Mercurial Barometer* requiring a perpendicular Posture, and the *Quick-silver* vibrating

therein with great Violence upon any Agitation, is therefore uncapable of being used at Sea (tho' it hath lately been contrived to be made portable), so it remain'd to find out some other Principle, wherein the Position of the Instrument was not so indispensably necessary: For this, all those that use the Sea are obliged to the great facility Dr. *Hook* has always shewn, in applying Philosophical Experiments to their proper uses.

It is about forty Years since, that the *Thermometers* of *Robert de Fluctibus*, depending on the Dilatation and Contraction of included Air by Heat and Cold, have been disused, upon discovery that the Airs pressure is unequal; that inequality mixing it self with the Effects of the warmth of the Air in that Instrument. And instead thereof was substituted the seal'd *Thermometer*, including Spirit of Wine (first brought into *England*, out of *Italy*, by Sir *Robert Southwell*) as a proper Standard of the temper of the Air, in relation to Heat and Cold; that Ætherial Spirit being of all the known Liquors the most susceptible of Dilatation and Contraction, especially with a {252}
moderate degree of either Heat or Cold. Now this being allow'd as a Standard, and the other *Thermometer* that includes Air, being graduated with the same Divisions, so as at the time when the Air was included, to agree with the Spirit-*Thermometer* in all the degrees of Heat and Cold, noting at the same time the precise height of the *Mercury* in the common Barometers: It will readily be understood, that whensoever these two *Thermometers* shall agree, the pressure of the Air is the same it was, when the Air was included, and the Instrument graduated: That if in the Air-*Thermometer* the Liquor stand higher than the Division marked thereon, corresponding with that on the Spirit-glass, it is an indication that there is a greater pressure of the Air at that time, than when the Instrument was graduated. And the contrary is to be concluded, when the Air-glass stands lower than the Spirit, *viz.* that then the Air is so much lighter, and the *Quick silver*, in the ordinary Barometer lower than at the said time of Graduation.

And the Spaces answering to an Inch of *Mercury*, will be more or less, according to the quantity of Air so included, and the smallness of the Glass Cane, in which the Liquor rises and falls, and may be augmented almost in any proportion, under that of the Specifick Gravity of the Liquor of the *Thermometer* to *Mercury*. So as to have a Foot or more for an Inch of *Mercury*, which is another great convenience.

It has been observed by some, that in long keeping this Instrument, the Air included either {253}
finds a means to escape, or deposites some Vapours mixt with it, or else for some other cause becomes less Elastick, whereby, in process of time, it gives the height of the *Mercury* somewhat greater than it ought; but this, if it should happen in some of them, hinders not the usefulness thereof, for that it may at any time very easily be corrected by Experiment, and the rising and falling thereof are the things chiefly remarkable in it, the just height being barely a Curiosity.

In these Parts of the World, long Experience has told us, that the rising of the *Mercury* forebodes fair Weather after foul, and an Easterly or Northerly Wind; and that the falling thereof, on the contrary, signifies Southerly or Westerly Winds, with Rain, or stormy Winds, or both; which latter it is of much more consequence to provide against at Sea than at Land; and in a Storm, the *Mercury* beginning to rise is a sure sign that it begins to abate, as has been experienced in high Latitudes, both to the Northwards and Southwards of the Æquator.

The Form of this Instrument is shown in the Cut, by Tab. 4. Fig. 1. wherein,

AB represents the Spirit-*Thermometer*, graduated from 0, or the freezing Point, through all the possible degrees of the Heat or Cold of the Air, at least in these Climates.

CD, is the Air-*Thermometer*, graduated after the same manner with the like Degrees.

EF, is a Plate applied to the side of the *Thermometer* CD, graduated into Spaces answering to {254}
Inches and parts of an Inch of *Mercury*, in the common Barometers.

G, a Hand standing on the Plate at the height of the *Mercury* thereon, as it was when the Instrument was graduated, as suppose here at 29½ Inches.

LM, a Wire on which the Plate EF, slips up and down, parallel to the Cane of the *Thermometer* CD.

K, any Point at which the Spirit stands at the time of Observation; suppose at 38 on the Spirit-*Thermometer*; Slide the Plate EF till the Hand G stand at 38 on the Air-*Thermometer*, and if the Liquor therein stand at 38 likewise, then is the pressure of the Air the same as at the time of Graduation, *viz.* 29,5; but if it stand higher, as at 30, at I; then is the pressure of the Air greater; and the division on the sliding Plate against the Liquor, shews the present height of the *Mercury* to be twenty nine Inches seven Tenths. And this may suffice as to the manner of using it.

I had one of these Barometers with me in my late Southern Voyage, and it never failed to prognostick and give early notice of all the bad Weather we had, so that I depended thereon, and made provision accordingly; and from my own Experience I conclude that a more useful Contrivance hath not for this long time been offer for the benefit of Navigation.

These Instruments are made according to the Direction of Dr. *Hook*, by Mr. *Henry Hunt*, {255}
Operator to the Royal Society, who will furnish any Gentlemen with them, and give them

Directions how to use them.

{256}

A Discourse concerning the Proportional Heat of the Sun in all Latitudes, with the Method of collecting the same; as it was read before the Royal Society, in one of their late Meetings. By E. Halley.

THere having lately arisen some Discourse about that part of the Heat of Weather, simply produced by the Action of the Sun; and I having affirmed, that if that were considered, as the only Cause of the Heat of the Weather, I saw no Reason, but that under the Pole the solstitical Day ought to be as hot as it is under the Æquinoctial, when the Sun comes vertical, or over the Zenith: For this Reason, that for all the 24 Hours of that Day under the Pole, the Sun's Beams are inclined to the Horizon, with an Angle of 23½ Degrees; and under the Æquinoctial, though he come vertical, yet he shines no more than 12 Hours, and is again 12 Hours absent; and that for 3 Hours 8 Minutes of that 12 Hours, he is not so much elevated as under the Pole; so that he is not 9 of the whole 24, higher than 'tis there, and is 15 Hours lower. Now the simple Action of the Sun is, as all other Impulses or Stroaks, more or less forceable, according to the *Sinus* of {257}
the Angle of Incidence, or to the Perpendicular let fall on the Plain, whence the vertical Ray (being that of the greatest Heat,) being put *Radius*, the force of the Sun on the Horizontal Surface of the Earth will be to that, as the *Sinus* of the Sun's Altitude at any other time. This being allow'd for true, it will then follow, that the time of the continuance of the Sun's shining being taken for a *Basis*, and the *Sines* of the Sun's Altitudes erected thereon as Perpendiculars, and a Curve drawn through the Extremities of those Perpendiculars, the *Area* comprehended shall be proportionate to the Collection of the Heat of all the Beams of the Sun in that space of time. Hence it will follow, that under the Pole the Collection of all the Heat of a tropical Day, is proportionate to a Rectangle of the *Sine* of 23½ *gr.* into 24 Hours, or the Circumference of a Circle; that is, the *Sine* of 23½ *gr.* being nearly 4 Tenths of *Radius*; as $^{3}/_{10}$ into 12 Hours. Or the Polar Heat is equal to that of the Sun containing 12 Hours above the Horizon, at 53 *gr.* height, than which the Sun is not 5 Hours more elevated under the Æquinoctial.

But that this Matter may the better be understood, I have exemplified it by a Scheme, (*Tab. 4. Fig. 2*) wherein the *Area ZGHH*, is equal to the *Area* of all the *Sines* of the Sun's Altitude under the Æquinoctial, erected on the respective Hours from Sun-rise to the Zenith; and the *Area ♋HH♋* is in the same proportion to the Heat of the same 6 Hours under the Pole on the Topical Day; and *⊙HHQ*, is proportional to the collected Heat of 12 Hours, or half a Day under the Pole, {258}
which space *⊙HHQ*, is visibly greater than the other *Area HZGH*, by as much as the *Area HGQ* is greater than the *Area ZG⊙*; which, that it is so, is visible to sight, by a great excess; and so much in proportion does the Heat of the 24 Hours Sun-shine under the Pole, exceed that of the 12 Hours under the Æquinoctial: Whence, *Cæteris paribus*, it is reasonable to conclude, that were the Sun perpetually under the Tropick, the Pole would be at least as warm, as it is now under the Line it self.

But whereas the Nature of Heat is to remain in the Subject, after the Cause that heated is removed, and particularly in the Air; under the Æquinoctial, the 12 Hours absence of the Sun does very little still the Motion impressed by the part Action of his Rays, wherein Heat consists, before he arise again: But under the Pole the long absence of the Sun for 6 Months, wherein the extremity of Cold does obtain, has so chill'd the Air, that it is as it were frozen, and cannot, before the Sun has got far towards it, be any way sensible of his presence, his Beams being obstructed by thick Clouds, and perpetual Fogs and Mists, and by that Atmosphere of Cold, as the late Honourable Mr. *Boyle* was pleased to term it, proceeding from the everlasting Ice, which in immense Quantities does chill the Neighbouring Air, and which the too soon retreat of the Sun leaves unthawed, to encrease again, during the long Winter that follows this short interval of Summer. But the differing Degrees of Heat and Cold, in differing Places, depend in great measure upon the Accidents of the Neighbourhood of high Mountains, whose height exceedingly {259}
chills the Air brought by the Winds over them; and of the Nature of the Soil, which variously retains the Heat, particularly the Sandy, which in *Africa*, *Arabia*, and generally where such Sandy Desarts are found, do make the Heat of the Summer incredible to those that have not felt it.

In the prosecution of this first Thought, I have solved the Problem generally, *viz.* to give the proportional Degree of Heat, or the Sum of all the *Sines* of the Sun's Altitude, while he is above the Horizon in any oblique Sphere, by reducing it to the finding of the Curve Surface of a Cylindrick Hoof, or of a given part thereof.

Now this Problem is not of that difficulty as appears at first sight, for in *Tab. 4. Fig. 3.* let the Cylinder ABCD be cut obliquely with the Ellipse BKDI, and by the Center thereof H, describe the Circle IKLM; I say, the Curve Surface IKLB is equal to the Rectangle of IK and BL, or of HK and 2 BL or BC: And if there be supposed another Circle, as NQPO, cutting the said Ellipse in the Points P, Q; draw PS, QR, parallel to the Cylinders Axe, till they meet with the aforesaid Circle IKLM in the Points R, S, and draw the Lines RTS, QVP bisected in T and V. I say again, that the Curve

Surface RMSQDP is equal to the Rectangle of BL or MD and RS, or of 2 BL or AD and ST or VP; and the Curve Surface QNPD is equal to RS × MD----the Arch RMS × SP, or the Arch MS × 2 SP: Or it is equal to the Surface RMSQDP, substracting the Surface RMSQNP. So likewise the Curve Surface QBPO is equal to the Sum of the Surface RMSQDP, or RS × MD, and of the Surface RLSQOP, or the Arch LS × 2 SP. {260}

This is the most easily demonstrated from the Consideration, That the Cylindrick Surface IKLB is to the inscrib'd Spherical Surface IKLE, either in the whole, or in its Analogous Parts, as the tangent BL is to the Arch EL, and from the Demonstrations of *Archimedes de Sphæra & Cylindro, Lib. I. Prop.* XXX, and XXXVII, XXXIIX. which I shall not repeat here, but leave the Reader the pleasure of examining it himself; nor will it be amiss to consult Dr. *Barrow*'s Learned Lectures on that Book, Publish'd at *London*, *Anno 1684*, *viz. Probl.* IX. and the Corollaries thereof.

Now to reduce our Case of the Sum of all the *Sines* of the Sun's Altitude in a given Declination and Latitude to the aforesaid Problem, let us consider (*Tab. 4. Fig. 4.*) which is the *Analemma* projected on the Plain of the *Meridian*, Z the Zenith, P the Pole, HH the Horizon, ææ the Æquinoctial, ♋♋, ♑♑ the two Tropicks, ♋1 the *Sine* of the Meridian Altitude in ♋; and equal thereto, but perpendicular to the Tropick, erect ♋I, and draw the Line TI intersecting the Horizon in T, and the Hour Circle of 6, in the Point 4, and 64 shall be equal to 6R, or to the Sine of the Altitude at 6: And the like for any other Point in the Tropick, erecting a Perpendicular thereat, terminated by the Line T I: Through the Point 4 draw the Line 4, 5, 7 parallel to the Tropick, and representing a Circle equal thereto; then shall the Tropick ♋♋ in *Fig. 4.* answer to the Circle NOPQ, in *Fig. 3.* the Circle 457 shall answer the Circle IKLM, T4I shall answer to the Elliptick Segment QIBKP, 6R or 64 shall answer to SP, and 5I to BL, and the Arch ♋T, to the Arch LS, being the semidiurnal Arch in that Latitude and Declination; the *Sine* whereof, tho' not expressible in *Fig. 4.* must be conceived as Analogous to the Line TS or UP in *Fig. 3.* {261}

The Relation between these two Figures being well understood, it will follow from what precedes, That, *the sum of the* Sines *of the Meridian Altitudes of the Sun in the two Tropicks, (and the like for any two opposite Parallels) being multiplied by the* Sine *of the semidiurnal Arch, will give an* Area *Analogous to the Curve Surface RIMSQDP; and thereto adding in Summer, or substracting in Winter, the Product of the length of the semidiurnal Arch, (taken according to* Van Ceulen*'s Numbers) into the difference of the above-said* Sines *of the Meridian Altitude: The sum in one case, and difference in another, shall be as the Aggregate of all the* Sines *of the Sun's Altitude, during his appearance above the Horizon; and consequently of all his Heat and Action on the Plain of the Horizon in the proposed Day*. And this may also be extended to the parts of the same Day; for if the aforesaid Sum of the *Sines* of the Meridian Altitudes, be multiplied by half the Sum of the *Sines* of the Sun's Horary distance from Noon, when the Times are before and after Noon; or by half their difference, when both are on the same side of the Meridian; and thereto in Summer, or therefrom in Winter, be added or substracted the Product of half the Arch answerable to the proposed interval of Time, into the difference of the *Sines* of Meridian Altitudes, the Sum in one case and Difference in the other, shall be proportional to all the Action of the Sun during that space of time.

I fore-see it will be Objected, that I take the *Radius* of my Circle on which I erect my Perpendiculars always the same, whereas the Parallels of Declination are unequal; but to this I answer, That our said Circular Bases ought not to be Analogous to the Parallels, but to the Times of Revolution, which are equal in all of them. {262}

It may perhaps be useful to give an Example of the Computation of this Rule, which may seem difficult to some. Let the Solstitical Heat in ♋ and ♑ be required at *London*, *Lat.* 51° 32'.

380- 2'28	*Co-Lat*
23-30	*Decl.* ☉
61-58	*Sinus* = ,8826 4
14-58	*Sinus* = ,258257
	Summa 1,140931
	Diff. ,624417

Diff. Ascen.	3300-1'1.
Arch. Semid. æstiv.	123-11.
Ar. Sem. hyb. 56-49. *S.*	638923
Arch. æstiv. mensura	2,149955
Arc. hyb. mensura	991683

Then 1,140931 in ,836923 + 624417 in 2,149955 = 2,29734. And 1,140931 in 836929 - ,624417 in ,991638 = 33895.

So that 2,29734 will be as the Tropical Summers Day Heat, and 0,33895 as the Action of the Sun in the Day of the Winter Solstice.

After this manner I computed the following Table for every tenth Degree of Latitude, to the

Æquinoctial and Tropical Sun, by which an Estimate may be made of the intermediate Degrees.

{263}

Lat.	Sun in ♈ ♎	Sun in ♋	Sun in ♑
0	20000	18341	18341
10	19696	20290	15834
20	18794	21737	13166
30	17321	22651	10124
40	15321	23048	6944
50	12855	22991	3798
60	10000	22773	1075
70	6840	23543	000
80	3473	24673	000
90	0000	25055	000

Those that desire more of the Nature of this Problem, as to the Geometry thereof, would do well to compare the XIII. *Prop. Cap. V.* of the Learned Treatise, *De Calculo Centri Gravitatis*, by the Reverend Dr. *Wallis*, Published *Anno 1670*.

From this Rule there follow several Corollaries worth Note: As I. That the Æquinoctial Heat, when the Sun comes Vertical, is as twice the Square of *Radius*, which may be proposed as a Standard to compare with, in all other Cases. II. That under the Æquinoctial, the Heat is as the *Sine* of the Sun's Declination. III. That in the Frigid Zones when the Sun sets not, the Heat is as the Circumference of a Circle into the *Sine* of the Altitude at 6. And consequently, that in the same Latitude these Aggregates of Warmth, are as the *Sines* of the Sun's Declinations; and in the same Declination of *Sol*, they are as the *Sines* of the Latitude, and generally they are as the *Sines* {264} of the Latitude into the *Sines* of Declination. IV. That the Æquinoctial Days Heat is every where as the Co-sine of the Latitude. V. In all places where the Sun sets, the difference between the Summer and Winter Heats, when the Declinations are contrary, is equal to a Circle into the *Sine* of the Altitude at six in the Summer Parallel, and consequently those differences are as the *Sines* of Latitude into, or multiplied by the *Sines* of Declination. VI. From the Table I have added, it appears, that the Tropical Sun under the Æquinoctial, has, of all others, the least Force. Under the Pole it is greater than any other Days Heat whatsoever, being to that of the Æquinoctial as 5 to 4.

From the Table and these Corollaries may a general *Idea* be conceived of the Sum of all the Actions of the Sun in the whole Year, and that part of the Heat that arises simply from the Presence of the Sun be brought to a Geometrical Certainty: And if the like could be performed for Cold; which is something else than the bare Absence of the Sun, as appears by many Instances, we might hope to bring what relates to this part of *Meteorology* to a perfect Theory.

{265}

Concerning the Distance of the Fix'd Stars. By the Honourable Francis Roberts*, Esq; S. R. S.*

THE Ancient Astronomers, who had no other way of computing the Distances of the Heavenly Bodies, but by their Parallax to the Semi-diameter of the Earth; and being never able to discover any in the fix'd Stars, did from thence rightly enough infer, that their Distance was very great, and much exceeding that of the Planets, but could go no farther otherwise than by uncertain guess.

Since the *Pythagorean* System of the World has been reviv'd by *Copernicus*, (and now by all Mathematicians accepted for the true one) there seem'd Ground to imagine that the Diameter of the Earth's Annual Course (which, according to our best Astronomers, is at least 40000 times bigger than the Semi-diameter of the Earth) might give a sensible Parallax to the fix'd Stars, though the other could not, and thereby determine their Distance more precisely.

But though we have a Foundation to build on so vastly exceeding that of the Ancients, there are some Considerations may make us suspect that even this is not large enough for our purpose.

Monsieur *Hugens* (who is very exact in his Astronomical Observations) tells us, he could never {266} discover any visible Magnitude in the fix'd Stars, though he used Glasses which magnified the apparent Diameter above 100 times.

Now, since in all likelyhood the fix'd Stars are Suns, (perhaps of a different Magnitude) we may as a reasonable *Medium* presume they are generally about the bigness of the Sun.

Let us then (for Example) suppose the Dog-Star to be so. The Distance from us to the Sun being about 100 times the Sun's Diameter (as is demonstrable from the Sun's Diameter being 32 Minutes) it is evident, that the Angle under which the Dog-Star is seen in Mr. *Hugens*'s Telescope, must be near the same with the Angle of its Parallax to the Sun's Distance, or Semi-

diameter of the Earth's Annual Course; so that the Parallax to the whole Diameter, can be but double such a quantity, as even to Mr. *Hugens*'s nice Observation is altogether insensible.

The Distance therefore of the fix'd Stars seems hardly within the reach of any of our Methods to determine; but from what has been laid down, we may draw some Conclusions that will much illustrate the prodigious vastness of it.

1. That the Diameter of the Earth's Annual Orb (which contains at least 160 Millions of Miles) is but as a Point in comparison of it; at least it must be above 6000 times the Distance of the Sun. For if a Star should appear thro' the aforesaid Telescope half a Minute broad (which is a pretty sensible Magnitude) the true apparent Diameter would not exceed 18 3d Minutes, which is less than the 6000th part of the apparent Diameter of the Sun, and consequently the Sun's Distance not the 6000th part of the Distance of the Star. {267}

2. That could we advance towards the Stars 99 Parts of the whole Distance, and have only $^{1}/_{100}$ Part remaining, the Stars would appear little bigger to us than they do here; for they would shew no otherwise than they do through a Telescope, which magnifies an Hundred-fold.

3. That at least Nine Parts in Ten of the Space between us and the fix'd Stars, can receive no greater Light from the Sun, or any of the Stars, than what we have from the Stars in a clear Night.

4. That Light takes up more time in travelling from the Stars to us, than we in making a *West-India* Voyage (which is ordinarily perform'd in six Weeks.) That a Sound would not arrive to us from thence in 50000 Years, nor a Cannon-bullet in a much longer time. This is easily computed, by allowing (according to Mr. *Newton*) Ten Minutes for the Journey of Light from the Sun hither, and that a Sound moves about 1300 Foot in a Second.

{268}

The Famous Mr. Isaac Newton*'s Theory of the* Moon.

THIS *Theory* which hath been long expected by all the true Lovers of *Astronomy*, was communicated from Mr. *Newton* to Dr. *Gregory*, *Astronomy* Professor at *Oxford*, and by him published in his *Astron. Elem. Philos.* and *Geomet.* p. 336. From whence, as it was lately translated into *English*, I thought fit to insert it here.

By this Theory, what by all Astronomers was thought most difficult and almost impossible to be done, the Excellent Mr. *Newton* hath now effected; *viz.* to determine the Moon's Place even in her Quadratures, and all other Parts of her Orbit, besides the Syzygys, so accurately by Calculation, that the Difference between that and her true Place in the Heavens, shall scarce be above two minutes in her Syzygys, or above three in her Quadratures, and is usually so small, that it may well enough be reckon'd only as a Defect in the Observation. And this Mr. *Newton* experienced, by comparing it with very many Places of the Moon, observ'd by Mr. *Flamsteed*, and communicated to him.

The Royal Observatory at *Greenwich*, is to the West of the Meridian of *Paris*, 2 degrees, 19 minutes. Of *Uraniburgh*, 12 degrees, 51 minutes, 30 seconds. And of *Gedanum*, 18 degrees, 48 minutes.

The mean Motions of the Sun and Moon, accounted from the Vernal Æquinox at the Meridian of *Greenwich*, I make to be as followeth. {269}

The last Day of *December 1680*, at Noon (*Old Stile*) the mean Motion of the Sun was 9 Signs, 20 degrees, 34 minutes, 46 seconds. Of the Sun's Apogæum, was 3 S. 7 deg. 23 min. 30 seconds.

That the mean Motion of the Moon at that time, was 6 S. 1 degree, 45 minutes, 45 seconds. And of her Apogee, 8 S. 4 degrees, 28 minutes, 5 seconds. Of the ascending Node of the Moon's Orbit, 5 S. 24 deg. 14 min. 35 seconds, *&c.*

And on the last Day of *December, 1700*, at Noon, the mean Motion of the Sun was 9 S. 20 degrees, 43 minutes, 50 seconds. Of the Sun's Apogee, 3 S. 7 degrees, 44 minutes, 30 seconds. The mean Motion of the Moon was 10 S. 15 degrees, 19 minutes, 50 seconds. Of the Moon's Apogee, 11 S. 8 degrees, 18 minutes, 20 seconds. And of her ascending Node, 4 S. 27 degrees, 24 minutes, 20 seconds. For in 20 *Julian* Years, or 7305 Days, the Sun's Motion is 20 Revol. 0 S. 0 degrees, 9 minutes, 4 seconds. And the Motion of the Sun's Apogee, 21 minutes, 0 seconds.

The Motion of the Moon in the same time, is 267 Revol. 4 S. 13 degrees, 34 minutes, 5 seconds. And the Motion of the Lunar Apogee, is 2 Revol. 3 S. 3 degrees, 50 minutes, 15 seconds. And the Motion of her Node, 1 Revol. 0 S, 26 degrees, 50 minutes, 15 seconds.

All which Motions are accounted from the Vernal Æquinox: Wherefore if from them there be subtracted the Recession or Motion of the Æquinoctial Point, in *Antecedentia*, during that space, which is 16 minutes, 40 seconds, there will remain the Motions in reference to the fix'd Stars in 20 *Julian* Years; *viz.* the Sun's 19 Revol. 11 S. 29 degrees, 52 minutes, 24 seconds. Of his Apogee, 4 minutes, 20 seconds. And the Moon's 267 Revol. 4 S. 13 degrees, 17 minutes, 25 seconds. Of {270}

her Apogee, 2 Revol. 3 S. 3 degrees, 33 minutes, 35 seconds. And of the Node of the Moon, 1 Revol. 0 S. 27 degrees, 6 minutes, 55 seconds.

According to this Computation, the *Tropical Year* is 365 Days, 5 Hours, 48 Minutes, 57 Seconds. And the *Sydereal Year* is 365 Days, 6 Hours, 9 Minutes, 14 Seconds.

These mean Motions of the Luminaries are affected with various Inequalities: Of which,

1. There are the Annual Equations of the aforesaid mean Motions of the Sun and Moon, and of the Apogee and Node of the Moon.

The Annual Equation of the mean Motion of the Sun, depends on the Eccentricity of the Earth's Orbit round the Sun, which is $16^{11}/_{12}$ of such Parts, as that the Earth's mean Distance from the Sun shall be 1000: Whence 'tis call'd the *Equation of the Centre*; and is, when greatest, 1 degree, 56 minutes, 20 seconds.

The greatest Annual Equation of the Moon's mean Motion, is 11 degrees, 49 seconds; of her Apogee, 20 minutes, and of her Node, 9 minutes, 30 seconds.

And these four Annual Equations are always mutually proportional one to another: Wherefore when any of them is at the greatest, the other three will also be greatest; and when any one lessens, the other three will also be diminished in the same Ratio. {271}

The Annual Equation of the Sun's Centre being given, the three other corresponding Annual Equations will be also given; and therefore a Table of that will serve for all. For if the Annual Equation of the Sun's Centre be taken from thence, for any Time, and be call'd P, and let $\frac{1}{10}P = Q$, $Q + \frac{1}{60}Q = R$, $\frac{1}{6}P = D$, $D + \frac{1}{30}D = E$, and $D - \frac{1}{50}D = 2F$; then shall the Annual Equation of the Moon's mean Motion for that time be R, that of the Apogee of the Moon will be E, and that of the Node F.

Only observe here, That if the Equation of the Sun's Centre be required to be added; then the Equation of the Moon's mean Motion must be subtracted, that of her Apogee must be added, and that of the Node subducted, And on the contrary, if the Equation of the Sun's Centre were to be subducted, the Moon's Equation must be added, the Equation of her Apogee subducted, and that of her Node added.

There is also an *Equation of the Moon's mean Motion*, depending on the situation of her Apogee, in respect of the Sun; which is greatest when the Moon's Apogee is in an Octant with the Sun, and is nothing at all when it is in the Quadratures or Syzygys. This Equation, when greatest, and the Sun in *Perigæo*, is 3 Minutes, 56 Seconds. But if the Sun be in *Apogæo*, it will never be above 3 Minutes, 34 Seconds. At other Distances of the Sun from the Earth, this Equation, when greatest, is reciprocally as the Cube of such Distance. But when the Moon's Apogee is any where {272} but in the *Octants*, this Equation grows less, and is mostly at the same distance between the Earth and Sun, as the Sine of the double Distance of the Moon's Apogee, from the next Quadrature or Syzygy, to the Radius.

This is to be added to the Moon's Motion, while her Apogee passes from a Quadrature with the Sun to a Syzygy; but this is to be subtracted from it, while the Apogee moves from the Syzygy to the Quadrature.

There is moreover another *Equation of the Moon's Motion*, which depends on the Aspect of the Nodes of the Moon's Orbit with the Sun: And this is greatest, when her Nodes are in *Octants* to the Sun, and vanishes quite, when they come to their Quadratures or Syzygys. This Equation is proportional to the Sine of the double Distance of the Node from the next Syzygy, or Quadrature; and at greatest, is but 47 seconds. This must be added to the Moon's mean Motion, while the Nodes are passing from their Syzygys with the Sun, to their Quadratures with him; but subtracted while they pass from the Quadratures to the Syzygys.

From the Sun's true Place, take the equated mean Motion of the Lunar Apogee, as was above shew'd, the Remainder will be the Annual Argument of the said Apogee. From whence the *Eccentricity of the Moon*, and the *second Equation* of her Apogee may be computed after the manner of the following (*which takes place also in the Computation of any other intermediate Equations*).

Tab. 3. Fig. 6. Let T represent the Earth, TS, a Right Line joining the Earth and Sun, TACB, a {273} Right Line drawn from the Earth to the middle or mean Place of the Moon's Apogee, equated, as above: Let the Angle STA be the Annual Argument of the aforesaid Apogee, TA the least Eccentricity of the Moon's Orbit, TB the greatest. Bissect AB in G; and on the Centre C, with the Distance AC describe a Circle AFB, and make the Angle BCF = to the double of the Annual Argument. Draw the Right Line TF, that shall be the Eccentricity of the Moon's Orbit; and the Angle BTF, is the second Equation of the Moon's Apogee required.

In order to whose Determination, let the mean Distance of the Earth from the Moon, or the Semi-diameter of the Moon's Orbit, be 100000; then shall its greatest Eccentricity TB be 66782 such Parts; and the least TA, 43319. So that the greatest Equation of the Orbit, *viz.* when the

Apogee is in the Syzygys, will be 7 degrees, 39 minutes, 30 seconds, or perhaps 7 degrees, 40 minutes, (for I suspect there will be some Alteration, according to the Position of the Apogee in *Cancer* and *Capricorn*.) But when it is Quadrate to the Sun, the greatest Equation aforesaid will be 4 degrees, 57 minutes, 56 seconds; and the greatest Equation of the Apogee, 12 degrees, 15 minutes, 4 seconds.

Having from these Principles made a Table of the Equation of the Moon's Apogee, and of the Eccentricities of her Orbit to each degree of the Annual Argument, from whence the Eccentricity TF, and the Angle BTF (*viz.* the second and the principal Equation of the Apogee) may easily be {274}
had for any Time required; let the Equation thus found be added to the first Equated Place of the Moon's Apogee, if the Annual Argument be less than 90 degrees, or greater than 180 degrees, and less than 270; otherwise it must be subducted from it; and the Sum or Difference shall be the Place of the Lunar Apogee secondarily equated; which being taken from the Moon's Place equated a third time, shall leave the mean Anomaly of the Moon corresponding to any given Time. Moreover, from this mean Anomaly of the Moon, and the before-found Eccentricity of her Orbit, may be found (by means of a Table of Equations of the Moon's Centre made to every degree of the mean Anomaly, and some Eccentricities, *viz.* 45000, 50000, 55000, 60000, and 65000) the *Prostaphæresis*, or Equation of the Moon's Centre, as in the common way: And this being taken from the former Semi-circle of the middle Anomaly, and added in the latter to the Moon's Place thus thrice equated, will produce the Place of the Moon a fourth time equated.

The greatest Variation of the Moon (*viz.* that which happens when the Moon is in an Octant with the Sun) is nearly, reciprocally as the Cube of the Distance of the Sun from the Earth. Let that be taken 37 minutes, 25 seconds, when the Sun is *in Perigæo*, and 33 minutes, 40 seconds, when he is *in Apogæo*: And let the Differences of this Variation in the Octants be made reciprocally, as the Cubes of the Distances of the Sun from the Earth; and so let a Table be made of the aforesaid Variation of the Moon in her Octants (or its Logarithms) to every Tenth, Sixth, or {275}
Fifth Degree of the mean Anomaly: And for the Variation out of the Octants, make, as Radius to the Sine of the double Distance of the Moon from the next Syzygy, or Quadrature :: so let the afore-found Variation in the Octant be to the Variation congruous to any other Aspect; and this added to the Moon's Place before found in the first and third Quadrant (accounting from the Sun) or subducted from it in the second and fourth, will give the Moon's Place equated a fifth time.

Again, as Radius to the Sine of the Summ of the Distances of the Moon from the Sun, and of her Apogee from the Sun's Apogee (or the Sine of the Excess of that Summ above 360 degrees,) :: so is 2 minutes, 10 seconds, to a sixth Equation of the Moon's Place, which must be subtracted, if the aforesaid Summ or Excess be less than a Semi-circle; but added, if it be greater. Let it be made also, as Radius to the Sine of the Moon's distance from the Sun :: so 2 degrees, 20 secants, to a seventh Equation; which when the Moon's Light is increasing, add; but when decreasing, subtract; and the Moon's Place will be equated a seventh time, and this is her Place *in her proper Orbit*.

Note here, the Equation thus produced by the mean Quantity 2 degrees, 20 seconds, is not always of the same magnitude; but is increased and diminished, according to the Position of the Lunar Apogee. For if the Moon's Apogee be in Conjunction with the Sun's, the aforesaid Equation {276}
is about 54 seconds greater: But when the Apogees are in Opposition, 'tis about as much less; and it librates between its greatest Quantity 3 minutes, 14 seconds, and its least, 1 minute, 26 seconds. And this is, when the Lunar Apogee is in Conjunction, or Opposition with the Sun's: But in the Quadratures, the aforesaid Equation is to be lessen'd about 50 seconds, or 1 minute, when the Apogees of the Sun and Moon are in Conjunction; but if they are in Opposition, for want of a sufficient number of Observations, I cannot determine, whether it is to be lessen'd or increas'd. And even as to the Argument or Decrement of the Equation, 2 minutes, 20 seconds, above mentioned, I dare determine nothing certain, for the same Reason, *viz.* the want of Observations accurately made.

If the sixth and seventh Equations are augmented or diminished in a reciprocal *Ratio* of the distance of the Moon from the Earth; *i. e.* in a direct *Ratio* of the Moon's Horizontal Parallax, they will become more accurate: And this may be readily done, if Tables are first made to each minute of the said Parallax, and to every sixth or fifth degree of the Argument of the sixth Equation for the Sixth, as of the distance of the Moon from the Sun, for the Seventh Equation.

From the Sun's Place, take the mean motion of the Moon's ascending Node, equated as above; the Remainder shall be the Annual Argument of the Node, whence its second Equation may be computed after the following manner in the preceding Figure.

Let T, as before, represent the Earth; TS a Right Line, conjoining the Earth and Sun: Let also {277}
the Line TACB, be drawn to the Place of the ascending Node of the Moon, as above equated; and let STA be the Annual Argument of the Node. Take TA from a Scale, and let it be to AB :: as 56 to 3, or as 11⅔ to 1. Then bissect BA in C, and on C as a Centre, with the Distance CA, describe a Circle, as AFB, and make the Angle BCF, equal to double the Annual Argument of the Node before-found: So shall the Angle BTF, be the second Equation of the ascending Node; which must be added, when the Node is passing from the Quadrature to a Syzygy with the Sun; and

subducted, when the Node moves from a Syzygy towards a Quadrature. By which means, the true Place of the Node of the Lunar Orbit will be gained: Whence from Tables made after the common way, the *Moon's Latitude, and the Reduction of her Orbit to the Ecliptick*, may be computed, supposing the Inclination of the Moon's Orbit to the Ecliptick, to be 4 degrees, 59 minutes, 35 seconds, when the Nodes are in Quadrature with the Sun; and 5 degrees, 17 minutes, 20 seconds, when they are in the Syzygys.

And from the Longitude and Latitude thus found, and the given Obliquity of the Ecliptick, 23 degrees, 29 minutes, the Right Ascension and Declination of the Moon will be found.

The Horizontal Parallax of the Moon, when she is in the Syzygys, at a mean distance from the Earth, I make to be 57 minutes, 30 seconds; and her Horary Motion, 33 minutes, 32 seconds, 32 {278}
thirds; and her apparent Diameter 31 minutes, 30 seconds. But in her Quadratures at a mean Distance from the Earth, I make the Horizontal Parallax of the Moon to be 59 minutes, 40 seconds, her Horary Motion 32 minutes, 12 seconds, 2 thirds, and her apparent Diameter, 31 minutes, 3 seconds. The Moon in an Octant to the Sun, and at a mean distance, hath her Centre distant from the Centre of the Earth about $60\frac{2}{9}$ of the Earth's Semi-diameters.

The Sun's Horizontal Parallax I make to be 10 seconds, and its apparent Diameter at a mean distance from the Earth, I make 32 minutes, 15 seconds.

The Atmosphere of the Earth, by dispersing and refracting the Sun's Light, casts a Shadow, as if it were an Opake Body, at least to the height of 40 or 50 Geographical Miles (by a Geographical Mile, I mean the sixtieth part of a Degree of a great Circle, on the Earth's Surface.) This Shadow falling upon the Moon in a Lunar Eclipse, makes the Earth's Shadow be the larger or broader. And to each Mile of the Earth's Atmosphere, is correspondent a Second in the Moon's Disk, so that the Semi-diameter of the Earth's shadow projected upon the Disk of the Moon, is to be increased about 50 seconds: Or, which is all one, in a Lunar Eclipse, the Horizontal Parallax of the Moon is to be increased in the Ratio of about 70 to 69.

Thus far the Theory of this Incomparable Mathematician. And if we had many Places of the Moon accurately observ'd, especially about her Quadratures, and these well compar'd with her {279}
Places, at the same time calculated according to this Theory; it would then appear, whether there yet remain any other sensible Equations; which when accounted for, might serve to improve and enlarge this Theory.

{280}

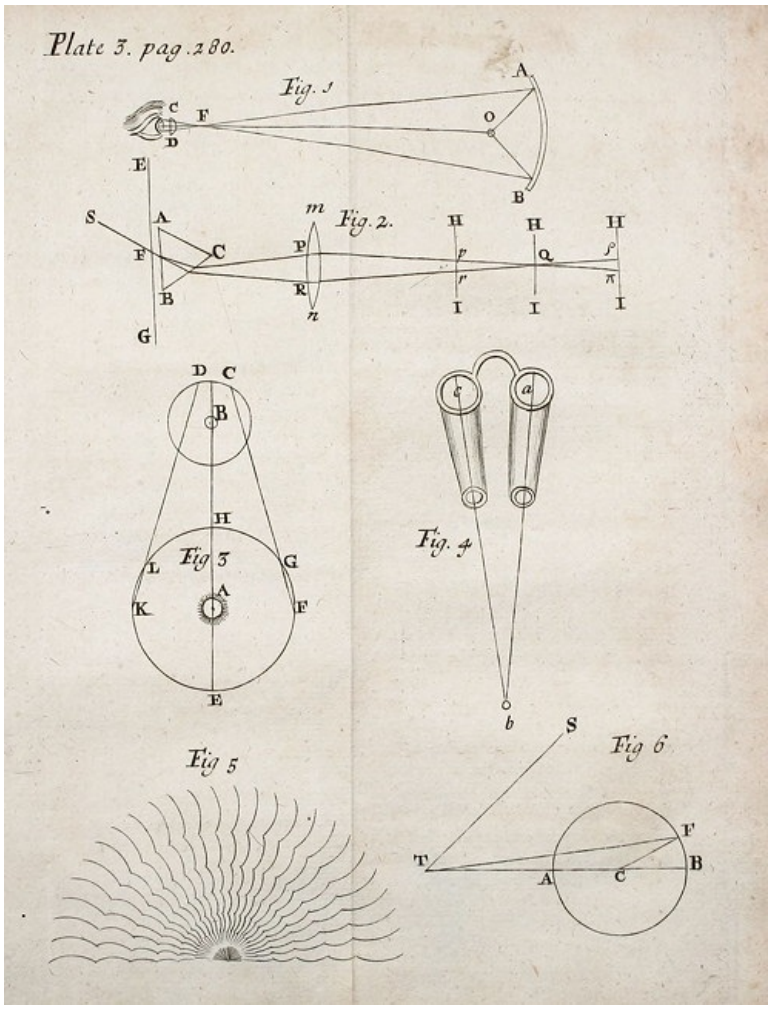


Plate 3. pag. 280.

An Estimate of the Degrees of the Mortality *of Mankind, drawn from curious* Tables *of the* Births *and* Funerals *at the City of* Breslaw*; with an Attempt to ascertain the Price of* Annuities *upon* Lives*. By Mr.* E. Halley*, R. S. S.*

THE Contemplation of the *Mortality* of *Mankind*, has besides the *Moral*, its *Physical* and *Political* Uses, both which have been some Years since most judiciously consider'd by the Curious Sir *William Petty*, in his *Natural* and *Political* Observations on the Bills of *Mortality* of *London*, own'd by Captain *John Graunt*: And since in a like Treatise on the Bills of *Mortality* of *Dublin*. But the Deduction from those Bills of *Mortality* seemed even to their Authors to be defective: First, In that the *Number* of the People was wanting. Secondly, That the *Ages* of the People dying was not to be had. And Lastly, That both *London* and *Dublin*, by reason of the great and casual Accession of *Strangers* who die therein, (as appeared in both, by the great Excess of the *Funerals* above the *Births*) rendred them incapable of being Standards for this purpose; which requires, if it were possible, that the People we treat of, should not at all be changed, but {281} die where they were born, without any adventitious Increase from Abroad, or Decay by Migration elsewhere.

This *Defect* seems in a great measure to be satisfied by the late curious Tables of the Bills of *Mortality* at the City of *Breslaw*, lately communicated to this Honourable Society by Mr. *Justell*, wherein both the Ages and Sexes of all that die, are Monthly delivered, and compared with the number of the *Births*, for Five Years last past, *viz.* 1687, 88, 89, 90, 91, seeming to be done with all the Exactness and Sincerity possible.

This City of *Breslaw* is the Capital City of the Province of *Silesia*; or, as the *Germans* call it, *Schlesia*, and is situated on the Western Bank of the River *Oder*, anciently call'd *Viadrus*, near the Confines of *Germany* and *Poland*, and very nigh the Latitude of *London*. It is very far from the Sea, and as much a *Mediterranean* Place as can be desired, whence the Confluence of Strangers is but small, and the Manufacture of Linnen employs chiefly the poor People of the Place, as well as of the Country round about; whence comes that sort of Linnen we usually call your *Sclesiæ Linnen*; which is the chief, if not the only Merchandize of the Place. For these Reasons, the People of this City seem most proper for a *Standard*; and the rather, for that the *Births* do a small matter exceed the Funerals. The only thing wanting, is the Number of the whole People, which in some measure I have endeavour'd to supply, by the comparison of the *Mortality* of the People of all Ages, which I shall from the said Bills trace out with all the Accuracy possible.

It appears that in the Five Years mentioned, *viz.* from 87 to 91 inclusive, there were born 6193 {282} Persons, and buried 5869; that is, born *per Annum* 1238, and buried 1174; whence an *Increase* of the People may be argued of 64 *per Annum*, or of about a 20th part, which may perhaps be balanc'd by the Levies for the *Emperor*'s Service in his Wars. But this being contingent, and the Births certain, I will suppose the People of *Breslaw* to be increased by 1238 *Births* annually. Of these it appears by the same Tables, that 348 do die *yearly* in the *first Year* of their *Age*, and that but 890 do arrive at a full *Year's Age*; and likewise, that 198 do die in the *Five Years* between 1 and 6 compleat, taken at a *Medium*; so that but 692 of the Persons *born* do survive *Six* whole *Years*. From this *Age* the Infants being arrived at some degree of Firmness, grow less and less *Mortal*; and it appears, that of the whole People of *Breslaw* there die *yearly*, as in the following Table, wherein the upper Line shews the *Age*, and the next under it, the *Number* of Persons of that Age *dying yearly*.

{283}

7	8	9		14		18		21		27	28		35
11	11	6	5½	2	3½	5	6	4½	6½	9	8	7	7
36		42		45		49	54	55	56		63		70
8	9½	8	9	7	7	10	11	9	9	10	12	9½	14
71	72		77		81		84		90	91	98	99	100
9	11	9½	6	7	3	4	2	1	1	1	0	⅕	⅗

And where no Figure is placed over, it is to be understood of those that die between the Ages of the precedent and consequent *Column*.

From this Table it is evident, that from the Age of 9 to about 25, there does not die above 6 *per Annum* of each Age, which is much about 1 *per Cent.* of those that are of those *Ages*: And whereas in the 14, 15, 16, 17 *Years*, there appear to die much fewer, as 2 and 3½; yet that seems rather to be attributed to Chance, as are the other Irregularities in the Series of Ages, which would rectifie themselves, were the number of Years much more considerable, as 20 instead of 5. And by our own Experience in *Christ-Church Hospital*, I am inform'd there die of the *Young Lads*, much about 1 *per Cent. per Annum*, they being of the aforesaid *Ages*. From 25 to 50, there seem to die from 7 to 8 and 9 *per Annum* of each Age; and after that to 70, they growing more *crasie*, though the number be much diminished, yet the *Mortality increases*, and there are found to die 10 or 11 of each Age *per Annum*: From thence the number of the Living being grown very small, {284} they gradually decline till there be none left to *die*; as may be seen at one View in the Table.

From these Considerations I have form'd the *adjoined Table*, whose Uses are manifold, and give a more just *Idea* of the *State* and *Condition* of *Mankind*, than any thing yet extant that I know of. It exhibits the *Number* of *People* in the City of *Breslaw* of all Ages, from the *Birth* to extreme *Old Age*, and thereby shews the Chances of *Mortality* at all *Ages*, and likewise how to make a certain Estimate of the Value of *Annuities* for *Lives*, which hitherto has been only done by an imaginary *Valuation*: Also the *Chances* that there are that a *Person* of any *Age* proposed does live to any other *Age* given; with many more, as I shall hereafter shew. This *Table* does shew the *Number* of Persons that are living in the *Age* current annexed thereto, as follows:

{285}

Age. Curt.	Persons.	Age. Curt.	Persons.	Age. Curt.	Persons.	Age. Curt.	Persons.
1	1000	8	680	15	628	22	586
2	855	9	670	16	622	23	579
3	798	10	661	17	616	24	573
4	760	11	653	18	610	25	567
5	732	12	646	19	604	26	560
6	710	13	640	20	598	27	553
7	692	14	634	21	592	28	546
29	539	36	481	43	417	50	346
30	531	37	472	44	407	51	335
31	523	38	463	45	397	52	324
32	515	39	454	46	387	53	313
33	507	40	445	47	377	54	302
34	499	41	436	48	367	55	292
35	490	42	427	49	357	56	282
57	272	64	202	71	131	78	58
58	262	65	192	72	120	79	49
59	252	66	182	73	109	80	41
60	242	67	172	74	98	81	34
61	232	68	162	75	88	82	28
62	222	69	152	76	78	83	23
63	212	79	142	77	68	84	20

Age.	Persons.
7	5547
14	4584
21	4270
28	3964
35	3604
42	3708
49	2709
56	2194
63	1694
70	1204
77	692
84	253
100	107
	34000
Sum	Total.

{286}

Thus it appears, that the whole People of *Breslaw* does consist of 34000 *Souls*, being the Sum *Total* of the Persons of all Ages in the *Table*: The first use hereof is to shew the Proportion of *Men* able to bear *Arms* in any *Multitude*, which are those between 18 and 56, rather than 16 and 60; the one being generally too weak to bear the *Fatigues* of *War*, and the Weight of *Arms*; and the other too crasie and infirm from *Age*, notwithstanding particular Instances to the contrary. Under 18 from the *Table*, are found in this City 11997 Persons, 3950 above 56, which together make 15947, so that the Residue to 34000 being 18053, are Persons between those *Ages*. At least one half thereof are Males, or 9027: So that the whole Force this City can raise of *Fencible Men*, as the *Scotch* call them, is about 9000, or $^{9}/_{34}$, or somewhat more than a quarter of the *Number* of *Souls*; which may parhaps pass for a Rule for all other places.

The *Second Use* of this *Table*, is, to shew the differing degrees of *Mortality*, or rather *Vitality*, in all *Ages*; for if the Number of Persons of any *Age* remaining after one Year, be divided by the difference between that and the number of the *Age* proposed, it shews the *Odds* that there is, that a Person of that *Age* does not die in a *Year*. As for Instance, a Person of 25 *Years* of *Age* has the Odds of 560 to 7, or 80 to 1, that he does not *die* in a *Year*: Because that of 567, living of 25 *Years* of *Age*, there do die no more than 7 in a *Year*, leaving 560 of 26 Years old.

So likewise for the *Odds*, that any Person does not die before he attain any proposed *Age*: Take the *number* of the remaining Persons of the *Age* proposed, and divide it by the difference between it and the number of those of the *Age* of the Party proposed; and that shews the *Odds* there is between the Chances of the Party's living or dying. As for Instance; What is the *Odds* that a Man of 40 lives 7 Years: Take the number of Persons of 47 Years, which in the Table is 377, and subtract it from the number of Persons of 40 Years, which is 445, and the *difference* is 68: Which shews that the *Persons dying* in that 7 Years, are 68, and that it is 377 to 68, or 5½ to 1, that a Man of 40 does live 7 Years. And the like for any other *number* of *Years*. {287}

Use III. But if it be enquired at what number of *Years*, it is an even Lay that a Person of any *Age* shall die, this Table readily performs it; For if the *number* of Persons *living* of the *Age* proposed, be *halfed*, it will be found by the *Table* at what Year the said *Number* is reduced to half by *Mortality*; and that is the *Age*, to which it is an even Wager, that a Person of the *Age* proposed shall arrive before he *die*. As for Instance; A Person of 30 Years of *Age* is proposed, the number of that *Age* is 531, the half thereof is 265, which number I find to be between 57 and 58 Years; so that a Man of 30 may reasonably expect to live between 27 and 28 Years.

Use IV. By what has been said, the *Price* of *Insurance* upon Lives ought to be regulated, and the difference is discovered between the *Price* of insuring the *Life* of a *Man* of 20 and 50. For Example; It being 100 to 1, that a Man of 20 dies not in a Year, and but 38 to 1, for a Man of 50 Years of Age. {288}

Use V. On this depends the Valuation of *Annuities* upon *Lives*; for it is plain, that the *Purchaser* ought to pay for only such a part of the Value of the *Annuity*, as he has Chances that he is living; and this ought to be computed yearly, and the Sum of all those yearly Values being added together, will amount to the Value of the *Annuity* for the *Life* of the Person proposed. Now the present Value of Money payable after a Term of Years, at any given Rate of Interest, either may be had from Tables already computed; or almost as compendiously, by the Table of Logarithms: For the Arithmetical Complement of the Logarithm of Unity, and its yearly Interest, (that is, of 1,06 for Six *per Cent.* being 9,974694.) being multiplied by the number of Years proposed, gives the present Value of One Pound payable after the end of so many Years. Then by the foregoing Proposition, it will be as the number of Persons living after that Term of Years, to the number dead; so are the Odds that any one Person is alive or dead. And by consequence, as the Sum of both, or the number of Persons living of the *Age* first proposed, to the number remaining after so many Years, (both given by the Table) so the present Value of the yearly Sum payable after the Term proposed, to the Sum which ought to be paid for the Chance the Person has to enjoy such an *Annuity* after so many Years. And this being repeated for every Year of the Person's Life, the Sum of all the present Values of those Chances is the true Value of the Annuity. This will without doubt appear to be a most laborious Calculation; but it being one of the principal Uses of this Speculation, and having found some *Compendia* for the Work, I took the pains to compute the following Table, being the short Result of a not ordinary number of Arithmetical Operations: It shews the Value of Annuities for every Fifth Year of Age, to the Seventieth, as follows. {289}

Age.	Years Pur.	Age.	Years Pur.	Age.	Years Pur.
1	10,28	25	12,27	50	9,21
5	13,40	30	11,72	55	8,51
10	13,44	35	11,12	60	7,60
15	13,33	40	10,57	65	6,54
20	12,78	45	9,91	70	5,32

This shews the great Advantage of putting Money into the present *Fund* lately granted to Their Majesties, giving 14 *per Cent. per Annum*, or at the Rate of 7 Years Purchase for a Life; when young Lives, at the usual Rate of Interest, are worth above 13 Years Purchase. It shews likewise the Advantage of young Lives over those in Years; a Life of Ten Years being almost worth 13½ Years Purchase, whereas one of 36 is worth but 11.

Use VI. Two Lives are likewise valuable by the same Rule; for the number of Chances of each single Life, found in the Table, being multiplied together, become the Chances of the Two Lives. And after any certain Term of Years, the Product of the two remaining Sums is the Chances that both the Persons are living. The Product of the two Differences, being the numbers of the Dead of both Ages, are the Chances that both the Persons are dead. And the two Products of the remaining Sums of the one Age multiplied by those dead of the other, shew the Chances that there are, that each Party survives the other: Whence is derived the Rule to estimate the Value of the Remainder of one Life after another. Now as the Product of the Two Numbers in the Table for the Two Ages proposed, is to the difference between that Product, and the Product of the two numbers of Persons deceased in any space of time; so is the Value of a Sum of Money to be paid after so much time, to the Value thereof under the Contingency of Mortality. And as the aforesaid Product of the two Numbers answering to the Ages proposed, to the Product of the Deceased of one Age multiplied by those remaining alive of the other; so the Value of a Sum of Money to be paid after any time proposed, to the Value of the Chances, that the one Party has that he survives {290}

the other, whose number of Deceased you made use of, in the second Term of the Proportion. This perhaps may be better understood, by putting *N* for the number of the younger Age, and *n* for that of the Elder; *Y*, *y* the Deceased of both Ages respectively, and *R*, *r* for the Remainders; and $R + Y = N$, and $r + y = n$. Then shall *Nn* be the whole Number of Chances; *Nn* - *Yy* be the Chances that one of the two Persons is living, *Yy* the Chances that they are both dead; *Ry* the {291} Chances that the elder Person is dead, and the younger living; and *rY* the Chances, that the elder is living, and the younger dead. Thus two Persons of 18 and 35 are proposed, and after 8 Years these Chances are required. The Numbers for 18 and 35, are 610 and 490; and there are 50 of the First Age dead in 8 Years, and 73 of the Elder Age. There are in all 610 × 490, or 298900 Chances; of these there are 50 × 73, or 3650, that they are both dead. And as 298900, to 298900 - 3650, or 295250: So is the present Value of a Sum of Money to be paid after 8 Years, to the present Value of a Sum to be paid, if either of the two live. And as 560 × 73, so are the Chances that the Elder is dead, leaving the Younger; and as 417 × 50, so are the Chances that the Younger is dead, leaving the Elder. Wherefore as 610 × 490 to 560 × 73, so is the present Value of a Sum to be paid at 8 Years end, to the Sum to be paid for the Chance of the Younger's Survivance; and as 610 × 490 to 417 × 50, so is the same present Value to the Sum to be paid for the Chance of the Elder's Survivance.

This possibly may be yet better explained, by expounding these Products by Rectangular Parallelograms, as in *Fig. 7.* wherein *AB* or *CD* represents the number of Persons of the younger Age, and *DE*, *BH* those remaining alive after a certain Term of Years; whence *CE* will answer the number of those dead in that time: So *AC*, *BD* may represent the number of the elder Age; *AF*, *BI* the Survivors after the same Term; and *CF*, *DI*, those of that Age that are dead at that time. Then {292} shall the whole Parallelogram *ABCD* be *Nn*, or the Product of the two Numbers of Persons, representing such a number of Persons of the two Ages given; and by what was said before, after the Term proposed, the Rectangle *HD* shall be as the number of Persons of the younger Age that survive, and the Rectangle *AE* as the number of those that die. So likewise the Rectangles *AI*, *FD* shall be as the Numbers, living and dead, of the other Age. Hence the Rectangle *HI* shall be as an equal number of both Ages surviving. The Rectangle *FE* being the Product of the Deceased, or *Yy*, an equal number of both dead. The Rectangle *GD* or *Ry*, a number living of the younger Age, and dead of the elder: And the Rectangle *AG* or *rY* a number living of the elder Age, but dead of the younger. This being understood, it is obvious, that as the whole Rectangle *AD* or *Nn* is to the *Gnomon FABDEG* or *Nn* - *Yy*, so is the whole number of Persons or Chances, to the number of Chances that one of the two Persons is living: And as *AD* or *Nn* is to *FE* or *Yy*, so are all the Chances, to the Chances that both are dead; whereby may be computed the Value of the Reversion after both Lives. And as *AD* to *GD* or *Ry*, so the whole number of Chances, to the Chances that the younger is living, and the other dead; whereby may be cast up what Value ought to be paid for the Reversion of one Life after another, as in the Case of providing for Clergy-men's Widows, and others, by such Reversions. And as *AD* to *AG*, or *rY*, so are all the {293} Chances, to those that the elder survives the younger. I have been the more particular, and perhaps tedious, in this Matter, because it is the Key to the Case of Three Lives, which of it self would not have been so easie to comprehend.

VII. If Three Lives are proposed, to find the Value of an Annuity during the continuance of any of those three Lives; the Rule is, *As the Product of the continual Multiplication of the Three Numbers, in the Table, answering to the Ages proposed, is to the difference of that Product, and of the Product of the Three Numbers of the Deceased of those Ages, in any given Term of Years: So is the present Value of a Sum of Money, to be paid certainly after so many Years, to the present Value of the same Sum to be paid, provided one of those Three Persons be living at the Expiration of that Term.* Which Proportion being yearly repeated, the Sum of all those present Values will be the Value of an Annuity granted for three such Lives. But to explain this, together with all the Cases of Survivance in Three Lives: Let *N* be the Number in the Table for the younger Age, *n* for the second, and ν for the elder Age; let *Y* be those dead of the younger Age in the Term proposed, *y* those dead of the second Age, and υ those of the elder Age; and let *R* be the Remainder of the younger Age, *r* that of the middle Age, and ρ the Remainder of the elder Age. Then shall $R + Y$ be equal to *N*, $r + y$ to *n*, and $\rho + \upsilon$ to ν, and the continual Product of the three Numbers *N*, *n*, ν, shall be equal to the continual Product of $R + Y \times r + y \times \rho + \upsilon$, which being {294} the whole Number of Chances for three Lives, is compounded of the eight Products following. (1) *Rr*ρ, which is the Number of Chances that all three of the Persons are living. (2) *r*ρ*Y*, which is the Number of Chances that the two elder Persons are living, and the younger dead. (3) *R*ρ*y* the Number of Chances that the middle Age is dead, and the younger and elder living. (4) *Rr*υ being the Chances that the two younger are living, and the elder dead. (5) ρ*Yy* the Chances that the two younger are dead, and the elder living. (6) *rY*υ the Chances that the younger and elder are dead, and the middle Age living. (7) *Ry*ν, which are the Chances that the younger is living, and the two other dead. And Lastly and Eighthly, *Yy*ν, which are the Chances that all three are dead. Which latter subtracted from the whole Number of Chances *Nn*ν, leaves *Nn*ν - *Yy*ν the Sum of all the other seven Products; in all of which one or more of the three Persons are surviving.

To make this yet more evident, I have added *Fig. 8.* wherein these eight several Products are at

one view exhibited. Let the rectangled Parallelepipedon *ABCDEFGH* be constituted of the sides *AB*, *GH*, *&c.* proportional to *N* the Number of the younger Age; *AC*, *BD*, *&c.* proportional to *n*; and *AG*, *CE*, *&c.* proportional to the Number of the elder, or ν. And the whole Parallelepipedon shall be as the Product *Nn*ν, or our whole Number of Chances. Let *BP* be as *R*, and *AP* as *Y*; let *CL* be as *r*, and *Ln* as *y*; and *GN* as ρ, and *NA* as υ; and let the Plain *PRea* be made parallel to the {295}
Plain *ACGE*; the Plain *NVbY* parallel to *ABCD*; and the Plain *LXTQ* parallel to the Plain *ABGH*. And our first Product *Rr*ρ shall be as the Solid *STWIFZeb*. The Second, or *r*ρ*Y* will be as the Solid *EYZeQSMI*. The Third, *R*ρ*y*, as the Solid *RHOVWIST*. And the Fourth, *Rr*υ, as the Solid *ZabDWXIK*. Fifthly, ρ*Yy*, as the Solid *GQRSIMNO*. Sixthly, *rY*υ, as *IKLMGYZA*. Seventhly, *Ry*υ, as the Solid *IKPOBXVW*. And Lastly, *AIKLMNOP* will be as the Product of the 3 Numbers of Persons dead, or *Yy*υ. I shall not apply this in all the Cases thereof, for brevity sake; only to shew in one how all the rest may be performed, let it be demanded what is the Value of the Reversion of the younger Life after the two elder proposed. The proportion is as the whole Number of Chances, or *Nn*ν to the Product *Ry*υ; so is the certain present Value of the Sum payable after any Term proposed, to the Value due to such Chances as the younger Person has to bury both the elder, by the Term proposed; which therefore he is to pay for. Here it is to be noted, that the first Term of all these Proportions is the same throughout, *viz. Nn*ν. The second changing yearly according to the Decrease of *R*, *r*, ρ, and Increase of *Y*, *y*, υ. And the third are successively the present Values of Money payable after one, two, three, *&c.* years, according to the Rate of Interest agreed on. These Numbers, which are in all Cases of Annuities of necessary Use, I have put into the following Table, they being Decimal Values of one Pound payable after the Number of Years in {296}
the Margent, at the Rate of 6 *per Cent.*

Years.	Pres. Value of 1 *l.*	Years.	Pres. Value of 1 *l.*	Years.	Pres. Value of 1 *l.*
1	0,9434	19	0,3305	37	0,1158
2	0,8900	20	0,3118	38	0,1092
3	0,8396	21	0,2941	39	0,1031
4	0,7921	22	0,2775	40	0,0972
5	0,7473	23	0,2618	45	0,0726
6	0,7050	24	0,2470	50	0,0543
7	0,6650	25	0,2330	55	0,0406
8	0,6274	26	0,2198	60	0,0303
9	0,5919	27	0,2074	65	0,0227
10	0,5584	28	0,1956	70	0,0169
11	0,5268	29	0,1845	75	0,0126
12	0,4970	30	0,1741	80	0,0094
13	0,4688	31	0,1643	85	0,0071
14	0,4423	32	0,1550	90	0,0053
15	0,4173	33	0,1462	95	0,0039
16	0,3936	34	0,1379	100	0,0029
17	0,3714	35	0,1301		
18	0,3503	36	0,1227		

It were needless to advertise, that the great trouble of working so many Proportions will be very much alleviated by using Logarithms; and that instead of using *Nn*ν - *Yy*υ for the second Term of the Proportion in finding the Value of Three Lives, it may suffice to use only *Yy*υ, and then deducting the fourth Term so found out of the third, the Remainder shall be the present Value sought; or all these fourth Terms being added together, and deducted out of the Value of {297}
the certain Annuity for so many Years, will leave the Value of the contingent Annuity upon the Chance of Mortality of all those Three Lives. For Example; Let there be Three Lives of 10, 30, and 40 Years of Age proposed, and the Proportions will be thus;

As 661 in 531 in 445 or 156190995, or *Nn*ν to 8 in 8 in 9, or 576, or *Yy*υ for the first Year, so 0,9434. to 0,00000348.
To 15 in 16 in 18, or 4320, for the second Year, so 0,8900. to 0,00002462.
To 21 in 24 in 28, or 14112 for the third Year, so 0,8396. to 0,00008128.
To 27 in 32 in 38, for the fourth Year, so 0,7921. to 0,00016650.
To 33 in 41 in 48, for the fifth Year, so 0,7473. to 0,00031071.
To 39 in 50 in 58, for the sixth Year, so 0,7050. to 0,00051051.

And so forth to the 60th Year, when we suppose the elder Life of Forty certainly to be expired; from whence till Seventy we must compute for the First and Second only, and from thence to Ninety for the single youngest Life. Then the Sum Total of all these Fourth Proportionals being taken out of the Value of a certain Annuity for 90 Years, being 16,58 Years Purchase, shall leave the just Value to be paid for an Annuity during the whole Term of the Lives of Three Persons of the Ages proposed. And note, that it will not be necessary to compute for every Year singly; but {298}
that in most Cases every 4th or 5th Year may suffice, interpoling for the intermediate Years *seceundum artem*.

It may be objected, that the different *Salubrity* of Places does hinder this Proposal from being *universal*; nor can it be denied. But by the Number that die, being 1174. *per Annum* in 34000, it does appear that about a 30th part die yearly, as Sir *William Petty* has computed for *London*; and the Number that die in Infancy, is a good Argument that the Air is but indifferently salubrious. So that by what I can learn, there cannot perhaps be one better Place proposed for a Standard. At least 'tis desired, that in Imitation hereof the Curious in other Cities would attempt something of the same Nature, than which nothing perhaps can be more useful.

Were this *Calculus* founded on the Experience of a very great number of Years, it would be very well worth the while to think of Methods for facilitating the Computation of the Value of two, three, or more Lives; which, as proposed in my former, seems (as I am inform'd) a Work of too much Difficulty for the ordinary Arithmetician to undertake.

I have sought, If it were possible, to find a Theorem that might be more concise than the Rules there laid down, but in vain; for all that can be done to expedite it, is, by Tables of Logarithms ready computed, to exhibit the *Rationes* of *N* to *Y* in each single Life, for every third, fourth, or fifth Year of Age, as occasion shall require; and these Logarithms being added to the Logarithms of the present Value of Money payable after so many Years, will give a Series of Numbers, the {299}
Sum of which will shew the Value of the Annuity sought. However, for each Number of this Series, two Logarithms for a single Life, three for two Lives, and four for three Lives, must necessarily be added together. If you think the Matter, under the Uncertainties I have mentioned, to deserve it, I shall shortly give you such a Table of Logarithms, as I speak of, and an Example or two of the use thereof: But by Vulgar Arithmetick, the Labour of these Numbers were immense; and nothing will more recommend the useful Invention of Logarithms to all Lovers of Numbers, than the advantage of Dispatch in this and such like Computations.

Besides the Uses mentioned, it may perhaps not be an unacceptable thing to infer from the same Tables, how unjustly we repine at the shortness of our Lives, and think our selves wronged if we attain not old Age; whereas it appears hereby, that the one half of those that are born are dead in Seventeen Years time, 1238 being in that time reduced to 616. So that instead of murmuring at what we call an untimely Death, we ought with Patience and Unconcern to submit to that Dissolution which is the necessary Condition of our perishable Materials, and of our nice and frail Structure and Composition: And to account it as a Blessing that we have survived, perhaps by many Years, that Period of Life, whereat the one half of the whole Race of Mankind does not arrive.

A second Observation I make upon the said Table, is that the Growth and Increase of Mankind {300}
is not so much stinted by any thing in the Nature of the *Species*, as it is from the cautious difficulty most People make to adventure on the State of *Marriage*, from the Prospect of the Trouble and Charge of providing for a Family. Nor are the poorer sort of People herein to be blamed, since their difficulty of subsisting is occasion'd by the unequal Distribution of Possessions, all being necessarily fed from the Earth, of which yet so few are Masters. So that besides themselves and Families, they are yet to work for those who own the Ground that feeds them: And of such does by very much the greater part of Mankind consist; otherwise it is plain, that there might well be four times as many Births as we now find. For by Computation from the Table, I find that there are nearly 15000 Persons above 16, and under 45, of which at least 7000 are Women capable to bear Children. Of these notwithstanding there are but 1238 born yearly, which is but little more than a sixth part: So that about one in six of these Women do breed yearly; whereas were they all married, it would not appear strange or unlikely, that four of six should bring a Child every Year. The Political Consequences hereof I shall not insist on; only the Strength and Glory of a King being in the multitude of his Subjects, I shall only hint, that above all things, Celibacy ought to be discouraged, as, by extraordinary Taxing and Military Service: And those who have numerous Families of Children to be countenanced and encouraged by such Laws as the *Jus trium Liberorum* among the *Romans*. But especially, by an effectual Care to {301}
provide for the Subsistence of the Poor, by finding them Employments, whereby they may earn their Bread, without being chargeable to the Publick.

{302}

A Discourse concerning Gravity*, and its Properties, wherein the Descent of* Heavy Bodies*, and the Motion of* Projects *is briefly, but fully handled: Together with the* Solution *of a* Problem *of great Use in* Gunnery*. By* E. Halley*.*

NATURE, amidst the great Variety of *Problems*, wherewith She exercises the Wits of Philosophical Men, scarce affords any one wherein the Effect is more visible, and the Cause more concealed, than in those of the *Phænomena* of *Gravity*. Before we can go alone, we must learn to defend our selves from the Violence of its Impulse, by not trusting the *Center* of *Gravity* of our Bodies beyond our reach; and yet the acutest Philosophers, and the subtilest Enquirers into the Original of this Motion, have been so far from satisfying their Readers, that they themselves seem little to have understood the Consequences of their own *Hypotheses*.

Des Cartes his Notion, I must needs confess to be to me incomprehensible, while he will have the Particles of his *Cœlestial Matter*, by being reflected on the Surface of the *Earth*, and so ascending therefrom, to drive down into their Places those *Terrestrial Bodies* they find above {303} them: This is, as near as I can gather, the Scope of the 20, 21, 22, and 23 *Sections* of the last Book of his *Principia Philosophiæ*; yet neither he, nor any of his Followers, can shew how a Body suspended in *Libero Æthere*, shall be carried downwards by a continual Impulse tending upwards, and acting upon all its Parts equally: And besides the Obscurity wherewith he expresses himself, particularly, *Sect. 23.* does sufficiently argue according to his own Rules, the confused *Idea* he had of the thing he wrote.

Others, and among them Dr. *Vossius*, assert the Cause of the *Descent* of *heavy Bodies*, to be the *Diurnal Rotation* of the *Earth* upon its *Axis*, without considering, that according to the Doctrine of Motion fortified with Demonstration, all Bodies moved *in Circulo*, would recede from the Center of their Motion; whereby the contrary to *Gravity* would follow, and all loose Bodies would be cast into the Air in a *Tangent* to the *Parallel* of *Latitude*, without the intervention of some other Principle to keep them fast, such as is that of *Gravity*. Besides, the Effect of this Principle is throughout the whole Surface of the Globe found nearly equal; and certain Experiments have proved it rather less near the *Æquinoctial*, than towards the *Poles*; which could not be by any means, if the *Diurnal Rotation* of the *Earth* upon its *Axis* were the Cause of *Gravity*; for where the Motion was swiftest, the Effect would be most considerable.

Others assign the Pressure of the *Atmosphere*, to be the Cause of this Tendency towards the Center of the Earth; but unhappily they have mistaken the Cause for the Effect; it being from {304} undoubted Principles plain, that the *Atmosphere* has no other Pressure but what it derives from its *Gravity*; and that the Weight of the upper Parts of the *Air*, pressing on the lower Parts thereof, do so far bend the Springs of that *Elastick* Body, as to give it a Force equal to the Weight that compress'd it, having of it self no force at all: And supposing it had, it will be very hard to explain the *Modus*, how that Pressure should occasion the Descent of a Body circumscribed by it, and pressed equally above and below, without some other Force to draw, or thrust it downwards. But to demonstrate the contrary of this Opinion, an *Experiment* was long since shewn before the *Royal Society*, whereby it appeared, that the *Atmosphere* was so far from being the Cause of *Gravity*, that the Effects thereof were much more vigorous, where the Pressure of the *Atmosphere* was taken off; for a long *Glass-Receiver* having a light Down-feather included, being evacuated of Air, the Feather, which in the Air would hardly sink, did *in vacuo* descend with nearly the same *Velocity*, as if it had been a Stone.

Some think to illustrate this Descent of Heavy Bodies, by comparing it with the Vertue of the *Loadstone*; but setting aside the difference there is in the manner of their Attractions, the *Loadstone* drawing only in and about its Poles, and the Earth near equally in all Parts of its Surface, this Comparison avails no more than to explain *ignotum per æque ignotum*.

Others assign a certain *Sympæthetical Attraction* between the Earth and its Parts, whereby {305} they have, as it were, a desire to be united, to be the Cause we enquire after: But this is so far from explaining the *Modus*, that it is little more, than to tell us in other Terms, that Heavy Bodies descend, because they descend.

This, I say, not that I can pretend to substitute any Solution of this Important Philosophical Problem, that shall more happily explicate the Appearances of Gravity; only it may be serviceable to those with whom the Credit of great Authors sways much, and who too readily assent *in Verba Magistri*, to let them see that their Books are not always infallible: Besides, the detection of Errors is the first and surest Step towards the discovery of Truth.

Though the efficient Cause of *Gravity* be so obscure, yet the final Cause thereof is clear enough; for it is by this single *Principle*, that the *Earth* and all the *Cœlestial Bodies* are kept from *Dissolution*; the least of their *Particles* not being suffer'd to recede far from their *Surfaces*, without being immediately brought down again by Virtue of this *Natural Tendency*; which, for their Preservation, the Infinite Wisdom of their *Creator* has ordained to be towards each of their *Centers*; nor can the *Globes* of the *Sun* and *Planets* otherwise be destroy'd, but by taking from them this Power of keeping their Parts united.

The Affections or Properties of *Gravity*, and its manner of acting upon *Bodies falling*, have been in a great measure discovered, and most of them made out by *Mathematical Demonstration* in {306} this our *Century*, by the accurate diligence of *Galilæus*, *Torricellius*, *Hugenius*, and others, and now lately by our worthy Countryman, Mr. *Isaac Newton*, which Properties it may be very material here to enumerate, that they may serve for a Foundation to all those that shall be willing to spend their Thoughts in search of the true Cause of this *Descent of Bodies*.

The first Property is, That by this Principle of *Gravitation*, all Bodies do descend towards a Point, which either is, or else is very near to the Center of Magnitude of the Earth and Sea, about which the Sea forms it self exactly into a *Spherical Surface*, and the *Prominences* of the Land, considering the Bulk of the whole, differ but insensibly therefrom.

Secondly, That this Point or Center of *Gravitation*, is fix'd within the *Earth*, or at least has been

so, ever since we have any *Authentick History*: For a Consequence of its Change, though never so little, would be the over-flowing of the low Lands on that side of the *Globe* towards which it approached, and the leaving new Islands bare on the opposite side, from which it receded; but for this Two Thousand Years it appears, that the low Islands of the *Mediterranean Sea* (near to which the ancientest Writers liv'd) have continued much at the same height above the Water, as they now are found; and no *Inundations* or *Recesses* of the *Sea* arguing any such Change, are recorded in History; excepting the *Universal Deluge*, which can no better way be accounted for, {307} than by supposing this Center of *Gravitation* removed for a time, towards the middle of the then inhabited Parts of the World; and a change of its Place, but the Two Thousandth Part of the *Radius* of this *Globe*, were sufficient to bury the Tops of the highest Hills under Water.

Thirdly, That in all Parts of the *Surface* of the *Earth*, or rather in all Points equidistant from its *Center*, the Force of *Gravity* is nearly equal; so that the length of the *Pendulum* vibrating *Seconds of Time*, is found in all Parts of the World to be very near the same. 'Tis true at St. *Helena*, in the *Latitude* of 16 Degrees *South*, I found that the *Pendulum* of my Clock, which vibrated *Seconds*, needed to be made shorter than it had been in *England*, by a very sensible Space (but which at that time I neglected to observe accurately) before it would keep time; and since the like Observations have been made by the *French Observers*, near the *Æquinoctial*: Yet I dare not affirm, that in mine it proceeded from any other Cause, than the great Height of my Place of Observation above the *Surface* of the *Sea*, whereby the *Gravity* being diminished, the length of the *Pendulum* vibrating *Seconds*, is proportionably short'ned.

Fourthly, That *Gravity* does equally affect all *Bodies*, without regard either to their *Matter*, *Bulk*, or *Figure*; so that the Impediment of the *Medium* being removed, the most compact and most loose, the greatest and smallest *Bodies* would descend the same *Spaces* in equal Times; the {308} Truth thereof will appear from the Experiment I before-cited. In these two last Particulars, is shewn the great difference between *Gravity* and *Magnetism*, the one affecting only *Iron*, and that towards its *Poles*, the other all *Bodies* alike in every part. As a *Corollary*, from hence it will follow, that there is no such thing as *positive Levity*, those things that appear light, being only comparatively so; and whereas several things rise and swim in *Fluids*, 'tis because, Bulk for Bulk, they are not so heavy as those *Fluids*; nor is there any Reason why *Cork*, for Instance, should be said to be light, because it swims on Water, any more than *Iron*, because it swims on *Mercury*.

Fifthly, That this Power increases as you descend, and decreases as you ascend from the Center, and that in the Proportion of the Squares of the *Distances* therefrom *reciprocally*, so as at a double Distance to have but a quarter of the Force; this Property is the Principle on which Mr. *Newton* has made out all the *Phænomena* of the *Cœlestial Motions*, so easily and naturally, that its Truth is past Dispute. Besides that, it is highly rational, that the *attractive* or *gravitating* Power should exert it self more vigorously in a small Sphere, and weaker in a greater, in proportion as it is contracted or expanded; and if so, seeing that the *Surfaces* of *Spheres* are as the *Squares* of their *Radii*, this Power, at several Distances, will be as the *Squares* of those *Distances reciprocally*; and then its whole Action upon each *Spherical Surface*, be it great or small, will be always equal. And this is evidently the Rule of *Gravitation* towards the *Centers* of {309} the *Sun*, *Jupiter*, *Saturn* and the *Earth*, and thence is reasonably inferred, to be the general Principle observed by *Nature*, in all the rest of the *Cœlestial Bodies*.

These are the principal Affections of *Gravity*, from which the Rules of the *Fall* of *Bodies*, and the *Motion* of *Projects* are *Mathematically* deducible. Mr. *Isaac Newton* has shew'd how to define the Spaces of the *Descent* of a *Body*, let fall from any given height, down to the *Center*, supposing the *Gravitation* to increase, as in the fifth Property; but considering the smallness of heighth, to which any *Project* can be made ascend, and over how little an *Arch* of the *Globe* it can be cast by any of our *Engines*, we may well enough suppose the *Gravity* equal throughout, and the Descents of *Projects* in parallel Lines, which in Truth are towards the *Center*, the difference being so small as by no means to be discovered in *Practice*. The *Opposition* of the *Air*, 'tis true, is considerable against all light Bodies moving through it, as likewise against small ones (of which more hereafter) but in great and ponderous Shot, this Impediment is found by *Experience* but very small, and may safely be neglected.

Propositions concerning the Descent of Heavy Bodies, and the Motion of Projects.

Prop. I. The *Velocities* of *Falling Bodies*, are proportionate to the Times from the beginning of their *Falls*.

This follows, for that the Action of *Gravity* being *continual*, in every Space of Time, the falling {310} Body receives a new Impulse, equal to what it had before, in the same Space of Time, received from the same Power: For Instance, in the first Second of Time, the falling Body has acquired a *Velocity*, which in that time would carry it to a certain Distance, suppose 32 Foot, and were there no new Force, would descend at that rate with an *equable Motion*: But in the next Second of Time, the same Power of *Gravity* continually acting thereon, superadds a new *Velocity* equal to the former; so that at the end of two Seconds, the *Velocity* is double to what it was at the end of the first, and after the same manner may it be proved to be triple, at the end of the third Second,

and so on. Wherefore the *Velocities* of *falling Bodies*, are proportionate to the Time of their *Falls*, *Q. E. D.*

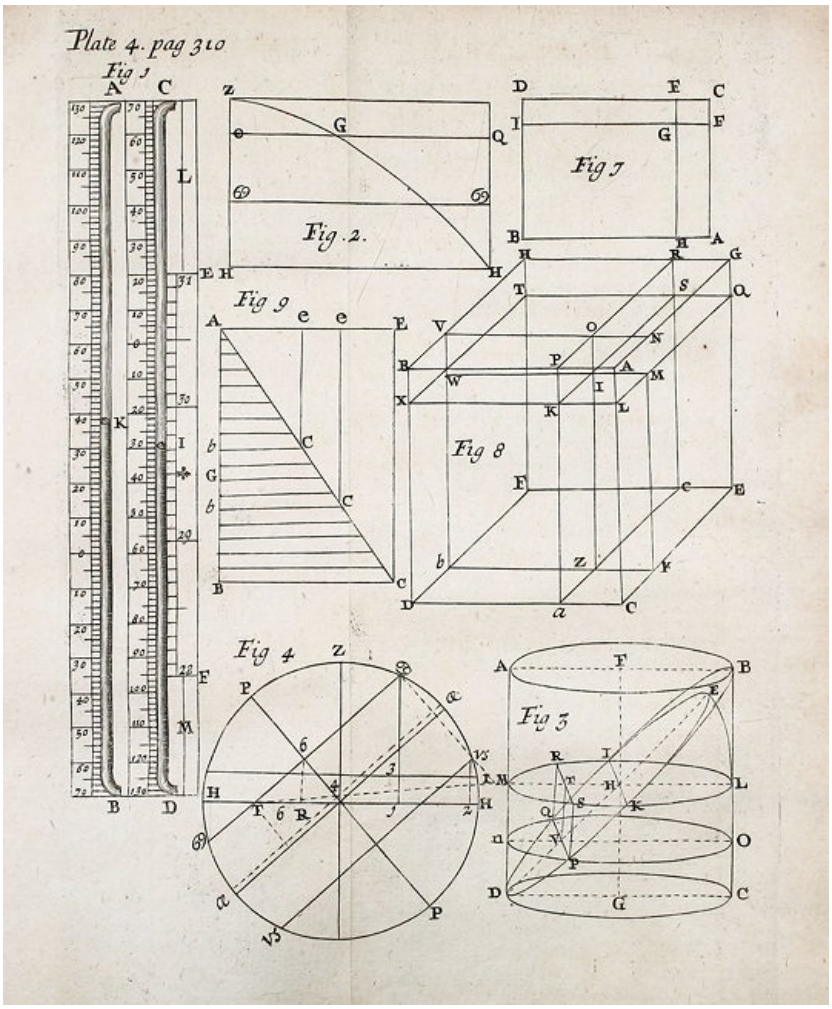


Plate 4. pag. 310.

Prop. II. The *Spaces* described by the Fall of a Body, are as the *Squares* of the Times, from the beginning of the *Fall*.

Demonstration. Let AB (*Fig. 9. Tab. 4.*) represent the *Time* of the *Fall* of a *Body*, BC perpendicular to AB, the *Velocity* acquired at the end of the *Fall*, and draw the Line AC; then divide the Line AB representing the Time, into as many equal Parts as you please, as b, b, b, b, *&c.* and through these Points draw the Lines bc, bc, bc, bc, *&c.* parallel to BC, 'tis manifest that the several Lines, bc, represent the several *Velocities* of the falling Body, in such Parts of the *Time* as Ab is of AB, by the former Proposition. It is evident likewise, that the *Area* ABC is the {311}
Sum of all the Lines bc being taken, according to the Method of *Indivisibles*, infinitely many; so that the *Area* ABC represents the Sum of all the *Velocities*, between none and BC supposed infinitely many; which Sum is as the Space descended in the Time represented by AB. And by the same Reason the *Areas* Abc, will represent the Spaces descended in the Times Ab; so then the Spaces descended in the Times AB, Ab, are as the *Areas* of the *Triangles* ABC, Abc, which by the 20th of the 6 of *Euclid*, are as the *Squares* of their *Homologous Sides* AB, Ab, that is to say, of the *Times*: Wherefore the Descents of *falling Bodies*, are as the *Squares* of the Times of their *Fall*, *Q. E. D.*

Prop. III. The *Velocity* which a *falling Body* acquires in any Space of time, is double to that, wherewith it would have moved the Space, descended by an equable Motion, in the same *time*.

Demonstration. Draw the Line EC parallel to AB, and AE parallel to BC in the same *Fig. 9.* and compleat the *Parallelogram* ABCE, it is evident that the *Area* thereof may represent the Space, a *Body* moved equably with the *Velocity* BC would describe in the Time AB, and the *Triangle* ABC represents the *Space* describ'd by the *Fall* of a *Body*, in the same Time AB, by the second Proposition. Now the *Triangle* ABC is half of the *Parallelogram* ABCE, and consequently the Space described by the *Fall*, is half what would have been described by an *equable Motion* with the *Velocity* BC, in the same Time; wherefore the *Velocity* BC at the end of the *Fall*, is double to {312}
that *Velocity*, which in the Time AB, would have described the *Space fallen*, represented by the

Triangle ABC with an *equable Motion*, *Q. E. D.*

Prop. IV. All *Bodies* on or near the Surface of the *Earth*, in their *Fall*, descend so, as at the end of the first Second of Time, they have described 16 Feet, 1 Inch, *London Measure*, and acquired the *Velocity* of 32 Feet, 2 Inches, in a Second.

This is made out from the 25th Proposition of the second Part of that excellent Treatise of Mr. *Hugenius de Horologio Oscillatorio*; wherein he demonstrates the time of the least *Vibrations* of a *Pendulum*, to be to the Time of the *Fall* of a *Body*, from the heighth of half the length of the *Pendulum*, as the *Circumference* of a *Circle* to its *Diameter*; whence, as a *Corollary*, it follows, That as the *Square* of the *Diameter* to the *Square* of the *Circumference*, so half the length of the *Pendulum* vibrating *Seconds*, to the *Space* described by the *Fall* of a *Body* in a *Second* of *Time*: And the Length of the *Pendulum* vibrating *Seconds*, being found 39, 125, or ⅛ Inches, the *Descent* in a *Second* will be found by the aforesaid *Analogy* 16 Foot and 1 Inch; and, by the third Proposition, the *Velocity* will be double thereto; and near to this it hath been found by several Experiments, which by reason of the *swiftness* of the *Fall*, cannot so exactly determine its *Quantity*. The Demonstration of *Hugenius* being the Conclusion of a long Train of *Consequences*, I shall for brevity sake omit; and refer you to his Book, where these things are more amply treated of.

From these Four *Propositions*, all *Questions* concerning the *Perpendicular Fall of Bodies*, are {313}
easily *solved*, and either *Time*, *Height*, or *Velocity* being assign'd, one may readily find the other two. From them likewise is the Doctrine of *Projects* deducible, assuming the two following *Axioms*; *viz.* That a *Body* set a moving, will move on continually in a right *Line* with an *equable Motion*, unless some other Force or Impediment intervene, whereby it is accelerated, or retarded, or deflected.

Secondly, That a *Body* being agitated by two *Motions* at a time, does by their *compounded Forces* pass through the same *Points*, as it would do, were the two *Motions divided* and acted *successively*. As for Instance, Suppose a *Body* moved in the Line GF, (*Fig. 1. Tab. 5.*) from G to R, and there stopping, by another *Impulse*, suppose it moved in a *Space* of *Time* equal to the former, from R towards K, to V. I say, the *Body* shall pass through the Point to V, though these two *several Forces* acted both in the *same time*.

Prop. V. The *Motion* of all *Projects* is in the *Curve* of a *Parabola*: Let the *Line* GRF (in *Fig.* 1.) be the *Line* in which the *Project* is directed, and in which by the first *Axiom* it would move equal *Spaces* in equal *Times*, were it not deflected downwards by the Force of *Gravity*. Let GB be the *Horizontal Line*, and GC a *Perpendicular* thereto. Then the *Line* GRF being divided into equal Parts, answering to equal *Spaces* of *Time*, let the *Descents* of the *Project* be laid down in *Lines parallel* to GC, proportioned as the *Squares* of the *Lines* GS, GR, GL, GF, or as the *Squares* of the *Times*, from S to T, from R to V, from L to X, and from F to B, and draw the *Lines* TH, VD, XY, BC {314}
parallel to GF; I say, the Points T, V, X, B, are Points in the *Curve* described by the *Project*, and that that *Curve* is a *Parabola*. By the second *Axiom*, they are Points in the *Curve*; and the Parts of the *Descent* GH, GD, GY, GC, = to ST, RV, LX, FB, being as the *Squares* of the *Times* (by the *Second Proposition*) that is, as the *Squares* of the *Ordinates*, HT, DU, YX, BC, equal to GS, GR, GL, GF, the *Spaces* measured in those Times; and there being no other *Curve* but the *Parabola*, whose Parts of the *Diameter* are as the *Squares* of the *Ordinates*, it follows that the *Curve* describ'd by a *Project*, can be no other than a *Parabola*: And saying, as RU the *Descent* in any *time*, to GR or UD the *direct Motion* in the same *time*, so is UD to a *third* proportional; that *third* will be the *Line* call'd by all Writers of *Conicks*, the *Parameter* of the *Parabola* to the *Diameter* GC, which is always the same in *Projects* cast with the same *Velocity*: And the *Velocity* being defined by the Number of *Feet* moved in a *Second* of Time, the *Parameter* will be found by dividing the *Square* of the *Velocity*, by 16 *Feet*, 1 *Inch*, the *Fall* of a *Body* in the same *Time*.

Lemma.

The *Sine* of the double of any *Arch*, is equal to twice the *Sine* of that *Arch* into its *Co-sine*, divided by *Radius*; and the *versed Sine* of the *double* of any *Arch* is equal to twice the *Square* of the *Sine* thereof divided by *Radius*.

Let the *Arch* BC (in *Fig. 2. Tab. 5.*) be double the *Arch* BF, and A the *Center*; draw the *Radii* AB, {315}
AF, AC, and the *Chord* BDC, and let fall BE perpendicular to AC, and the *Angle* EBC, will be equal to the *Angle* ABD, and the *Triangle* BCE, will be like to the *Triangle* BDA; wherefore it will be as AB to AD, so BC or twice BD, to BE; that is, as *Radius* to *Co-sine*, so twice *Sine* to *Sine* of the double *Arch*. And as AB to BD, so twice BD or BC to EC, that is, as *Radius* to *Sine*, so twice that *Sine*, to the *Versed Sine* of the double *Arch*; which two *Analogies* resolved into *Equations*, are the *Propositions* contained in the *Lemma* to be proved.

Prop. VI. The *Horizontal* Distances of *Projections* made with the same *Velocity*, at several *Elevations* of the *Line* of Direction, are as the *Sines* of the doubled *Angles* of *Elevation*.

Let GB (*Fig.* 1) the *Horizontal* Distance be = z, the *Sine* of the *Angle* of *Elevation*, FGB, be = s, its *Co-sine* = c, *Radius* = r, and the *Parameter* = p. It will be as c to s; so z to $^{sz}/_{c}$ = FB = GC, and by reason of the *Parabola* $^{psz}/_{c}$ = to the *Square* of CB, or GF; Now as c to r, so is z to $^{zr}/_{c}$ = GF, and its *Square* $^{zzrr}/_{cc}$ will be therefore = to $^{psz}/_{c}$: Which *Equation* reduced will be $^{psc}/_{rr} = z$. But by the former *Lemma* $^{2sc}/_{r}$ is equal to the *Sine* of the double *Angle*, whereof s is the *Sine*: Wherefore {316} 'twill be as *Radius* to *Sine* of double the *Angle* FGB, so is half the *Parameter*, to the *Horizontal Range* or *Distance* sought; and at the several *Elevations*, the *Ranges* are as the *Sines* of the double *Angles* of *Elevation*, *Q. E. D.*

Corollary.

Hence it follows, that half the *Parameter* is the greatest *Randon*, and that that happens at the *Elevation* of 45 Degrees, the *Sine* of whose double is *Radius*. Likewise that the *Ranges* equally distant above and below 45 are equal, as are the *Sines* of all double *Arches*, to the *Sines* of their doubled *Complements*.

Prop. VII. The *Altitudes* of *Projections* made with the same *Velocity*, at several *Elevations*, are as the *versed Sines* of the doubled *Angles* of *Elevation*: As c is to s; so is $^{psc}/_{rr}$ = GB to $^{pss}/_{rr}$ = BF: and UK = RU = BF/4, the *Altitude* of the *Projection* = $^{psc}/_{4rr}$. Now by the foregoing *Lemma* $^{2ss}/_{r}$ = to the *versed Sine* of the double *Angle*, and therefore it will be as *Radius*, to *versed Sine* of double the *Angle* FGB, so an 8th of the *Parameter* to the height of the *Projection* VK; and so these heights at several *Elevations*, are as the said *versed Sines*, *Q. E. D.*

Corollary. {317}

From hence it is plain, that the greatest *Altitude* of the perpendicular *Projection* is a 4th of *Parameter*, or half the greatest *Horizontal Range*; the *versed Sine* of 180 Degrees being = $2r$.

Prop. VIII. The *Lines* GF, or Times of the Flight of a *Project* cast with the same Degree of *Velocity* at different *Elevations*, are as the *Sines* of the *Elevations*.

As c is to r; so is $^{psc}/_{rr}$ = GB by the 6 Prop. to $^{ps}/_{r}$ GF; that is, as *Radius* to *Sine* of *Elevation*, so the *Parameter* to the *Line* GF; so the *Lines* GF are as the *Sines* of *Elevation*, and the *Times* are proportional to those *Lines*; wherefore the *Times* are as the *Sines* of *Elevation*: *Ergo constat propositio*.

Prop. IX. Problem. A *Projection* being made as you please, having the Distance and Altitude, or Descent, of an Object, through which the Project passes, together with the *Angle* of *Elevation* of the *Line* of *Direction*; to find the *Parameter* and *Velocity*, that is (in *Fig.* 1.) having the *Angle* FGB, GM, and MX.

Solution. As *Radius* to *Secant* of FGB, so GM the *Distance* given to GL; and as *Radius* to *Tangent* of FGB, so GM to LM. Then LM - MX in *Heights*, or + MX in *Descents*; or else MX - ML, if the *Direction* be below the *Horizontal Line*, is the *Fall* in the *Time* that the direct *Impulse* given in G would have carried the Project from G to L = LX = GY; then by Reason of the *Parabola*, as {318} LX or GY, is to GL or YX, so is GL to the *Parameter* sought. To find the *Velocity* of the *Impulse*: by Prop. 2, and 4, find the Time in Seconds that a Body would fall the Space LX; and by that dividing the Line GL, the *Quote* will be the *Velocity*, or Space moved in a Second sought, which is always a mean Proportional between the *Parameter*, and 16 Feet, 1 Inch.

Prop. X. Problem 2. Having the *Parameter*, Horizontal Distance, and Height or Descent of an *Object*, to find the Elevations of the Line of Direction necessary to hit the given *Object*; that is, having GM, MX, and the greatest *Randon* equal to half the *Parameter*; to find the *Angles* FGB.

Let the *Tangent* of the *Angle* sought be = t, the *Horizontal Distance* GM = b, the Altitude of the *Object* MX = h, the *Parameter* = p, and *Radius* = r, and it will be,

As r to t, so b to $^{tb}/_{r}$ = ML and $^{tb}/_{r} \mp h \begin{Bmatrix} \text{in ascents} \\ \text{in descents} \end{Bmatrix}$ = LX, and

$^{ptb}/_{r} \mp ph$ = GL *quad.* = XY *quad. ratione Parabolæ*; but

$bb \mp {}^{ttbb}/_{rr}$ = GL *quad.* 47. 1. *Euclid*. Wherefore

$^{ptb}/_{r} \mp ph = bb \mp {}^{ttbb}/_{rr}$ which Equation transposed, is

$^{ttbb}/_{rr} = {}^{ptb}/_{r} \mp ph - bb$, divided by bb is $^{tt}/_{rr} = {}^{pt}/_{br} \mp {}^{ph}/_{bb} - 1$. {319}

this Equation shews the Question to have 2 Answers, and the Roots thereof are $^{t}/_{r} = {}^{p}/_{2b} \mp \sqrt{}$

$\frac{pp \mp 4ph}{4bb}$ - 1; from which I derive the following Rule.

Divide half the *Parameter* by the Horizontal distance, and keep the Quote; *viz.* $^{p}/_{2b}$ then say, as *square* of the *distance* given to the half *Parameter*, so half *Parameter* ∓ double $\frac{\text{height}}{\text{descent}}$ to the *square* of a *Secant* = $\frac{pp \mp 4ph}{4bb}$. The *Tangent* answering to that *Secant*, will be $\sqrt{\frac{pp \mp 4ph}{4bb}}$ - 1 or Square of Radius, so then the sum and difference of the afore-found *Quote*, and this *Tangent* will be the Roots of the *Equation*, and the *Tangents* of the *Elevations* sought.

Note here, that in *Descents*, if the *Tangent* exceed the *Quote*, as it does when *ph* is more than *bb*, the *direction* of the lower *Elevation* will be below the *Horizon*, and if *ph* = *bb*, it must be directed *Horizontal*, and the *Tangent* of the upper *Elevation* will be $^{pr}/_{b}$: Note likewise, that if 4*bb* + 4*ph* in *Ascents*, or 4*bb* - 4*ph* in *Descents*, be equal to *pp*, there is but one *Elevation* that can hit the *Object*, and its *Tangent* is $^{pr}/_{2b}$. And if 4*bb* + 4*ph* in *Ascents*, or 4*bb* - 4*ph* in *descents*, do {320} exceed *pp*, the *Object* is without the reach of a *Project* cast with that *Velocity*, and so the thing impossible.

From this *Equation* 4*bb* ∓ 4*ph* = *pp* are determined the utmost limits of the reach of any *Project*, and the Figure assigned, wherein are all the *heights* upon each *Horizontal distance* beyond which it cannot pass; for by reduction of that *Equation*, *h* will be found = ¼*p* - $^{bb}/_{p}$ in *heights*, and $^{bb}/_{p}$ - ¼*p* in *descents*; from whence it follows, that all the Points *h* are in the *Curve* of the *Parabola*, whose *Focus* is the Point from whence the *Project* is cast, and whose *Latus rectum*, or *Parameter ad Axem* is = *p*. Likewise from the same *Equation* may the least *Parameter* or *Velocity* be found capable to reach the *Object* proposed; for *bb* = ¼*pp* ∓ *ph* being reduced, ½*p* will be = $\sqrt{bb + hh} \pm h \begin{Bmatrix} \text{in ascents} \\ \text{in descents} \end{Bmatrix}$ which is the *Horizontal Range* at 45 degrees, of a Project cast with the least Velocity that would just reach the *Object*, and the *Elevation* requisite will be easily had; for dividing the so found *Semi-parameter* by the *Horizontal distance* given *b*, the *Quote* into *Radius* will be the *Tangent* of the *Elevation* sought. This Rule may be of good use to all *Bombardiers* and *Gunners*, not only that they may use no more Powder than is necessary, to cast their *Bombs* into the place assigned, but that they may shoot with much more certainty, for that a small Error committed in the *Elevation* of the *Piece*, will produce no sensible Difference in the fall of the Shot: For which Reasons the *French* Engineers in their late Sieges have used Mortar- {321} pieces inclin'd constantly to the *Elevation* of 45, proportioning their Charge of Pouder according to the distance of the *Object* they intend to strike on the Horizon.

And this is all that need to be said concerning this *Problem* of shooting upon *Heights* and *Descents*. But if a *Geometrical* Construction thereof be required; I think I have one that is as easy as can be expected, which I deduce from the foregoing *Analytical Solution*, *viz.* $^{t}/_{r} = {}^{p}/_{2b} \pm \sqrt{\frac{¼pp \pm ph - bb}{bb}}$, and 'tis this, having made the right Angle GDF, (*Tab. 5. Fig. 3.*) make DF = ½*p*, or greatest Range, and GD = *b* the Horizontal Distance, and DB = *h* the perpendicular heighth of the Object; to be laid upwards from D, if the Object be above the Horizon, or downwards if below it. Parallel to GD draw FA, and make it equal to GB the Hypothenusal Distance of the Object; and with the Center A and Radius FB = ½*p* ± *h*, sweep an Arch, which shall if the thing be possible, intersect the indeterminate Perpendicular DF in two Points K and L, to which draw the Lines, GL, GK; I say, the Angles DGK, DGL, are the Elevations requisite to strike the Object B.

Demonstration. The Square of FK or FL, is equal to FB*q* - GB*q*: or $(½p \pm h)^2$ - *bb* - *hh* or ¼*pp* ± *ph* - *bb*, and therefore √ ¼*pp* ± *ph* - *bb* is = FK = FL, and by Consequence DK, DL = ½*p* ± √ ½*pp* {322} ± *ph* - *bb*. And as DG: DK and DL :: Radius: Tangents sought, which coincides with our Algebraical Expression thereof.

Prop. XI. To determine the Force or *Velocity* of a *Project*, in every Point of the *Curve* it describes.

To do this we need no other *Præcognita*, but only the third Proposition, *viz.* That the *Velocity* of *falling Bodies*, is double to that which in the same time, would have described the Space *fallen* by an equable Motion: For the *Velocity* of a Project, is compounded of the constant equal *Velocity* of the impressed Motion, and the *Velocity* of the *Fall*, under a given *Angle*, *viz.* the Complement of the *Elevation*: For Instance, in *Fig. 2.* in the time wherein a Project would move from G to L, it descends from L to X, and by the third *Proposition* has acquired a *Velocity*, which in that time would have carried it by an equable Motion from L to Z, or twice the Descent LX; and drawing the Line GZ, I say, the *Velocity* in the Point X, compounded of the *Velocities* GL and LZ under the Angle GLZ, is to the *Velocity* impress'd in the Point G, as GZ is to GL; this follows from our second *Axiom*, and by the 20 and 21 *Prop. lib. 1. conic. Midorgii*, XO parallel and equal to GZ shall touch the *Parabola* in the Point X. So that the *Velocities* in the several Points, are as the

lengths of the *Tangents* to the *Parabola* in those Points, intercepted between any two *Diameters*: And these again are as the *Secants* of the *Angles*, which those *Tangents* continued make with the *Horizontal* Line GB. From what is here laid down, may the comparative Force of a *Shot* in any {323}
two Points of the *Curve*, be either *Geometrically* or *Arithmetically* discover'd.

Corollary.

From hence it follows, that the force of a Shot is always least at U, or the *Vertex* of the *Parabola*, and that at equal distances therefrom, as at T and X, G and B its force is always equal, and that the least force in U is to that in G and B, as *Radius* to the Secant of the *Angle* of *Elevation* FGB.

These *Propositions* considered, there is no question relating to *Projects*, which, by the help of them, may not easily be Solved; and tho' it be true that most of them are to be met withal, in *Galileus*, *Torricellius* and others, who have taken them from those Authors, yet their Books being Foreign, and not easy to come by, and their *Demonstrations* long and difficult, I thought it not amiss to give the whole *Doctrine* here in *English*, with such short *Analytical* Proof of my own, as might be sufficient to evince their Truth.

The Tenth *Proposition* contains a *Problem*, untouch'd by *Torricellius*, which is of the greatest use in *Gunnery*, and for the sake of which this *Discourse* was principally intended: It was first Solved by Mr. *Anderson*, in his Book of the Genuine Use and Effects of the *Gun*, Printed in the Year 1674; but his Solution required so much Calculation, that it put me upon search, whether it might not be done more easily, and thereupon in the Year 1678 I found out the Rule I now Publish, and from it the *Geometrical* Construction: Since which time there has a large *Treatise* of this Subject, Intituled, *L'Art dejetter les Bombes*, been Published by *Monsieur Blondel*, wherein {324}
he gives the Solutions of this *Problem* by *Messieurs Buot*, *Romer* and *de la Hire*: But none of them being the same with Mine, or, in my Opinion, more easy, and most of them more Operose, and besides mine finding the *Tangent*, which generally determines the *Angle* better than its *Sine*, I thought my self obliged to Print it for the use of all such, as desire to be informed in the *Mathematical* part of the Art of *Gunnery*.

Now these Rules were rigidly true, were it not, as I said before, for the Opposition of the Medium, whereby not only the direct imprest Motion is continually retarded, but likewise the increase of the *Velocity* of the *Fall*, so that the Spaces described thereby, are not exactly as the Squares of the Times: But what this Opposition of the *Air* is, against several *Velocities*, *Bulks*, and *Weights*, is not so easie to determine. 'Tis certain that the weight of *Air* to that of *Water*, is nearly as 1 to 800, whence the weight thereof, to that of any *Project* is given; 'tis very likely, that to the same *Velocity* and *Magnitude*, but of different Matter, the *Opposition* should be *reciprocally* as the weights of the Shot; as likewise that to Shot of the same *Velocity* and Matter, but of different *Sizes*, it should be as the *Diameters reciprocally*: Whence generally the *Opposition* to Shot with the same *Velocity*, but of differing *Diameters*, and *Materials*, should be as their *Specifick Gravities* into their *Diameters reciprocally*; but whether the *Opposition*, to differing *Velocities* of the same Shot, be as the *Squares* of those *Velocities*, or as the *Velocities* themselves, or otherwise, is yet a harder Question. However it be, 'tis certain, that in large Shot of *Metal*, whose {325}
weight many Thousand times surpasses that of the *Air*, and whose force is very great, in proportion to the *Surface* wherewith they press thereon; this *Opposition* is scarce discernable; For by several *Experiments* made with all Care and Circumspection with a *Mortarpiece*, Extraordinary well fix'd to the Earth on purpose, which carried a solid Brass Shot of four Inches and a half *Diameter*, and of about fourteen Pound Weight, the *Ranges* above and below forty five *Degrees* were found nearly equal; if there were any difference, the under *Ranges* went rather the farthest, but those differences were usually less than the Errors committed in ordinary Practice, by the unequal Goodness and Dryness of the same sort of Powder, by the Unfitness of the Shot to the Bore, and by the Loosness of the Carriage.

In a smaller Brass-Shot of about an Inch and half Diameter, cast by a Cross-Bow which ranged it, at most about four Hundred Foot, the Force being much more equal than in the Mortarpiece, this difference was found more Curiously: and Constantly and most Evidently, the under Ranges out-went the upper. From which Trials I conclude, that although in small and light Shot, the Opposition of the Air, ought and must be accounted for; yet in Shooting of great and weighty Bombs, there need be very little or no allowance made; and so these Rules may be put in practice to all Intents and Purposes, as if this Impediment were absolutely remov'd.

A Proposition of general Use in the Art of Gunnery, shewing the Rule of laying a Mortar to pass, in order to strike an Object above or below the Horizon. {326}

It was formerly the Opinion of those concerned in Artillery, that there was a certain requisite of Powder for each Gun, and that in Mortars, where the distance was to be varied, it must be done by giving a greater or lesser Elevation to the Piece. But now our later Experience has taught us that the same thing may be more certainly and readily performed by increasing and diminishing the quantity of Powder, whether regard be had to the Execution to be done, or to the Charge of

doing it. For when Bombs are discharged with great Elevations of the Mortar, they fall too Perpendicular, and bury themselves too deep in the Ground, to do all that damage they might, if they came more Oblique, and broke upon or near the Surface of the Earth; which is a thing acknowledg'd by the Besieged in all Towns, who unpave their Streets, to let the Bombs bury themselves, and thereby stifle the force of their Splinters. A Second Convenience is, that at the extream Elevation, the Gunner is not obliged to be so curious in the direction of his Piece, but it will suffice to be within a Degree or two of the Truth; whereas in the other Method of Shooting he ought to be very curious. But a Third, and no less considerable Advantage is, in the saving the Prince's Powder, which in so great and so numerous Discharges, as we have lately seen, must needs amount to a considerable Value. And for Sea-Mortars, it is scarce practicable otherwise to {327} use them, where the agitation of the Sea continually changes the Direction of the Mortar, and would render the Shot very uncertain, were it not that they are placed about 45 Degrees Elevation, where several Degrees above or under, make very little difference in the Effect.

In the precedent Discourse, I considered all the Propositions relating to the Motion of Projectiles, and gave a Solution to this Problem; *viz. To hit an Object above or below the Horizontal Line with the greatest Certainty and least Force.* That is, that the Horizontal distance of the Object being put = *b*, and the Perpendicular Heighth = *b*, the Charge requisite to strike the Object with the greatest Advantage, was that which with an Elevation of 45° would cast the Shot on the Horizontal Line, to the distance of $\sqrt{bb+hh}$, when the Object was above the Horizon; or if it were below it, the Charge must be lesser, so as to reach on the Horizon, at 45° Elevation, no greater a Distance than $\sqrt{bb+hh}-h$; that is, in the one Case, the Sum of the Hypothenusal Distance of the Object from the Gun, and the Perpendicular Heighth thereof above the Gun; and in the other Case, when the Object is below the Horizon, the difference of the same *per* 47. I *Eucl.* And I then shew'd how to find the Elevation proper for the Gun so charged, *viz.* As the Horizontal Distance of the Object, to the Sum or Difference of the Hypothenusal Distance and Perpendicular Height: So Radius to the Tangent of the Elevation sought. But I was not at that time aware that the aforesaid Elevation did constantly bisect the Angle between the {328} Perpendicular and the Object, as is demonstrated from the Difference and Sum of the *Tangent* and *Secant* of any Arch being always equal to the *Tangent* and *Cotangent* of the half Complement thereof to a Quadrant. Having discovered this, I think nothing can be more compendious, or bids fairer to compleat the Art of Gunnery, it being as easie to shoot with a Mortar at any Object on demand, as if it were on the Level; neither is there need of any Computation, but only simply laying the Gun to pass, in the middle Line between the Zenith and the Object, and giving it its due Charge. Nor is there any great need of Instruments for this purpose: For if the Muzzle of the Mortar be turned truly Square to the Bore of the Piece, as it usually is or ought to be, a piece of Looking-glass Plate applied parallel to the Muzzle, will by its Reflection give the true Position of the Piece, the Bombardeer having no more to do, but to look perpendicularly down on the Looking-glass, along a small Thread with a Plumbet, and to raise or depress the Elevation of the Piece, till the Object appear reflected on the same Point of the *Speculum*, on which the Plumbet falls; for the Angle of Incidence and Reflection being equal, in this Case a Line at Right Angles to the *Speculum*, as is the *Axis* of the Chase of the Piece, will bisect the Angle between the Perpendicular and the Object, according as our Proposition requires. So that it only remains by good and valid Experiments to be assured of the Force of Gunpowder, how to make and conserve it equal, and to know the Effect thereof in each Piece; that is, how far differing Charges will cast the same Shot out of it; which may most conveniently be engraven on the outside thereof, as a {329} standing Direction to all Gunners, who shall from thence forward have occasion to use that Piece: And were this Matter well ascertained, it might be worth the while to make all Mortars of the like Diameter as near as may he, alike in length of Chase, Weight, Chamber, and all other Circumstances.

This Discovery that the utmost Range on an inclined Plane, is, when the *Axis* of the Piece makes equal Angles with the Perpendicular and the Object; compared with what I have demonstrated of the same Problem in the aforesaid Discourse does lead to and discover two very ready Theorems; the one, to find the greatest Horizontal Range at 45° Elevation, by any Shot made upon any inclined Plane, with any Elevation of the Piece whatsoever: And the other to find the Elevations proper to strike a given Object, with any Force greater than what suffices to reach it with the aforesaid middle Elevation. Both which being performed by one single Proportion, may be very serviceable to such as are concerned in the Practice of Gunnery, but are unwilling to trouble themselves with tedious and difficult Rules. The two Propositions are these.

P R O P. I.

A Shot being made on an inclined Plane, having the Horizontal Distance of the Object it strikes, with the Elevation of the Piece, and the Angle at the Gun between the Object and the Perpendicular; to find the greatest Horizontal Range of that Piece, laden with the same Charge; {330} that is, half the *Latus rectum* of all the *Parabolæ* made with the same *Impetus*.

R U L E.

Take half the Distance of the Object from the *Nadir*, and take the Difference of the given

Elevation from that half; the Versed Sine of twice that Difference subtract from the Versed Sine of the Distance of the Object from the *Zenith*: Then shall the Difference of those Versed Sines be to the Sine of the Distance of the Object from the *Zenith*, as the Horizontal Distance of the Object strook, to the greatest Horizontal Range at 45°.

P R O P. II.

Having the greatest Horizontal Range of a Gun, the Horizontal Distance and Angle of Inclination of an Object to the Perpendicular, to find the two Elevations necessary to strike that Object.

R U L E.

Halve the Distance of the Object from the *Nadir*; this half is always equal to the half Sum of the two Elevations we seek. Then say, *As the greatest Horizontal Range is to the Horizontal Distance of the Object: So is the Sine of the Angle of Inclination or Distance of the Object from the Perpendicular, to a fourth Proportional; which fourth being subtracted from the Versed Sine of the Distance of the Object from the* Zenith*, leaves the Versed Sine of the Difference of the Elevations sought; which Elevations are therefore had by adding and subtracting the half Difference to and from the aforesaid half Sum.* {331}

I shall not need to speak of the Facility of these Solutions, I shall only observe that they are both General, without Exception or Caution, and derived from the Knowledge that these two Elevations are equidistant above and below the Line, bisecting the Angle between the Object and the *Zenith*.

{332}

A Discourse concerning the Measure of the Airs Resistance to Bodies moved in it. By the Learned John Wallis*, S. T. D. and R. S. S.*

THAT the Air (and the like of any other *Medium*) doth considerably give Resistance to Bodies moved in it; and doth thereby abate their Celerity and Force; is generally admitted. And Experience doth attest it: For otherwise, a Cannon Bullet projected Horizontally, should (supposing the Celerity and Force undiminished) strike as hard against a Perpendicular Wall, erected at a great distance, as near at hand; which we find it doth not.

2. But at what Rate, or in what Proportion, such Resistance is; and (consequently, at what Rate the Celerity and Force is continually diminished) seems not to have been so well examined. Whence it is, that the Motion of a Project (secluding this Consideration) is commonly reputed to describe a Parabolick Line; as arising from an Uniform or equal Celerity in the Line of Projection, and a Celerity uniformly accelerated in the Line of Descent; which two so compounded, do create a Parabola.

3. In order to the Computation hereof, I first premise this *Lemma*, (as the most rational that doth occur for my first footing,) That (supposing other things equal) the Resistance is proportional to the Celerity. For in a double Celerity, there is to be removed (in the same time) twice as much Air, (which is a double Impediment) in a treble, thrice as much; and so in other Proportions. {333}

4. Suppose we then the Force impressed (and consequently the Celerity, if there were no Resistance) as 1; the Resistance as *r*. (which must be less than the Force, or else the Force would not prevail over the Impediment, to create a Motion.) And therefore the effective Force at a first Moment, is to be reputed as 1 - *r*: That is, so much as the Force impressed, is more than the Impediment or Resistance.

5. Be it as 1 - *r* to 1; so one to *m*. (which *m* is therefore greater than 1.)

6. And therefore the effective Force (and consequently the Celerity) as to a first Moment, is to be $\frac{1}{m}$ of what it would be, had there been no Resistance.

7. This $\frac{1}{m}$ is also the remaining Force after such first Moment; and this remaining Force is (for the same Reason) to be proportionally abated as to a second Moment; that is, we are to take $\frac{1}{m}$ thereof, that is $\frac{1}{mm}$ of the impressed Force. And for a third Moment (at equal distance of time) $\frac{1}{mmm}$; for a fourth $\frac{1}{m^4}$; and so onward infinitely.

8. Because the length dispatched (in equal times) is proportional to the Celerities; the Lines of Motion (answering to those equal Times) are to be as $\frac{1}{m}$, $\frac{1}{m^2}$, $\frac{1}{m^3}$, $\frac{1}{m^4}$, *&c.* of what they would have been, in the same Times, had there been no Resistance. {334}

9. This therefore is a Geometrical Progression; and (because of *m* greater than 1) continually decreasing.

10. This decreasing Progression infinitely continued (determining in the same Point of Rest,

where the Motion is supposed to expire) is yet of a finite Magnitude; and equal to $\frac{1}{m-1}$, of what it would have been in so much Time, if there had been no Resistance. As is demonstrated in my Algebra, *Chap.* 95. *Prop.* 8. For (as I have elsewhere demonstrated) the Sum or Aggregate of a Geometrical Progression is $\frac{VR-A}{R-1}$ (supposing V the greatest Term, A the least, and R the common Multiplier.) That is $\frac{VR}{R-1}$ - $\frac{A}{R-1}$. Now in the present Case, (supposing the Progression infinitely continued) the least Term A, becomes infinitely small, or = 0. And consequently $\frac{A}{R-1}$ doth also vanish, and thereby the Aggregate becomes = $\frac{VR}{R-1}$. That is (as will appear by dividing VR by R - 1;) $V + {}^{V}\!/_{R} + {}^{V}\!/_{RR} + {}^{V}\!/_{R^3}$ + &c. = $\frac{VR}{R-1}$[14]; (supposing the Progression to begin at V = 1.) That is (dividing all by R, that so the Progression may begin at ${}^{V}\!/_{R} = {}^{1}\!/_{m}$:) $\frac{V}{R-1} = {}^{V}\!/_{R} + {}^{V}\!/_{RR} + {}^{V}\!/_{R^3}$ + &c., That is, in our present Case (because of V = 1, & $R = m$:) ${}^{1}\!/_{m} + {}^{1}\!/_{mm} + {}^{1}\!/_{m^3}$ &c. = $\frac{1}{m-1}$. That is, (putting $n = m - 1$) ${}^{1}\!/_{n}$ of what it would have been if there had been no Resistance. {335}

11. This infinite Progression is fitly expressed by an Ordinate in the Exterior Hyperbola, parallel to one of the Asymptotes; and the several Members of that, by the several Members of this, cut in continual Proportion. As is there demonstrated at *Prop.* 15. For let *SH*, (*vid.* Fig. 4. Tab. 5.) be an Hyperbola between the Asymptotes *AB*, *AF*: And let the Ordinate *DH* (in the Exterior Hyperbola, parallel to *AF*,) represent the impressed Force undiminished; or the Line to be described in such time, by a Celerity answerable to such undiminished Force. And let *BS* (a like Ordinate) be ${}^{1}\!/_{m}$ thereof; which therefore, being less than *DH* (as being equal to a Part of it) will be farther than it from *AF*. In *AB* (which I put = 1) let *Bd* be such a Part thereof, as is *BS* of *DH*. Now because (as is, well known) all the inscribed Parallelograms, in the Exterior Hyperbola, *AS*, *AH*, *&c.* are equal; and therefore their sides reciprocal: Therefore as $Ad = 1 - {}^{1}\!/_{m}$ (supposing *Bd* to be taken, from *B* towards *A*,) to $AB = 1$, or as $m - 1$ to m: so is $BS = {}^{1}\!/_{m}DH$, to *dh*, which is therefore equal to $\frac{1}{m-1}$ of *DH*; that is (as will appear by dividing 1, by $m - 1$,) to ${}^{1}\!/_{m} + {}^{1}\!/_{mm} + {}^{1}\!/_{m^3}$, *&c.* of *DH*.[15] {336}

Or if *Bd* be taken beyond *B*; then as $Ad = 1 + {}^{1}\!/_{m}$ to $AB = 1$, or as $m + 1$ to m, so is ${}^{1}\!/_{m}$ *DH* to *dh*, which is therefore equal to $\frac{1}{m+1}$DH; that is (as will appear by like dividing of 1 by $m + 1$;) = to ${}^{1}\!/_{m} - {}^{1}\!/_{mm} + {}^{1}\!/_{m^3}$ - *&c.* of *DH*.

12. Let such ordinate *dh*, or (equal to it in the Asymptote) *AF*, be so divided in *L*, *M*, *N*, *&c.* (by Perpendiculars cutting the Hyperbola in *l*, *m*, *n*, *&c.*) as that *FL*, *LM*, *MN*, be as ${}^{1}\!/_{m}$, ${}^{1}\!/_{mm}$, ${}^{1}\!/_{m^3}$, *&c.* That is, so continually decreasing as that each Antecedent be to its Consequent, as 1 to ${}^{1}\!/_{m}$, or as m to 1. See *Fig. 5. Tab. 5.* {337}

13. This is done by taking *AF*, *AL*, *AN*, *&c.* in such proportion. For, of continual Proportionals, the Differences are also continually proportional, and in the same proportion. For let *A*, *B*, *C*, *D*, *&c.* be such Proportionals, and their Differences *a*, *b*, *c*, *&c.* That is, $A - B = a$, $B - C = b$, $C - D = c$, *&c.*

Then, because A, B, C, D, *&c.* are in continual proportion,
That is, A. B :: B. C :: C. D :: *&c.*
And dividing (A - B). B :: (B - C). C :: (C - D). D :: *&c.*
That is, *a*. B :: *b*. C :: *d*. D :: *&c.*
And alternly *a. b. c. &c.* :: B. C. D. *&c.* :: A. B. C. *&c.*
That is, in continual proportion as A to B, or as m to 1.

14. This being done; the Hyperbolick Spaces *Fl*, *Lm*, *Mn*, &c. are equal. As is demonstrated by *Gregory San-Vincent*; and as such is commonly admitted.

15. So that *Fl*, *Lm*, *Mn*, *&c.* may fitly represent equal Times, in which are dispatched unequal Lengths, represented by *FL*, *LM*, *MN*, *&c.*

16. And because they are in Number infinite (though equal to a finite Magnitude) the Duration is infinite: And consequently the impressed Force, and Motion thence arising, never to be wholly extinguished (without some further Impediment) but perpetually approaching to *A*, in the Nature of Asymptotes. {338}

17. The Spaces *Fl*, *Fm*, *Fn*, &c. are therefore as Logarithms (in Arithmetical Progression increasing) answering to the Lines *AF*, *AL*, *AM*, &c. or to *FL*, *LM*, *MN*, &c. in Geometrical Progression decreasing.

18. Because *FL*, *LM*, *MN*, &c. are as ${}^{1}\!/_{m}$, ${}^{1}\!/_{mm}$, ${}^{1}\!/_{m^3}$, &c. (infinitely) terminated at *A*; therefore

(by ¶ 10) their Aggregate *FA* or *dh*, is to *DH*, (so much Length as would have been dispatched, in the same time, by such impressed Force undiminished) as 1 to $m - 1 = n$.

19. If therefore we take, as 1 to *n*, so *AF* to *DH*; this will represent the Length to be dispatched, in the same time, by such undiminished Force.

20. And if such *DH* be supposed to be divided into equal Parts innumerable (and therefore infinitely small;) these answer to those (as many) Parts unequal in *FA*, or *hd*.

21. But, what is the Proportion of *r* to 1, or (which depends on it) of 1 - *r* to 1, or 1 to *m*; remains to be inquired by Experiment?

22. If the Progression be not infinitely continued; but end (suppose) at *N*, and its least Term be $A = MN$; then, out of $\frac{V}{R-1} = {}^{1}\!/_{m} + {}^{1}\!/_{mm} + {}^{1}\!/_{m^3}$, *&c.* is to be subducted $\frac{A}{R-1}$ (as at ¶ 10.) that is (as by Division will appear) ${}^{A}\!/_{R} + {}^{A}\!/_{R^2} + {}^{A}\!/_{R^3}$ &c. That is (in our present Case) ${}^{a}\!/_{m} + {}^{a}\!/_{mm} + {}^{a}\!/_{m^3}$ &c. And so the Aggregate will be $\frac{1-a}{m} + \frac{1-a}{mm} + \frac{1-a}{mmm}$ &c. $= \frac{1-a}{n}$. {339}

And thus as to the Line of Projection, in which (secluding the Resistance) the Motion is reputed uniform; dispatching equal Lengths in equal Times. Consider we next the Line of Descent.

23. In the Descent of Heavy Bodies, it is supposed that to each Moment of Time, there is superadded a new Impulse of Gravity to what was before: And each of these, secluding the Consideration of the Air's Resistance, to proceed equally (from their several beginnings) through the succeeding Moments. As (in the erect Lines) 1 1 1 1, *&c.* 1 1 1, *&c.* 1 1, *&c.* 1, *&c.* and so continually, as in the Line of Projection.[16]

24. Hence ariseth (in the transverse Lines) for the first Moment 1, for the second 1 + 1, for the third 1 + 1 + 1, and so forth, in Arithmetical Progression: As are the Ordinates in a Triangle, at equal distance.

25. And such are the continual Increments of the Diameter, or of the Ordinates in the exterior Parabola, answering to the interior Ordinates, or Segments of the Tangent, equally increasing; as is known, and commonly admitted.

26. If we take in the Consideration of the Air's Resistance; we are then, for each of these equal Progressions, to substitute a decreasing Progression Geometrical; in like manner (and for the same Reasons) as in the Line of Projection. {340}

27. Hence ariseth, for the first Moment ${}^{1}\!/_{m}$; for the second ${}^{1}\!/_{m} + {}^{1}\!/_{m^2}$; for the third ${}^{1}\!/_{m} + {}^{1}\!/_{m^2} + {}^{1}\!/_{m^3}$, *&c.*[17] And such is therefore the Descent of a heavy Body falling by its own weight. The several Impulses of Gravity being supposed equal.

28. That is (in the Figure of ¶ 12) as *FL*, *FM*, *FN*, &c. in the Line of Descent, answering to *FL*, *LM*, *MN*, &c. in the Line of Projection.

29. But though the Progressions for the Line of Projection, are like to each of those many in the Line of Descent; it is not to be thence inferred, that therefore ${}^{1}\!/_{m}$ in the one, is equal to ${}^{1}\!/_{m}$ in the other: But in the Line of Projection (suppose) ${}^{1}\!/_{m}\,f$ (such a Part of the Force impressed, and a Celerity answerable:) in the Line of Descent, ${}^{1}\!/_{m}\,g$ such a Part of the Impulse of Gravity.

30. Those for the Line of Descent (of the some Body) are all equal, each to other: Because *g* (the new Impulse of Gravity) in each Moment is supposed to be the same. {341}

31. But what is the Proportion of *f* to *g* (that of the Force impressed, to the Impulse of Gravity in each Body) remains to be inquired by Experiment.

32. This Proportion being found as to one known Force; the same is thence known as to any other Force (whose Proportion to this is given) in the same uniform *Medium*.

33. And this being known, as to one *Medium*; the same is thence known as to any other *Medium*, the Proportion of whose Resistance to that of this is known.

34. If a heavy Body be projected downward in a perpendicular Line; it descends therefore at the Rate ${}^{1}\!/_{m}$, ${}^{1}\!/_{mm}$, ${}^{1}\!/_{m^3}$, *&c.* of *f*, (the impressed Force) increased by ${}^{1}\!/_{m}$, ${}^{1}\!/_{m} + {}^{1}\!/_{m^2}$, ${}^{1}\!/_{m} + {}^{1}\!/_{m^2} + {}^{1}\!/_{m^3}$, *&c.* of *g* the impulse of Gravity, (by ¶ 7, and ¶ 27) Because both Forces are here united.

35. If in a perpendicular Projection upwards; it ascends in the rate of the former, abated by that of the latter. Because here the impulse of Gravity is contrary to the Force impressed.

36. When therefore this latter (continually increasing) becomes equal to that former (continually decreasing) it then ceaseth to ascend; and doth thenceforth descend at the rate wherein the latter continually exceeds the former.

37. In an Horizontal, or Oblique Projection: If to a Tangent, whose Increments are as *FL*, *LM*, {342}

MN, &c. that is as $^1/_m f$, &c. be fitted Ordinates (at a given Angle) whose Increments are as *FL*, *FM*, *FN*, &c. that is, as $^1/_m g$, &c. The Curve answering to the Compound of these Motions, is that wherein the Project is to move.

38. This Curve (being hitherto without a Name) may be call'd *Linea Projectorum*; the Line of Projects, or things projected; which resembles a Parabola deform'd.

39. The Celerity and Tendency, as to each Point of this Line, is determined by a Tangent at that Point.

40. And that against which it makes the greatest Stroke or Percussion, is that which (at that Point) is at right Angles to that Tangent.

41. If the Projection (at ¶ 27) be not infinitely continued, but terminate (suppose) at *N*, so that the last Term in the first Column or Series erect be *a*; and consequently in the second, *ma*; in the third, *mma*, &c. (each Series having one Term fewer than that before it:) Then (for the same Reasons, as at ¶ 22) the Aggregates of the several Columns (or erect Series) will be $\frac{1-a}{n}$, $\frac{1-ma}{n}$, $\frac{1-mma}{n}$, and so forth, till (the Multiple of *a* becoming = 1) the Progression expire.

42. Now all the Abatements here, *a*, *ma*, *mma*, &c. are the same with the Terms of the first Column taken backward. For *a* is the last, *ma* the next before it; and so of the rest.

43. And the Aggregate of all the Numerators is so many times 1, as is the Number of Terms {343} (suppose *t*,) wanting the first Column; that is $t - \frac{1-a}{n}$, or $\frac{nt-1+a}{n}$; and this again divided by the common Denominator *n*, becomes $\frac{nt-1+a}{nn}$. And therefore $\frac{nt-1+a}{nn} g$, is the Line of Descent by its own Gravity.

44. If therefore this be added to a projecting Force downward in a Perpendicular; or subducted from such projecting Force upward; that is, to or from $\frac{1-a}{n} f$: The Descent in the first Case will be $\frac{1-a}{n} f + \frac{nt-1+a}{nn} g$; and the Ascent in the other Case $\frac{1-a}{n} f - \frac{nt-1+a}{nn} g$. And in this latter Case, when the ablative Part becomes equal to the positive Part, the Ascent is at the highest; and thenceforth (the ablative Part exceeding the positive) will descend.

45. In an Horizontal or Oblique Projection, having taken $\frac{1-a}{n} f$, in the Line of Projection, and thence (at the Angle given) $\frac{nt-1+a}{nn} g$, in the Line of Descent; the Point in the Curve answering to these, is the Place of the Project answering to that Moment.

46. I am aware of some Objections to be made, whether to some Points of the Process, or to {344} some of the Suppositions. But I saw not well how to wave it, without making the Computation much more perplex'd. And in a Matter so nice, and which must depend upon Physical Observations, 'twill be hard to attain such Accuracy, as not to stand in need of some Allowances.

47. Somewhat might have been farther added to direct the Experiments suggested at ¶ 21, and 31. But that may be done at leisure, after deliberation had, which way to attempt the Experiment.

48. The like is to be said of the different resistance which different Bodies may meet with in the same *Medium*, according to their different Gravities (extensively or intensively consider'd) and their different Figures and Positions in Motion. Whereof we have hitherto taken no account; but supposed them, as to all these, to be alike and equal.

P O S T S C R I P T.

49. The Computation in ¶ 41, 42, 43, may (if that be also desired) be thus represented by Lines and Spaces. The Ablatives *a*, *ma*, *mma*, &c. (being the same with the first Column taken backward) are fitly represented by the Segments of *NF* (beginning at *N*) in Figure 5 and 6, and therefore by Parallelograms on these Bases, assuming the common height of *Fh*, or *NQ*; the Aggregate of which is *Nh*, or *FQ*. And, so many times 1, by so many equal Spaces, on the same Bases, between the same Parallels, terminated at the Hyperbola: The Aggregate of which is {345} *hFNQn*. From whence if we subduct the Aggregate of Ablatives *FY*; the remaining Trilinear *hQn*, represents the Descent.

50. If to this of Gravity, be joined a projecting Force; which is to the Impulse of Gravity as *hK* to *hF* (be it greater, less, or equal) taken in the same Line; the same Parallels determine proportional Parallelograms, whose Aggregate is *KQ*.

51. And therefore if this be a perpendicular Projection downwards; then *hKkn* (the Sum of this with the former) represents the Descent.

52. If it be a Perpendicular upwards; then the difference of these two represents the Motion; which so long as *KQ* is the greater, is Ascendent; but Descendent, when *hQn* becomes greater; and it is then at the highest when they be equal.

53. If the Projection be not in the same Perpendicular, (but Horizontal, or Oblique) then *KQ* represents the Tangent of the Curve; and *hQn* the Ordinates to that Tangent, at the given Angle.

54. But the Computation before given, I take to be of better use than this Representation in Figure. Because in such Mathematical Enquiries, I choose to separate (as much as may be) what purely concerns Proportions; and consider it abstractly from Lines, or other Matter wherewith it is incumbred.

As to the Question proposed; whether the resistance of the *Medium* do not always take off such a proportional part of the Force moving through it, as is the specifick Gravity of the *Medium* to that of the Body moved in it: (For, if so, it will save us the trouble of Observation.) {346}

I think this can by no means be admitted. For there be many other things of Consideration herein, beside the intensive Gravity (or, as some call it, the specifick Gravity) of the *Medium*.

A viscous *Medium* shall more resist, than one more fluid, though of like intensive Gravity.

And a sharp Arrow shall bore his way more easily through the *Medium*, than a blunt-headed Bolt, though of equal Weight, and like intensive Gravity.

And the same Pyramid with the Point, than with the Base forward.

And many other like Varieties, intended in my ¶ 48.

But this I think may be admitted, namely, That different *Mediums*, equally liquid, (and other Circumstances alike,) do in such proportion resist, as is their intensive Gravity. Because there is, in such proportion, a heavier Object to be removed, by the same Force. Which is one of the things to which ¶ 33 refers.

And again: The heavier Project once in Motion, (being equally swift, and all other Circumstances alike) moves through the same *Medium* in such proportion more strongly, as is its intensive Gravity. For now the Force is in such proportion greater, for the removal of the same resistance. And this Part of what my ¶ 32, insinuates.

But where there is a Complication of these Considerations one with another, and with many other Circumstances, whereof each is severally to be considered; there must be respect had to all of them. {347}

[14]

R - 1 *V*) *R* (*V* + *V/R*, *V/RR*, &c.

VR - V
+ V
+ V/VR
+ V/R
+
VV/RRR
+ V/RR
&c.

[15]

m - 1) 1 (1/*m* + 1/*mm* + 1/*m*^{3} + &c.

1 - 1/*m*
+ 1/*m*
+ 1/*m* - 1/*mm*
+
1/*mm*
+
1/*mm* - 1/*mmm*
+
1/*mmm*
&c.

[16]

1
1 1
1 1 1
1 1 1 1
&c.

[17]

1/*m*
1/*m*^{2} 1/*m*
1/*m*^{3} 1/*m*^{2} 1/*m*
1/*m*^{4} 1/*m*^{3} 1/*m*^{2} 1/*m*

{348}

An Instance of the Excellence of the Modern Algebra*, in the Resolution of the Problem of finding the* Foci *of Optick Glasses Universally. By* E. Halley*, S. R. S.*

THE Excellence of the *Modern Geometry* is in nothing more evident, than in those full and adequate Solutions it gives to Problems; representing all the possible Cases at one view, and in one general Theorem, many times comprehending whole Sciences; which deduced at length into Propositions, and demonstrated after the manner of the *Ancients*, might well become the Subjects of large Treatises: For whatsoever Theorem solves the most complicated Problem of the kind, does with a due Reduction reach all the subordinate Cases. Of this I now design to give a notable Instance in the Doctrine of *Dioptricks*.

This Dioptrick Problem is that of finding the *Focus* of any sort of *Lens*, exposed either to converging, diverging, or parallel Rays of Light, proceeding from, or tending to a given Point in the *Axis* of the *Lens*, be the *Ratio* of *Refraction* what it will, according to the Nature of the transparent Material whereof the *Lens* is formed, and also with allowance for the thickness of the *Lens* between the *Vertices* of the two Spherical Segments. This Problem being solved in one {349} Case, *mutatis mutandis*, will exhibit Theorems for all the possible Cases, whether the *Lens* be *Double-Convex* or *Double-Concave*, *Plano-Convex*, or *Plano-Concave*, or *Convexo-Concave*, which sort are usually call'd *Menisci*. But this only to be understood of those Beams which are nearest to the *Axis* of the *Lens*, so as to occasion no sensible difference by their Inclination thereto; and the *Focus* here formed, is by *Dioptrick Writers* commonly call'd the principal *Focus*, being that of use in *Telescopes* and *Microscopes*.

Let then (in *Fig. 7. Tab. 5.*) BEβ be a double Convex *Lens*, C the Center of the Segment EB, and K the Center of the Segment Eβ, Bβ the thickness of the *Lens*, D a Point in the *Axis* of the *Lens*; and it is required to find the Point F, at which the Beams proceeding from the Point D, are collected therein, the *Ratio* of Refraction being as *m* to *n*. Let the distance of the Object DB = DA = *d* (the Point A being supposed the same with B, but taken at a distance therefrom, to prevent the coincidence of so many Lines) the *Radius* of the Segment towards the Object CB or CA = *r*, and the *Radius* of the Segment from the Object Kβ or K = ρ; and let Bβ the thickness of the *Lens* be = *t*, and then let the Sine of the Angle of Incidence DAG be to the Sine of the refracted Angle HAG or CAφ as *m* to *n*: And in very small Angles, the Angles themselves will be in the same proportion; whence it will follow that,

As *d* to *r*, so the Angle at C to the Angle at D, and *d* + *r* will be as the Angle of Incidence GAD; {350} and again as *m* to *n*, so *d* + *r* to $\frac{dn + rn}{m}$, which will be as the Angle GAH = CAφ; This being taken from ACD which is as *d*, will leave $\frac{m - nd - nr}{m}$ analogous to the Angle AφD; and the Sides being in this Case proportional to the Angles they subtend, it will follow, that as the Angle AφD is to the Angle ADφ, so is the Side AD or BD to Aφ or Bφ: That is, Bφ will be = $\frac{mdr}{m - nd - nr}$, which shews in what Point the Beams proceeding from D, would be collected by means of the first Refraction; but if *nr* cannot be subtracted from *m* - *nd*, it follows that the Beams after Refraction do still pass on diverging, and the Point φ is on the same side of the *Lens* beyond D. But if *nr* be equal to *m* - *nd*, then they proceed parallel to the *Axis*, and the Point φ is infinitely distant.

The Point φ being found as before, and Bφ - Bβ being given, which we will call δ, it follows by a Process like the former, that βF, or the focal Distance sought, is equal to $\frac{\delta\rho n}{m - \delta + m\rho} = f$. And in the room of δ substituting Bφ - Bβ = $\frac{mdr}{m - nd - nr}$ - *t*, putting *p* for $\frac{n}{m - n}$, after due Reduction this following Equation will arise, $\frac{mpdr\rho - nd\rho t + npr\rho t}{mdr + md\rho - mpr\rho - m - ndt + nrt} = f$. {351} Which Theorem, however it may seem operose, is not so, considering the great Number of *Data* that enter the Question; and that one half of the Terms arise from our taking in the thickness of the *Lens*, which in most Cases can produce no great Effect; however it was necessary to consider it, to make our Rule perfect. If therefore the *Lens* consist of *Glass*, whose Refraction is as 3 to 2 'twill be $\frac{6dr\rho - 2d\rho t + 4r\rho t}{3dr + 3d\rho - 6r\rho - dt + 2rt} = f$. If of *Water*, whose Refraction is as 4 to 3, the Theorem will stand thus $\frac{12dr\rho - 3d\rho t + 9r\rho t}{4dr + 4d\rho - 12r\rho - dt + 3rt} = f$. If it could be made of *Diamant*, whose Refraction is as 5 to 2, it would be $\frac{{}^{10}\!/_{3}dr\rho - 2d\rho t + {}^{4}\!/_{3}r\rho t}{5dr + 5d\rho - {}^{10}\!/_{3}r\rho - 3dt + 2rt} = f$. And this is the universal Rule for the *Foci* of double Convex Glasses exposed to diverging Rays. But if the thickness of the *Lens* be rejected, as not sensible, the Rule will be much shorter, *viz.* $\frac{pdr\rho}{dr + d\rho - prt} = f$, or in Glass $\frac{2dr\rho}{dr + d\rho - 2r\rho} = f$, all the Terms wherein *t* is found being omitted, as equal to nothing. In this Case, if *d* be so small, as that 2*r*ρ exceed *dr* + *d*ρ, then will it be - *f*, or the *Focus* will be Negative, which shews that the Beams after both Refractions still proceed diverging.

To bring this to the other Cases, as of converging Beams, or of Concave Glasses, the Rule is {352} ever composed of the same Terms, only changing the Signs of + and -; for the distance of the Point of Concourse of converging Beams, from the Point B, or the first Surface of the *Lens*, I call a negative Distance or - *d*; and the Radius of a Concave *Lens* I call a negative Radius, or - *r* if it be the first Surface, and - ρ if it be the second Surface. Let then converging Beams fall on a double

Convex of Glass, and the Theorem will stand thus $\frac{-2dr\rho}{-dr-d\rho-2rt} = +f$, which shews that in this Case the *Focus* is always affirmative.

If the *Lens* were a *Meniscus* of Glass, exposed to diverging Beams, the Rule is $\frac{-2dr\rho}{-dr+d\rho+2r\rho} = f$, which is affirmative when $2r\rho$ is less than $dr - d\rho$ otherwise negative: But in the Case of converging Beams falling on the same *Meniscus*, 'twill be $\frac{+2dr\rho}{+dr-d\rho+2r\rho} = f$, and it will be $+f$, whilst $d\rho - dr$ is less than $2r\rho$; but if it be greater than $2r\rho$, it will always be found negative or $-f$. If the *Lens* be double Concave, the *Focus* of converging Beams is negative, where it was affirmative in the Case of diverging Beams on a double Convex, *viz.* $\frac{-2dr\rho}{+dr+d\rho-2r\rho} = f$, which is affirmative only when $2r\rho$ exceeds $dr + d\rho$: But diverging Beams passing a double Concave, have always a negative *Focus*, *viz.* $\frac{-2dr\rho}{+dr+d\rho+2r\rho} = -f$.

The Theorems for converging Beams, are principally of use to determine the *Focus* resulting from any sort of *Lens* placed in a Telescope, between the *Focus* of the Object-Glass and the Glass it self; the distance between the said *Focus* of the Object-Glass, and the interposed *Lens* being made $= -d$. {355}

I here suppose my Reader acquainted with the Rules of Analytical Multiplication and Division, as that + multiplied by + makes the Product +, + by - makes -, and - by - makes +; so dividing + by + makes the Quote +, + by - makes -, and - by - makes +; which will be necessary to be understood in the preceding Examples.

In case the Beams are parallel, as coming from an infinite distance, (which is supposed in the Case of Telescopes) then will d be supposed Infinite, and in the Theorem $\frac{pd\rho r}{dr+d\rho-pr\rho}$ the Term $pr\rho$ vanishes, as being finite, which is no part of the other infinite Terms; and dividing the Remainder by the infinite Part d, the Theorem will stand thus $\frac{p\rho r}{r+\rho} = f$, or in Glass, $\frac{2r\rho}{r+\rho} = f$.

In case the *Lens* were *Plano-Convex* exposed to diverging Beams, instead of $\frac{pd\rho r}{dr+d\rho-pr\rho}$, r being infinite, it will be $\frac{pd\rho}{d-p\rho} = f$, or $\frac{2d\rho}{d-2\rho}$ if the *Lens* be Glass.

If the *Lens* be Double-Convex, and r be equal to ρ, as being formed of Segments of equal Spheres, then will $\frac{pd\rho r}{dr+d\rho-pr\rho}$ be reduced to $\frac{pdr}{2d-pr}f$; and in case d be infinite, then it will yet be farther contracted to $\frac{1}{2}pr$, and p being $= \frac{n}{m-n}$, the focal distance in Glass will be $= r$, in Water $1\frac{1}{2}r$, but in Diamant $\frac{1}{3}r$. {356}

I am sensible that these Examples are too much for the compleat Analyst, though I fear too little for the less Skilful; it being very hard, if possible, in such Matters, so to write, as to give satisfaction to both; or to please the one, and instruct the other. But this may suffice to shew the extent of our Theorem, and how easie a Reduction adapts any one case to all the rest.

Nor is this only useful to discover the *Focus* from the other proposed *data*, but from the *Focus* given, we may thereby determine the distance of the Object; or from the *Focus* and Distance given, we may find of what Sphere it is requisite to take another Segment, to make any given Segment of another Sphere cast the Beams from the distance d to the *Focus* f. As likewise from the *Lens*, *Focus*, and Distance given, to find the *Ratio* of Refraction, or of m to n, requisite to answer those *Data*. All which it is obvious, are fully determined from the Equation we have hitherto used, *viz.* $pd\rho r = drf + d\rho f - pr\rho f$, for to find d the Theorem is $\frac{pr\rho f}{rf+\rho f-p\rho r} = d$, the distance of the Object.

For ρ the Rule is $\frac{drf}{pdr+df+prf} = \rho$. {357}

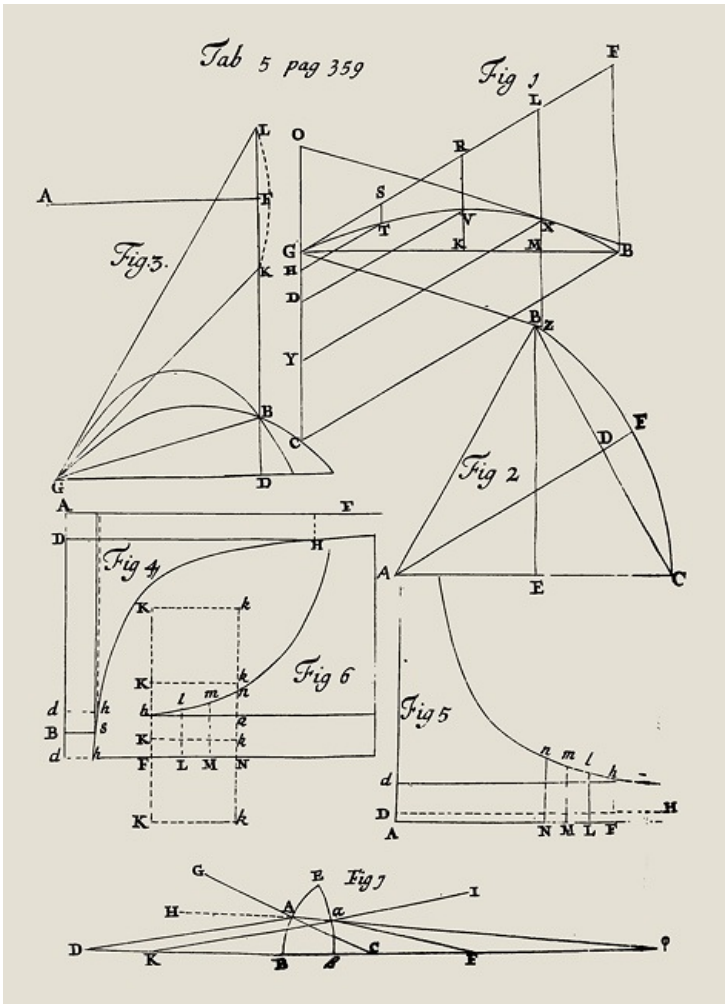
But for p will be $\frac{drf+d\rho f}{d\rho r+f\rho r} = p$, which latter determines the *Ratio* of Refraction, m being to n, as $1 + p$ to p.

I shall not expatiate on these Particulars, but leave them for the Exercise of those that are desirous to be informed in Optical Matters, which I am bold to say are comprehended in these three Rules, as fully as the most Inquisitive can desire them, and in all possible Cases; regard being had to the Signs + and -, as in the former Cases of finding the *Focus*. I shall only shew two considerable Uses of them; the one to find the distance whereat an Object being plac'd, shall by a given *Lens* be represented in a *Species* as large as the Object it self, which may be of singular Use in drawing Faces and other things in their true Magnitude, by transmitting the *Species* by a Glass into a dark Room, which will not only give the true Figure and Shades, but even the Colours themselves, almost as vivid as the Life. In this Case d is equal to f, and substituting d for f in the Equation, we shall have $pdr\rho = ddr + dd\rho - dp\rho r$, and dividing all by $dpr\rho = dr + d\rho - pr\rho$,

that is, $\frac{2pr\rho}{r+\rho} = d$; but if the two Convexities be of the same Sphere so as $r = \rho$, then will the distance be $= pr$; that is, if the *Lens* be Glass $= 2r$, so that if an Object be placed at the Diameter of the Sphere distant, in this Case the *Focus* will be as far within as the Object is without, and the {358}
Species represented thereby will be as big as the Life; but if it were a *Plano-Convex*, the same distance will be $= 2pr$, or in Glass to four times the *Radius* of the Convexity; but of this Method I may entertain the Curious at some other Time, and shew how to magnifie or diminish an Object in any proportion assign'd, (which yet will be obvious enough from what is here deliver'd) as likewise how to erect the Object which in this Method is represented inverted.

A Second Use is to find what Convexity or Concavity is required, to make a vastly distant Object be represented at a given *Focus*, after the one Surface of the *Lens* is formed; which is but a Corollary of our Theorem for finding ρ, having *p*, *d*, *r* and *f* given; for *d* being infinite, that Rule becomes $\frac{rf}{pr - f} = \rho$, that is in Glass $\frac{rf}{2r - f} = \rho$, whence if *f* be greater than $2r$, ρ becomes Negative, and $\frac{rf}{f - 2r}$ is the *Radius* of the Concave sought.

Those that are wholly to begin with this Dioptrical Science, cannot do better than to read with Attention a late Treatise of Dioptricks, published by *W. Molineux*, Esq, R. S. S. who has at large shewn the Nature of Optick Glasses, and the Construction and Use of Microscopes and Telescopes; and though some nicely Critical have endeavour'd to spy Faults, and to traduce the Book; yet having long since examin'd it with Care, I affirm, that if I can judge, it hath but two things that with any Colour may be call'd Faults; the one, an over-careful acknowledgment of {359}
every Trifle the Author had receiv'd from others; and the other that he labours to make easie this curious Subject, so little understood by most, in a manner perhaps too familiar for the *Learned Critick*, and which demonstrates that it was writ *cum animo docendi*, both which require but very little Friendship or good Nature in the Reader, to pass for Vertues in an Author.



Tab. 5. pag. 359

But to return to our first Theorem, which accounting for the thickness of the *Lens*, we will here again resume, *viz.* $\frac{mpdr\rho - nd\rho t + npr\rho t}{mdr + md\rho - mpr\rho - m - ndt + nrt} = f$.

And let it be required to find the *Focus* where a whole Sphere will collect the Beams proceeding from an Object at the distance *d*: Here *t* is equal to $2r$, and *r* equal to ρ. And after due

Reduction, the Theorem will stand thus, $\frac{mpdr - 2ndr + 2nprr}{2nd + 2nr - mpr} = f$; but if d be Infinite, it is contracted to $\frac{mpr}{2n} - r = \frac{2n - m}{2m - 2n} r = f$, wherefore a Sphere of Glass collects the Sun-Beams at half the Semi-diameter of the Sphere without it, and a Sphere of Water at a whole Semi-diameter. But if the *Ratio* of Refraction m to n be as 2 to 1, the *Focus* falls on the opposite Surface of the Sphere; but if it be of greater Inequality it falls within.

Another Example shall be when a Hemisphere is exposed to parallel Rays, that is, d and ρ being {360} infinite, and $t = r$, and after due Reduction the Theorem results $\frac{nn}{mm - mn} r = f$. That is, in Glass it is at $\frac{4}{3}r$, in Water at $\frac{9}{4}r$; but if the Hemisphere were Diamant, it would collect the Beams at $1\frac{4}{15}$ of the *Radius* beyond the Center.

Lastly, As to the Effect of turning the two sides of a *Lens* towards an Object; it is evident, that if the thickness of the *Lens* be very small, so as that you neglect it, or account $t = 0$; then in all Cases the *Focus* of the same *Lens*, to whatsoever Beams, will be the same, without any difference upon the turning the *Lens*: But if you are so curious as to consider the thickness, (which is seldom worth accounting for) in the Case of parallel Rays falling on a *Plano-Convex* of Glass, if the plain side be towards the Object, t does occasion no difference, but the focal distance $f = 2r$. But when the Convex-side is towards the Object, it is contracted to $2r - \frac{2}{3}t$, so that the *Focus* is nearer by $\frac{2}{3}t$. If the *Lens* be double Convex, the difference is less; if a *Meniscus*, greater. If the Convexity on both sides be equal, the focal length is about $\frac{1}{6}t$ shorter than when $t = 0$. In a *Meniscus* the Concave-side towards the Object increases the focal Length, but the Convex towards the Object diminishes it. A General Rule for the difference arising on turning the *Lens*, where the *Focus* is Affirmative, is this $\frac{2rt - 2\rho t}{3r + 3\rho - t}$, for double Convexes of differing Spheres. But for *Menisci* the same difference becomes $\frac{2rt + 2\rho t}{3r - 3\rho + t}$; of which I need give no other Demonstration, but {361} that by a due Reduction it will so follow from what is premised, as will the Theorems for all sorts of Problems relating to the *Foci* of Optick-Glasses.

APPENDIX.

{365}

An Analytical Resolution of certain Equations of the Third, Fifth, Seventh, Ninth Powers, and so on ad Infinitum*, in finite Terms, after the manner of* Cardan*'s Rules for Cubicks. By Mr.* A. Moivre*, Transact.* N^{o} 309*.*

LET (n) be any Number, (y) an unknown Quantity, or Root of the Equation, (a) a Quantity altogether known, or what they call *Homogeneum Comparationis*: And let the Relation of these Quantities to each other be exprest by the Equation.

$$ny + \frac{nn - 1}{2 \times 3} ny^3 + \frac{nn - 1}{2 \times 3} \times \frac{nn - 9}{4 \times 5} ny^5 + \frac{nn - 1}{2 \times 3} \times \frac{nn - 9}{4 \times 5} \times \frac{nn - 25}{6 \times 7} ny^7, \&c. = a.$$

Its plain from the Nature of this Series, that if n be any odd Number (that is an Integer, it matters not whether Affirmative or Negative) then the Series will Terminate, and the Equation arising will be one of the above defin'd, whose Root is

{366}

(1) $y = \frac{1}{2} \sqrt[n]{\sqrt{1 + aa} + a} - \frac{\frac{1}{2}}{\sqrt[n]{\sqrt{1 + aa} + a}}$ or,

(2) $y = \frac{1}{2} \sqrt[n]{\sqrt{1 + aa} + a} - \frac{1}{2} \sqrt[n]{\sqrt{1 + aa} - a}$ or,

(3) $y = \frac{\frac{1}{2}}{\sqrt[n]{\sqrt{1 + aa} - a}} - \frac{1}{2} \sqrt[n]{\sqrt{1 + aa} - a}$ or,

(4) $y = \frac{\frac{1}{2}}{\sqrt[n]{\sqrt{1 + aa} - a}} - \frac{\frac{1}{2}}{\sqrt[n]{\sqrt{1 + aa} + a}}$

For Example, Let the Root of this Equation of the Fifth Power be required $5y + 20y^3 + 16y^5 = 4$ in which case n is = 5, and a = 4, and the Root, according to the first Form, is

$$y = \frac{1}{2} \sqrt[5]{\sqrt{17 + 4}} - \frac{\frac{1}{2}}{\sqrt[5]{\sqrt{17 + 4}}}$$

which is Expeditiously resolved into Numbers after this manner.

$\sqrt{17} + 4$ is equal to 8.1231, whose Logarithm is 0,9097164, and the fifth part of it is 0,1819433, the Number answering it 1.5203 = $\sqrt[5]{\sqrt{17} + 4}$. But the Arithmetical Complement of 0.6577 is

9.8180567, the Number answering is 0.1819433 = $\frac{1}{\sqrt[5]{\sqrt{17}+4}}$ and the half difference of these Numbers is 0,4313 = *y*.

Here we may observe, that in the Room of the general Root, we may advantageously take {367}

$y = \frac{1}{2}\sqrt{2a} - \frac{\frac{1}{2}}{\sqrt[n]{2a}}$ if the quantity *a* be pretty large in respect of Unity. As if the Equation were $5y + 20y^3 + 16y^5 = 682$, the Logarithm of *2a* = 3.1348143 whose Fifth part is 0.6269628, the Number answering is 4.236, and the Number answering the Arithmetical Complement 9.3730372 is 0.236, the half difference of these Numbers is 2 = *y*.

But if in the aforegoing Equation the Signs are alternately Affirmative and Negative; or which is the same thing if the Series be after this manner,

$$ny + \frac{1-nn}{2\times 3}ny^3 + \frac{1-nn}{2\times 3}\times\frac{9-nn}{4\times 5}ny^5 + \frac{1-nn}{2\times 3}\times\frac{9-nn}{4\times 5}\times\frac{25-nn}{6\times 7}ny^7, \&c. = a.$$

The Root of it will be equal to

(1) $y = \frac{1}{2}\sqrt[n]{a+\sqrt{aa-1}} + \frac{\frac{1}{2}}{\sqrt[n]{a+\sqrt{aa-1}}}$ or,

(2) $y = \frac{1}{2}\sqrt[n]{a+\sqrt{aa-1}} + \frac{1}{2}\sqrt[n]{a-\sqrt{aa-1}}$ or,

(3) $y = \frac{\frac{1}{2}}{\sqrt[n]{a-\sqrt{aa-1}}} + \frac{1}{2}\sqrt[n]{a-\sqrt{aa-1}}$ or,

(4) $y = \frac{\frac{1}{2}}{\sqrt[n]{a-\sqrt{aa-1}}} + \frac{\frac{1}{2}}{\sqrt[n]{a+\sqrt{aa-1}}}$

Here it is to be noted, that if $\frac{n-1}{2}$ be an odd Number, the Sign of the Root found must be contrary to it. {368}

Let an Equation be propos'd $5y - 20y^3 + 16y^5 = 6$, whence *n* = 5, and *a* = 6, and the Root will be

$$= \frac{1}{2}\sqrt[5]{6+\sqrt{35}} + \frac{\frac{1}{2}}{\sqrt[5]{6+\sqrt{35}}}$$

or because $6 + \sqrt{35} = 11.916$ whose Logarithm is 1.0761304, and its Fifth part is 0.2152561, whose Arithmetical Complement is 9.7847439. The Numbers belonging to these Logarithms are 1.6415 and 0.6091, whose half Sum is 1.1253 = *y*.

But if it happen that *a* is less than Unity then the Second Form, as being more convenient, ought to be pitch'd on. So if the Equation had been $5y - 20y^3 + 16y^5 = \frac{61}{64}$ then *y* will be

$$= \frac{1}{2}\sqrt[5]{\frac{61}{64}+\sqrt{\frac{-375}{4096}}} + \frac{1}{2}\sqrt[5]{\frac{61}{64}-\sqrt{\frac{-375}{4096}}}$$

and if the Root of the Fifth Power can by any means be Extracted the true and possible Root of the Equation, will thence Emerge, tho' the Expression seems to insinuate an Impossibility. But the Root of the Fifth Power of the Binomial $\frac{61}{64} + \sqrt{\frac{-375}{4096}}$ is $\frac{1}{4} + \frac{1}{4}\sqrt{-15}$ and so the same Root of the Binomial $\frac{61}{64} + \sqrt{\frac{-375}{4096}}$ is $\frac{1}{4} - \frac{1}{4}\sqrt{-15}$ the half Sum of which Roots is = ¼ = *y*.

But if that Extraction can not be perform'd, or may seem too difficult, the thing may be solv'd by the help of a Table of Natural Sines, after the following manner; {369}

To the Radius 1 let $a = \frac{61}{64} = 0{,}95112$ the Sine of some Arch which is therefore 72° 23', whose Fifth part (because *n* is equal to 5) is 14° 28' the Sine of it is 0.24981 = ¼ nearly.

The same is the Method of proceeding in Equations of higher Dimensions.

{371}

A Discourse concerning the Action of the Sun and Moon on Animal Bodies; and the Influence which This may have in many Diseases. By Richard Mead*, M. D. F. R. S.*

PART I.

THAT some Diseases are properly the Effects of the Influence of the Heavenly Bodies, and that others do vary their Periods and Symptoms according to the different Positions of one or other of those Luminous Globes, is a very ancient and certain Observation. Upon this score

Hippocrates[18] advises his Son *Thessalus* to the study of Geometry and Numbers, because *the Knowledge of the Stars is of very great use in Physick*[19]. And the earliest Histories of Epidemic Distempers, particularly do all turn upon the alterations made in our Bodies by the Heavens.

But when in later Times Medicine came to be accommodated to the Reasonings of Philosophers; no body being able to account for the manner of this Celestial Action, It was allowed no farther share in affecting our Health, than what might be imputed to the changes in the manifest Constitution of the Air, excepting perhaps something of Truth which still remains {372} disguised and blended with the Jargon of Judiciary Astrology.

In order therefore to set this Matter in a little clearer light, I shall in the first place shew, That the Sun and Moon regarding their Nearness and Direction to the Earth only, besides the Effects of Heat, Moisture, *&c.* thereby caused in our Atmosphere, must at certain times make some Alterations in all Animal Bodies; then enumerate some Histories and Observations of such Changes, and enquire of what Use such Thoughts as these may be in the Practice of Physick.

It is a constant Observation of those who write the History of the *Winds*, That the most Windy Seasons of the Year, are the Time about the Vernal and Autumnal Equinox; for be the Air never so calm before or after, we never fail of having Winds at that Juncture. Every body likewise knows, that in the most quiet Weather we are sure of some Breeze at Mid-day and Mid-night, as also at Full Sea, *i.e.* always about the time the Sun or Moon arrive at the Meridian. Seamen and Country People reckon upon This, and order their Affairs accordingly. And the changes of the Weather as to Winds or Calms especially about the New and Full Moon, are too well known to require any Authority to confirm such Remarks. Those who desire a fuller account of these Observations, may see it in *De Chales*'s Navigation, *Gassendus*'s Natural Philosophy, and *J. Goad*, his *Astro-Meteoro-Logica*.

These things being Matters of Fact, and in a manner Regular and Universal, it may very well seem strange that Philosophers have not been more accurate in their Enquiries into the Reason of such Appearances. True indeed it is, that the Origin of Winds is various and uncertain, but {373} however, so constant and uniform an Effect must undoubtedly be owing to one necessary Cause.

It has bin, now a considerable time since, sufficiently made out, that our Atmosphere is a thin Elastic Fluid, one part of which gravitates upon another, and whose Pressure is communicated every way in a Sphere to any given Part thereof. From hence it follows, That if by any external Cause the Gravity of any one part shou'd be taken off or diminished, that from all sides around this part, the more heavy Air would rush in to restore the Equilibrium which must of necessity be preserved in all Fluids. Now this violent running in of the heavier Air would certainly produce a Wind, which is no more than a strong Motion of the Air in some determined Direction. If therefore we can find any outward Cause that would at these stated Seasons we have mentioned, diminish the Weight or Pressure of the Atmosphere; we shall have the genuine Reason of these Periodical Winds, and the necessary Consequences thereof.

The Flux and Reflux of the Sea was a Phænomenon too visible, and too much conducing to the Subsistance of Mankind, and all other Animals, to be neglected by those who applyed themselves to the Study of Nature; however all their Attempts to explain this Admirable Contrivance of infinite Wisdom were unsuccessfull, till Sir *Isaac Newton* reveal'd to the World juster Principles, and by a truer Philosophy than was formerly known, shew'd us how by the United or Divided Forces of the Sun and Moon, which are encreased and lessened by several Circumstances, all the Varieties of the Tides are to be accounted for. And since all the Changes we have enumerated in the Atmosphere do fall out at the same times when those happen in the Ocean; and likewise {374} whereas both the Waters of the Sea and the Air of our Earth, are Fluids subject, in a great Measure, to the same Laws of Motion; it is plain, that the Rule of our great Philosopher takes place here, *viz. That Natural Effects of the same kind are owing to the same Causes.*[20]

What difference that known Property of the Air, which is not in Water, makes in the Case, I shall shew anon; setting aside the Consideration of that for the present; It is certain, That as the Sea is, so must our Air, twice every 25 Hours, be rais'd upwards to a considerable height, by the Attraction of the Moon coming to the Meridian; so that instead of a *Spherical*, it must form it self into a *Spheroidal*, or *Oval* Figure, whose longest Diameter being produced, would pass thro' the Moon. That the like Raising must follow as often as the Sun is in the Meridian of any Place, either above or below the Horizon. Moreover, That this Elevation is *greatest* upon the New and Full Moons, because both Sun and Moon do then conspire in their Attraction; *least* on the Quarters, in that they then drawing different ways, 'tis only the Difference of their Actions produces the Effect. Lastly, That this Intumescence will be of a *middle degree*, at the time between the Quarters, and New and Full Moon.

From the same Principles, The Motion upwards of the Air will be strongest of all about the Equinoxes; the Equinoctial Line being over that Circle of the Globe, which has the greatest Diameter, either of the Luminaries when in that are nearer, and the Agitation of the Fluid {375} Spheroid revolving about a greater Circle, is greater; besides, the Centrifugal Force (arising from the Diurnal Rotation) is there greatest of all. This will still be more considerable about the New

and Full Moons happening at these times, for the Reasons just now mentioned. And the least Attraction will be about the Quadratures of these Lunar Months, because the Declination of the Moon from the Equator is then greatest. The different distances of the Moon in her Perigæum and Apogæum, are the Reason that these full changes fall out a little before the Vernal, and after the Autumnal Equinox. Now the Inverse of all this happens when the Luminaries are in the Solstitial Circles. Lastly, In the same Parallel, when the Moon's Declination is towards the Elevated Pole, the Attraction is strongest when the Moon is in that Places Meridian, and weakest when she is in the Opposite Places Meridian: The contrary happens in the Opposite Parallel; by reason of the Spheroidal Figure of the Earth and its Atmosphere.

Whatever has been said on this Head, is no more that applying what Sir *Isaac Newton* has Demonstrated of the Sea to our Atmosphere; and it is needless to shew how necessarily those Appearances, just now mentioned, of *Winds*, at the Stated Times, *&c.* must happen hereupon. It will be of more use to consider the Proportion of the Forces of the two Luminaries upon the *Air*, to that which they have upon the Water of our Globe; that it may the more plainly appear what Influence the Alterations hereby made, must have upon the Animal Body.

Sir *Isaac Newton* has demonstrated[21] That the Force of the Sun to move the Sea, is to the Force of Gravity, as 1 to 12868200. Let that be {376}

S. G :: 1. n. Hence, S = $^{G}/_{n}$.

And that the Force of the Moon to raise the Sea is to Gravity, as 1 to 2031821. Let this be

L. G :: 1. s. Hence, L = $^{G}/_{s}$.

And since the Centrifugal force of the Parts of the Earth arising from its Diurnal Motion is to Gravity, as 1 to 291. Let this be

C. G :: 1. C. Then C = $^{G}/_{e}$. Hence,

S + L. C :: $^{G}/_{n} + {}^{G}/_{s}$. $^{G}/_{e}$ :: $^{1}/_{n} + {}^{1}/_{s}$. $^{1}/_{e}$ :: 1. $\frac{sn}{(s+n)\times e}$ :: 1. 6031.

The same Philosopher has taught us[22] that the Centrifugal force raises the Water at the Equator above the Water at the Poles, to the height of 85200 Feet. Wherefore if that Force which is as 6031, raise the Ocean to 85200 Feet, the United forces of the Sun and Moon, which are as 1. will raise the same to 14 Feet, for $^{85200}/_{6031}$ = 14. *Proximé*.

Now we know that the more easily the Waters can obey the Attraction, with the more Force are the Tides moved; but since, as Mr. *Halley* has determin'd it,[23] our Atmosphere is extended to 45 Miles, whereas the middle depth of the Ocean is but about half a Mile; it is plain, that the Air revolving in a Sphere about 100 times larger than that of the Ocean, will have a proportionably greater Agitation. {377}

Besides, Rocks, Shelves, and the inequality of Shoars are a great stop to the Access and Recess of the Sea: But nothing repels the rising Air, which is also of such thinness and fluidity, that it is easily driven, and runs every way.

Nor ought we to omit, that it is the universal Law of Bodies Attracted, that the Force of Attraction is reciprocally as the Squares of their Distances; so that the Action of the Sun and Moon will be greater upon the Air than upon the Water, upon the Account of its Nearness.

But the Consideration of the Elasticity is still of greater Moment here, of which this is the nature, that it is reciprocally as the Pressure, so that the incumbent Weight being diminished by the Attraction, the Air underneath will upon this score be mightily expanded.

These and such like Causes will make the Tides in the Air to be much greater than those of the Ocean; nor is it necessary to our purpose to determine, by nice Calculations, their particular Forces; it is sufficient to have proved that these Motions must both be Universal, and also return at certain Intervals.

Now since the raising of the Water of the Ocean 14 Feet, produces Torrents of such a prodigious Force, we may easily conceive what Tempests of Winds (if not otherwise check'd) the Elevation of the Air much higher (perhaps above a Mile) will necessarily cause. And there is no doubt to be made, but that the same infinitely Wise Being, who contrived the Flux and Reflux of the Sea, to secure that vast Collection of Waters from Stagnation and Corruption (which would inevitably destroy all the Animals and Vegetables on this Globe) has ordered this Ebb and Flood of the Air of our Atmosphere, with the like good design, that is to preserve (in Case all other Causes should fail, as they may, and at times do in some Countries) the sweet Freshness, and brisk Temper of this Fluid, so necessary to Life, and keep it, by a kind of continual Circulation, from Deadness and Stinking. {378}

This Reasoning is liable to only one Objection that I know of, and that is this: That the Appearances we have mention'd cannot be owing to the Causes now assigned; since by Calculation from them, the Mercury must at New and Full Moon subside in the Barometer to a

certain degree, which yet we do not observe to happen.

In answer to which, (besides that there have been some Observations made of the sinking of the Mercury at those times; and it may perhaps be the fault of the Observers that these have not been reduced to any Rule) We are to Consider, That altho' Winds and Alterations in the Pressure of the Atmosphere, are the necessary consequents of the Lunar Attraction, and true Causes of the different Rise of the Mercury in the Barometer; yet these may be produced many others ways too, and therefore tho' regularly the Mercury would always fall at the New and Full Moon, those other {379}
Causes may be strong enough, even to raise it at those Seasons; in as much as two contrary Winds, for instance, blowing towards the Place of Observation, may accumulate the Air there, so as to increase both the height and weight of the incumbent Cylinder; in like manner, the Direction of two Winds may be such, as meeting at certain Angle they may keep the Gravity of the Air in the middle place unaltered; and a Thousand such Varieties there may be, by which the Regularity of Appearances of this nature may be hindered. Now the other Springs, from which such Changes in the Air may arise, are these.

1. Elastic Vapours forc'd from the Bowels of the Earth, by Subterraneous Heats, and condensed by whatever cause in the Atmosphere.

2. A mixture of Effluvia of different qualities in the Air, may by Rarefactions, Fermentations, *&c.* produce Winds and other Effects like those resulting from the Combination of some Chymical Liquors; and that such things happen, we are assured from the Nature of Thunder, Lightning, and Meteors.

3. From the Eruptions of Vulcanoes and Earthquakes in distant Places, Winds may be propagated to remoter Countries.

4. The divided or United Forces of the other Planets and of Comets, may variously disturb the influence of the Sun and Moon, *&c.* We know that there happen violent Tempests in the upper Regions of the Air, while we below enjoy a Calm; and how many Ridges of Mountains there are on our Globe, which interrupt and check the Propagation of the Winds; so that it is no wonder that {380}
the Phænomena we have ascribed to the Action of the Sun and Moon, are not always constant and uniform, and that every Effect does not hereupon follow; which, were there no other Powers in Nature able to alter the influence of this, might in a very regular and uniform manner be expected from it.

These things being premised, it will not be difficult to shew (as was proposed in the first Place) that these Changes in our Atmosphere at High Water, New and Full Moon, the Æquinoxes, *&c.* must occasion some Alterations in all Animal Bodies; and that from the following Considerations.

1. All living Creatures require Air of a determined Gravity to perform Respiration easily, and with Advantage; for it is by its weight that this Fluid insinuates it self into the Cavity of the Breast and Lungs. Now the Gravity, as we have proved, being lessened at these Seasons, a smaller quantity only will insinuate it self, and this must be of smaller force to comminute the Blood, and forward its Passage into the left Ventricle of the Heart, whence a slower Circulation insues, and the Secretion of Spirits is diminished.

2. This Effect will be the more sure, in that the Elasticity of the Atmosphere is likewise diminished. Animals want Air as heavy so Elastic to a certain degree; For as this is by its weight forced into the Cavity of the *Thorax* in Inspiration, so the Muscles of the *Abdomen* press it into the *Bronchi* in Expiration, where the bending force being somewhat taken off, and Springy Bodies when unbended, exerting their Power every way, in Proportion to their Pressures, the {381}
Parts of the Air push against all the sides of the *Vesiculæ*, and promote the Passage of the Blood.

We have a convincing Instance of all this, in those who go to the top of high Mountains, for the Air is there so pure (as they call it) that is, wants so much of its Gravity and Elasticity, that they Breathe with very great difficulty.

3. All the Fluids in Animals have in them a mixture of Elastic *Aura*, which when set at liberty, shews its Energy, and causes those Fermentations we observe in the Blood and Spirits: Now when the Pressure of the Atmosphere, upon the Surface of our Body is diminished, the inward Air in the Vessels must necessarily be inabled to exert its Force, in Proportion to the lessening the Gravity and Elasticity of the outward; hereupon the Juices begin to ferment, change the Union and Cohæsion of their Parts, break their Canals, *&c.*

This is very plain in living Creatures put into the Receiver, exhausted by the Air-Pump, which always swell as the Air is more and more drawn out; their Lungs at the same time contracting themselves, and falling so together as to be hardly discernible.[24]

Ere we proceed to Matters of Fact, it may be worth the while to take Notice, That Effects depending on such Causes as these, must of necessity be most visible in Weak Bodies and Morbid Constitutions, when other Circumstances concur to their taking Place. For this reason, whatever Mischiefs do hence follow, cannot in the least disparage the Wise Contrivance of Infinite Power in {382}

ordering these Tides of our Atmosphere. The Author of Nature, we know, has made all things to the greatest Advantage that could be, for the whole System of Animals on our Globe, but it was impossible that such a disposition shou'd not in some Cases be prejudicial to a Few. The Position and Distance of the Sun are so adjusted, as to give in the most beneficial manner possible, Heat and Light to the Earth; yet this notwithstanding, some Places may be too hot for some weakly Bodies; some Autumns too sultry to agree with some Animals, and some Winters too cold to be endured by some tender Creatures: The whole however we must own, is most carefully provided for. Besides, as most of these last mentioned Inconveniencies are by easy shifts to be avoided; so there are such Powerful Checks put to this Aereal Flux and Reflux, so many ways of abating the Damages accruing from it now and then; that these are of no account in comparison of the mighty Benefits hence arising, in which the Race of Mankind does universally share.

[18] *Epist. ad Thessalum Filium.*

[19] Υ̓υκ ἐλαχίστον μέρος συμβάλλεται Ἀστρονομίη εἰς Ἰητρικήν. De Aere Aquis & Locis.

[20] Newton, *Princip.* p. 402.

[21] *Princip. Lib.* 3. *Prop.* 36.

[22] *Ibid. Lib.* 3. *Prop.* 37.

[23] *Philos. Trans.* N^{o} 181.

[24] *Esperienze dell' Academia del Cimento*, p.m. 113.

PART II.

{383}

There are no Historys in Physick which we may more safely take upon the Credit of the Authors who relate 'em, than such as we are now going to mention. In some Cases a Point may perhaps be strained to serve a darling Hypothesis which the Writer has taken up, but here we are much more likely to have pure Matter of Fact, because hitherto no one has pretended the Appearances of this kind to be within the Reach of any Scheme of Philosophy.

Epileptical Diseases besides the other Difficultys with which they are attended, have this also surprizing, that in some the Fits do constantly return every New and Full Moon; *the Moon* (says Galen[25]) *governs the Periods of Epileptic Cases*. Upon this score, They who were thus affected were called Σεληνιακοὶ[26] and in the Historys of the Gospel Σεληνιαζόμενοι[27] by some of the Latins afterwards, *Lunatici*[28]. *Bartholin*[29] tells a Story of one Epileptic who had apparent Spots in her Face, which according to the Time of the Moon, varyed both their Colour and Magnitude.

{384}

But no greater Consent in such Cases was perhaps ever Observed than what I saw some time since in a Child about 5 years old, in which the Convulsions were so strong and frequent, that life was almost despair'd of, and by Evacuations and other Medicines very difficultly saved. The Girl, who was of a lusty full habit of Body, continued well for a few days, but was at Full Moon again seized with a most violent Fit, after which, the Disease kept its Periods constant and regular with the Tides; She lay always Speechless during the whole time of Flood, and Recovered upon the Ebb. The Father who lives by the *Thames* side, and does business upon the River, observed these Returns to be so punctual, that not only coming home He knew how the Child was before he saw it, but in the night has risen to his Employ, being warned by Cries when coming out of her Fit, of the turning of the Water. This continued 14 days, that is, to the next great Change of the Moon, and then a dry Scab on the Crown of the Head, (the effect of an Epispastic Plaister, with which I had covered the whole *Occiput* in the beginning of the Illness) broke, and from the Sore, tho' there had been no sensible Discharge this way for above a Fortnight, ran a considerable quantity of limpid Serum; upon which, the Fits returning no more, I took great care to promote this new Evacuation by proper Applications, with desired Success, for some time; and when it ceased, besides two or three Purges with *Mercurius Dulcis*, &c. ordered an Issue in the Neck, which being thought troublesome, was made in the Arm; the Patient however has never since felt any Attacks of those frightful Symptoms.

{385}

Whether or no it be thro' want of due Heed and Enquiry that we have not in all the Collections of Histories and Cases, any Instance of the like Nature so particular as this is, I know not; this is certain, that as the *Vertigo* is a Disease nearly related to the *Epilepsy*, and the *Hysterical Symptoms* do partake of the same Nature; so both one and the other are frequently observed to obey the Lunar Influence. In like manner, the raving Fits of Mad People, which keep Lunar Periods, are generally in some degree Epileptic too.

Tulpius[30] and *Piso*[31] afford us remarkable Instances of Periodical *Palseys*.

Every one knows how great a share the Moon has in forwarding those Evacuations of the weaker Sex, which have their Name from the constant Regularity they keep in their Returns; and there is no question to be made, but the Correspondency we here observe, would be greater still, and even Universal, did not many Accidents, and the infinite Varieties in particular Constitutions one way or other concur to make a difference. It is very observable that in Countries nearest to the Æquator, where we have proved the Lunar Action to be strongest; these Monthly Secretions are in much greater quantity than in those near the Poles, where this force is weakest. This *Hippocrates*[32] takes notice of, and gives it as one Reason why the Women in *Scythia* are not very

fruitful.

The Case being thus with Females, it is no wonder if we sometimes meet with Periodical Hæmorrhages answering to the times of the Moon in Males also. For as a greater quantity of {386}
Blood in proportion to the bulk in *one* Sex, is the reason of its discharging it self thro' proper Ducts, at certain Intervals, when the pressure of the external Air being diminish'd, the internal *Aura* can exert its Elasticity; so in the *other*, if at any time there happens to be a Superabundancy of the same Fluid, together with a weak Tone of the Fibres; it is plain that the Vessels will be most easily burst, when the Resistance of the Atmosphere is least. And this more especially, if any accidental hurt, or rarefying Force has first given occasion to the other Causes to take effect.

I know a Gentleman of a tender frame of Body, who having once, by over reaching, strained the parts about the Breast; fell thereupon into a spitting of Blood, which for a Year and half constantly return'd every New Moon, and decreasing gradually, continued always 4 or 5 days. The Fits being more or less considerable, according as his management about that time, contributed to a greater or lesser fullness of the Vessels.

We have two notable Instances of the like nature in our Philosophical Transactions; the one[33] of a Person, who from his Infancy to the 24th Year of his Age, had every full Moon an Eruption of Blood on the right side of the Nail of his left Thumb, at first to 3 or 4 Ounces, and after his sixteenth Year, to half a Pound each time; which when by searing the part with a hot Iron, he stopp'd, he fell into a *Sputum Sanguinis*, and by frequent Bleeding, *&c.* was very difficultly saved {387}
from a Consumption. The other[34] is a Story of an *Inn-Keeper* in *Ireland*, who from the 43rd Year of his Life, to the 55th (in which it killed him) suffered a Periodical Evacuation at the point of the Fore-Finger of his Right-hand; and altho the Fits here kept not their returns so certain as in the forementioned Case, (it may be either from the irregular way of living of the Patient, or the mighty change every Effusion made in his habit of Body, the quantity seldom amounting to less than four Pounds at a time) yet there is this remarkable Circumstance in the Relation, that the first beginning of this *Hæmorrhage* was at *Easter*, that is, the next Full Moon after the Vernal Equinox, which is one of the two Seasons of the Year, at which we have proved the attraction of the Air, or lessening of its Pressure, to be greater than at any other time whatsoever.

But we are besides this to consider, That the Static Chair, and nice Observation taught *Sanctorius*,[35] That *Men do increase a Pound or two in their weight every Month, which overplus is discharged at the Months end, by a Crisis of copious, or thick turbid Urine*.

It is not therefore at all strange that we should once a Month be liable to the returns of such Distempers as depend upon a Fullness of the Vessels, that these should take place at those times especially, when the ambient Air is least able to repress the Turgency; and that tho' New and Full Moon are both of equal Force, yet that sometimes one, and sometimes the other only should Influence the Periods, according as this or that happens to fall in with the inward Repletion. {388}

The Afflux of Humours to Ulcers is sometimes manifestly altered by this Power; [36] *Baglivi* was acquainted with a Learned Young Man at *Rome*, who labour'd under a *Fistula* in the *Abdomen*, penetrating to the *Colon*, which discharged so plentifully in the Increase, and so sparingly in the Decrease of the Moon, that he could make a very true judgment of the Periods and Quadratures of the Planet, from the different quantity of the *Matter* that came from Him.

Nephritic Paroxysms have frequently been observed to obey the Lunar Attraction: *Tulpius*[37] relates the Case of Mr. *Ainsworth*, an *English* Minister at *Amsterdam*, who had a Fit of the Gravel and suppression of Urine every Full Moon, of which he found no relief till the Moon decreased, unless by Bleeding at the Arm. After his death two large Stones were taken out of his Bladder, and the *Pelvis* of the left Kidney was enlarged to that degree by the quantity of Urine so often stopt there, as to contain almost as much as the Bladder it self.

I was present, not long since, at the Dissection of a Child about 5 or 6 Year old, who dyed of the frequent returns of *Nephritic* Fits, attended with Vomitings and a *Diarrhæa*. The Kidneys and Ureters were quite stuffed with a slimy calculous Matter, and it was very instructive to see the different degrees of Concretion in the several parts of it, from a clear limpid Water, to a hard friable Substance. Dr. *Groenvelt*, who had tended the Boy in his Illness, observed him to be {389}
seized with his Pains at every Full Moon for several Months together, which generally ended with the voiding of a Stone.

What Influence the Moon has in *Asthma's*,[38] *van Helmont* takes Notice, *Exacerbatur Paroxysmus* (says he) *Lunæ Stationibus, & ævi tempestatibus quas ideo præsentit & præsagit*.[39] And Sir *John Floyer*, who has given us a more particular History of this Disease than any Author, observes, that *The Fits usually return once in a Fortnight, and frequently happen near the Change of the Moon*.

'Tis a more uncommon Effect of this Attractive Power that is related by the Learned *Kerckringius*.[40] He knew a Young Gentlewoman, whose Beauty depended upon the Lunar Force, insomuch that at Full Moon she was Plump and very Handsome, but in the decrease of the Planet so Wan and ill Favoured, that she was asham'd to go abroad till the return of the New Moon gave

Fullness to her Face, and *Attraction* to her Charms.

Tho' this is indeed no more than an Influence of the same kind, with that the Moon has always been observed to have upon Shell-Fish, and some other living Creatures. For as the old *Latin* Poet *Lucilius* says,[41]

Luna alit Ostrea & implet Echinos, Muribu' fibras
Et Pecui addit — — —

And after him *Manilius*[42] {390}

Sic submersa fretris concharum & Carcere clausa,
Ad Lunæ motum variant animalia corpus.

It is very well worth the pains to enquire what share such an Alteration in the Weight and Pressure of the Atmosphere may have in the *Crises* or Changes of Acute Diseases. The Ancients made great Account of *Critical* Days, and regulated their Practice according to the Expectation they had from them; This Part of Physick is grown now into disuse, quite slighted, and even ridiculed; and that I suppose chiefly for these two reasons. In the first place, because the earliest Observations of this kind, which were drawn into Rules being made in *Eastern* Countries, when these came to be applied to the Distempers of *Northern* Regions, without allowance given for the difference of the Climate, they were oftentimes found not to answer. And secondly, Fevers of old were treated with few or no Medicines, the Motions of Nature were carefully watched, and no Violence offer'd to interrupt her Work. The Histories therefore of *Crises*, tho' of great Use, and certainty under such Management as this, were at length unavoidably set aside and lost; when Acute Cases came to be Cured, according to this or that Hypothesis, not only by Evacuations, but hot or cold Alteratives too; there being no longer any room for those Laws of Practice which supposed a regular and uniform Progress of the Distemper.

Wherefore, in order to understand a little both what might Induce the first Masters of our Profession to so nice and strict an Observance in this point; and what grounds there may be now, for a more due regard to their Precepts, even upon the score of the Lunar Attraction only, I propose the following Remarks. {391}

1. All Epidemic Diseases do in their regular course require a stated time, in which they come to their height, decline, and leave the Body free.

This is so constant and certain, that when a Fever of any *Constitution* which is *continual* in one Subject, happens from some other cause, in another to be *intermitting*, the Paroxysms do always return so often as all together to make up just as many days of Illness as he suffers, whose Distemper goes on from beginning to end, without any abatement.

Dr. *Sydenham*, a sworn Enemy to all Theories, learn'd thus much from downright Observation; and gives this reason why Autumnal Quartans hold six Months, because by computation the Fits of so long a time amount to 336 hours, or 14 days, the period of a continual Fever of the same Season.[43]

So *Galen* takes notice that when an Exquisite Tertian is terminated in seven Paroxysms, a true Continual at the same time has its Crisis in seven days; that is, the Fever lasts as long in one as in the other, in as much (says he) as *a Fit in an Intermitting Feaver answers to a day in a Continual*[44]. Now this so comes to pass, because

2. In these Cases there is always a Fermentation in the Blood, which goes not off till the active Particles are thrown out by those Organs of Secretion, which, according to the Laws of Motion, are most fitted to separate 'em. And {392}

3. As different Liquors put upon a Ferment, are depurated in different times, so the Arterial Fluid takes up a determined Period, of which it is discharged of an induced Effervescence.

4. The Symptoms, during this Ebullition, do not proceed all along in the same Tenour; but on some days particularly, they give such evident Marks of their good or bad Quality, that the nature of the ensuing *Solution* may very well be guess'd at, and foretold by 'em.

Things being thus, Those days on which the Disease was so evidently terminated one way or other, might very justly be call'd the days of *Crisis*; and those upon which the tendency of Illness was discovered by most visible Tokens, the *Indices* of the *Critical Days*.

And thus far the Foundation was good, but when a false Theory happen'd unluckily to be joined to true Observations, this did a little puzzle the Cause. *Hippocrates*, it is plain, knew not to what to ascribe that remarkable regularity with which he saw the Periods of Feavers were ended on the *Seventh*, *Fourteenth*, *One and Twentieth* day, *&c. Pythagoras* his Philosophy was in those Ages very Famous, of which *Harmony* and the *Mysteries of Numbers* made a considerable part, *Odd* were more Powerful than *Even*, and *Seven* was the most perfect of all. Our great Physician espoused these Notions,[45] and confined the Stages of acute Distempers to a *Septenary* Progression[46], upon which this Inconvenience follow'd, that when a Crisis fell out a day sooner or later than this Computation required, his Measures were quite broken; and that this must {393}

necessarily oftentimes happen, will appear by and by.

Upon this score *Asclepiades* rejected this whole Doctrine as vain,[47] and *Celsus* finding it to be too nice and scrupulous, observes that the *Pythagorean Numbers led the Ancients into the Error*.[48]

Galen being aware of this, succeeded much better in his reasoning upon the Matter, and very happily imputed the Critical Changes not to the Power of Numbers, but to the Influence of the Moon; which he observes, *has a mighty Action upon our Earth, exceeding the other Planets, not in Energy, but in Nearness*[49]. So that according to him, the Septenary Periods in Diseases are owing to the *Quarterly Lunar Phases, which are the times of the greatest Force, and which return in about seven days*.[50]

The result of the whole Affair, in short is this, A *Crisis* is no more than the Expulsion of the Morbific Matter out of the Body, thro' some or other of the Secretory Organs; in order to which, it is necessary that this should be prepar'd and comminuted to such a degree, as is required to {394} make it pass into the Orifices of the respective Glands; and therefore *as* the most *perfect Crisis* is by *Sweat*, (both by reason that the Subcutaneous Glands do naturally discharge more than all the other put together, and also that their Ducts being the smallest of any, whatsoever comes this way is certainly wery well divided and broken) *so* the most *imperfect* is an *Hæmorrhage*, because This is an Argument that what Offends is not fit to be cast off in any Part, and consequently breaks the Vessels by the Effervescence of the Blood. An *Abscess* in those Organs which separate thick, slimy Juices is of a middle nature betwixt these two.

Now it is very plain, That if the time, in which either the Peccant Humour is prepar'd for Secretion, or the Fermentation of the Blood is come to its height, falls in with those Changes in the Atmosphere which diminish its pressure; the *Crisis* will then be more compleat and large. And also, that this Work may be forwarded or delay'd a day, upon the account of such an Alteration in the Air; the Distention of the Vessels upon which it depends, being hereby made more easie, and a weak Habit of Body in some Cases standing in need of this outward Assistance. Thus a Fever which requires about a Week to its Period, may sometimes, as *Hippocrates* observed, have a good Crisis on the sixth, and sometimes not till the eighth day.

In Order therefore to make true Observations of this kind, the time of Invasion is to be considered, The genuine course of the Distemper must first be watched, which is not to be interrupted by any violent Methods: The strength of Nature in the Patient is to be considered, and by what Secretions the Crisis is most likely to be performed; and it will then be found, that {395} not only the *New* and *Full* Moons, but even the *Southings*, whether visible or latent, of the Planet, are here of considerable Moment.

For Confirmation of which, we need only to reflect on what Mr. *Paschal* has remark'd, *concerning the Motions of Diseases and Births and Deaths*[51]. Dividing the Νυχθήμερον into Four Senaries of Hours, the first consists of three hours before the Southing of the Moon, and three after; the second of the six hours following, and the third and fourth of the remaining Quarters of the natural day; He takes notice that none are born, or die a natural Death in the first and third Senaries, which he calls first and second Tides, but all either in the second or fourth Senaries, which he calls first and second Ebbs. In like manner, that in Agues, the tumult of the Fits generally lasts all the Tiding time, and then goes off in kindly Sweats in the Ebbs. From whence he very rationally concludes, that Motion, Vigour, Action, Strength, *&c.* appear most, and do best in the *Tiding Senaries*; and that Rest, Relaxation, Decay, Dissolution, *&c.* belong to the *Ebbing Senaries*.

[25] Τας τῶν ἐπιλήπτων τηρεῖ περιόδους. *De Dieb. Critic. lib.* 3.

[26] *Alexand. Trallian.* lib. 1. c. 15.

[27] Matth. c. 17. v. 15.

[28] *Apuleius de Virtutib. Herbar.* cap. 6. & 95.

[29] *Anatom. Centur.* 2. H. 72.

[30] *Observ. Med.* lib. 1. cap. 12.

[31] *De Morb. à serosâ Colluvie*, Obs. 28.

[32] *De Aere Aquis & Locis.*

[33] Nº 272.

[34] *Philos. Trans.* Nº 171.

[35] *Medicin. Static.* Sect. 1. Aph. 65.

[36] *De Experiment. circa Sanguin.* p. m. 341.

[37] *Observat.* Lib. 2. c. 43. *vid. etiam Observ.* 52.

[38] *Asthma & Tuss.* § 22.

[39] *Treatise of the Asthma*, p. 17.

[40] *Observat. Anatomic.* 92.

[41] *Apud* A. Gellium, lib. 20. c. 8.

[42] *Astronomic.* lib. 2.

[43] *De Feber. Intermit.* Ann. 1661. pag. *m.* 65.

[44] *Comment. in Aphor.* 59. lib. 4. & *de Crisib.* lib. 2. c. 6.

[45] *Epidem.* lib. 1. Sect. 3.

[46] αἱ μὲν οὖν ἡμέραι ἐπισημόταταί εἰσιν ἐν τοῖς πλείστοις αἵτε πρῶται καὶ ἑβδομιαῖαι, πολλαὶ μὲν περὶ νούσων, πολλαὶ δὲ καὶ τοῖς ἐμβρύοις. *de Septimestri Partu.*

[47] *Vid. Celsum* lib. 3. c. 4.

[48] *Ibid.*

[49] *De diebus Decretor.* lib. 3.

[50] *Ibid.*

[51] *Philos. Transact.* N^{o} 202.

A COROLLARY.

It having bin explained in the Beginning of this Discourse, how those Influences of the Heavens, which favour the *Returns* of *Diseases*, may likewise raise *Winds* at the same times; and that We feel the different Effects of *These* according as other Causes do concurr to the Motion of the Air; it will not be amiss, to shew in one Instance or two, how much Natural History confirms this Reasoning.

There happened on the 26th of *November*, 1703. a little before Midnight, a most terrible *Storm* of *Wind*, the Fury of it is still fresh in every ones Mind, which lasted above six Hours.

It is not to the present purpose to relate its History and Causes; What we observe is, That the Moon was at that time *in Perigæo*, and just upon the change to *New*. Upon both which accounts its Action in raising the Atmosphere must be great; And hence indeed the *Tides* which followed were also very great, and the *Mercury* in the *Barometer*, at least, in most places, fell very low. {398}

This Influence was, without all doubt, assisted by some such other Causes of *Winds*, as we have mentioned; These we can't know, but may however take notice how much the manifest State of the Air contributed to this Calamity.

After a greater quantity of Rains than ordinary had fallen in the Summer and Autumn, in those places where the Storm was felt, the Winter came on much warmer than usual; so that the Liquor in a Thermometer, of which the 84th Degree notes Frost, never fell below the 100th.[52]

Hence we may very well believe, that the Atmosphere was at that time fill'd with Atoms of *Salts* and *Sulphur*, out of the Vapours raised by the Heat from the moist Earth, which being variously combined and agitated, gave that deadly force to the Motion of the Air.

A Proof of this we have not only from the frequent *Flashes* of *Lightning*, observed a little before the Storm, but also from what the Country People took notice of the next day, that the Grass and Twiggs of the Trees, in Fields remote from the Sea, tasted very salt, so that the Cattle wou'd not feed on them. {399}

Our Histories mention another Storm, which if not equal to this last in Violence, is however thought the greatest that had then ever been known and memorable from the time at which it happened, *viz.* on the 3d of *September*, 1658. the day on which the Usurper *O. Cromwel* died.

No *Ephemerides* that I know of relate the Condition of the Air that Year, but it is sufficient to remark, That whatever other Causes concurr'd, their force was accompanied with a *Full Moon*, just before the time of the *Atumnal Equinox*.

Upon the same score it comes to pass, That in those Countries which are Subject to frequent *Inundations*, these Calamities are observed to happen at the times of the *Moon*'s greatest Influence, so that the Learned *Baccius*[53] has rightly enough laid the Cause of such Mischiefs upon immoderate *Tides of the Ocean*, being unhappily accompanied with the *attractive Force* of some or other *Stars*. {400}

Dr. *Childrey* in his *Britannia Baconica*[54] has from several Instances shewn the *Lunar* Action in Damages of this kind.

Such and the like *Natural* Causes have *Storms* and *Tempests*; for as to the Question of Divine Power, whether or no Calamities of this kind do not sometimes, by the Anger of Heaven, happen out of the Course of Nature, it is not my Business to Dispute, nor would I by any means indeavour to absolve Mens Minds from the Bands of Religion. For although we must allow all the Parts of the Machine of this World to be framed and moved by Established Laws, and that the same Disposition of its Fabrick, which is most beneficial to the Whole, must of necessity, in some few Places now and then occasion Hurts and Mischiefs; it is however most highly reasonable, that we should yield to the Supreme Creator an absolute Power over all his Works; Concluding withal, that it was perhaps agreeable to Divine Wisdom, to order the Make of the World after such a manner as might sometimes bring Mischiefs and Calamities upon Mankind, whom it was necessary by the Frights of *Storms*, *Thunder* and *Lightning* to keep in a continual Sence of their Duty. {401}

[52] *Vid.* Philos. Transact. N 289.

[53] *Del* Tevere, lib. 3. p. 228.

[54] Pag. 97.

The End.

*** END OF THE PROJECT GUTENBERG EBOOK MISCELLANEA CURIOSA, VOL. 1 ***

agreement before downloading, copying, displaying, performing, distributing or creating derivative works based on this work or any other Project Gutenberg™ work. The Foundation makes no representations concerning the copyright status of any work in any country other than the United States.

1.E. Unless you have removed all references to Project Gutenberg:

1.E.1. The following sentence, with active links to, or other immediate access to, the full Project Gutenberg™ License must appear prominently whenever any copy of a Project Gutenberg™ work (any work on which the phrase “Project Gutenberg” appears, or with which the phrase “Project Gutenberg” is associated) is accessed, displayed, performed, viewed, copied or distributed:

> This eBook is for the use of anyone anywhere in the United States and most other parts of the world at no cost and with almost no restrictions whatsoever. You may copy it, give it away or re-use it under the terms of the Project Gutenberg License included with this eBook or online at www.gutenberg.org. If you are not located in the United States, you will have to check the laws of the country where you are located before using this eBook.

1.E.2. If an individual Project Gutenberg™ electronic work is derived from texts not protected by U.S. copyright law (does not contain a notice indicating that it is posted with permission of the copyright holder), the work can be copied and distributed to anyone in the United States without paying any fees or charges. If you are redistributing or providing access to a work with the phrase “Project Gutenberg” associated with or appearing on the work, you must comply either with the requirements of paragraphs 1.E.1 through 1.E.7 or obtain permission for the use of the work and the Project Gutenberg™ trademark as set forth in paragraphs 1.E.8 or 1.E.9.

1.E.3. If an individual Project Gutenberg™ electronic work is posted with the permission of the copyright holder, your use and distribution must comply with both paragraphs 1.E.1 through 1.E.7 and any additional terms imposed by the copyright holder. Additional terms will be linked to the Project Gutenberg™ License for all works posted with the permission of the copyright holder found at the beginning of this work.

1.E.4. Do not unlink or detach or remove the full Project Gutenberg™ License terms from this work, or any files containing a part of this work or any other work associated with Project Gutenberg™.

1.E.5. Do not copy, display, perform, distribute or redistribute this electronic work, or any part of this electronic work, without prominently displaying the sentence set forth in paragraph 1.E.1 with active links or immediate access to the full terms of the Project Gutenberg™ License.

1.E.6. You may convert to and distribute this work in any binary, compressed, marked up, nonproprietary or proprietary form, including any word processing or hypertext form. However, if you provide access to or distribute copies of a Project Gutenberg™ work in a format other than “Plain Vanilla ASCII” or other format used in the official version posted on the official Project Gutenberg™ website (www.gutenberg.org), you must, at no additional cost, fee or expense to the user, provide a copy, a means of exporting a copy, or a means of obtaining a copy upon request, of the work in its original “Plain Vanilla ASCII” or other form. Any alternate format must include the full Project Gutenberg™ License as specified in paragraph 1.E.1.

1.E.7. Do not charge a fee for access to, viewing, displaying, performing, copying or distributing any Project Gutenberg™ works unless you comply with paragraph 1.E.8 or 1.E.9.

1.E.8. You may charge a reasonable fee for copies of or providing access to or distributing Project Gutenberg™ electronic works provided that:

- You pay a royalty fee of 20% of the gross profits you derive from the use of Project Gutenberg™ works calculated using the method you already use to calculate your applicable taxes. The fee is owed to the owner of the Project Gutenberg™ trademark, but he has agreed to donate royalties under this paragraph to the Project Gutenberg Literary Archive Foundation. Royalty payments must be paid within 60 days following each date on which you prepare (or are legally required to prepare) your periodic tax returns. Royalty payments should be clearly marked as such and sent to the Project Gutenberg Literary Archive Foundation at the address specified in Section 4, “Information about donations to the Project Gutenberg Literary Archive Foundation.”

- You provide a full refund of any money paid by a user who notifies you in writing (or by e-mail) within 30 days of receipt that s/he does not agree to the terms of the full Project Gutenberg™ License. You must require such a user to return or destroy all copies of the works possessed in a physical medium and discontinue all use of and all access to other copies of Project Gutenberg™ works.

- You provide, in accordance with paragraph 1.F.3, a full refund of any money paid for a work

or a replacement copy, if a defect in the electronic work is discovered and reported to you within 90 days of receipt of the work.

- You comply with all other terms of this agreement for free distribution of Project Gutenberg™ works.

1.E.9. If you wish to charge a fee or distribute a Project Gutenberg™ electronic work or group of works on different terms than are set forth in this agreement, you must obtain permission in writing from the Project Gutenberg Literary Archive Foundation, the manager of the Project Gutenberg™ trademark. Contact the Foundation as set forth in Section 3 below.

1.F.

1.F.1. Project Gutenberg volunteers and employees expend considerable effort to identify, do copyright research on, transcribe and proofread works not protected by U.S. copyright law in creating the Project Gutenberg™ collection. Despite these efforts, Project Gutenberg™ electronic works, and the medium on which they may be stored, may contain “Defects,” such as, but not limited to, incomplete, inaccurate or corrupt data, transcription errors, a copyright or other intellectual property infringement, a defective or damaged disk or other medium, a computer virus, or computer codes that damage or cannot be read by your equipment.

1.F.2. LIMITED WARRANTY, DISCLAIMER OF DAMAGES - Except for the “Right of Replacement or Refund” described in paragraph 1.F.3, the Project Gutenberg Literary Archive Foundation, the owner of the Project Gutenberg™ trademark, and any other party distributing a Project Gutenberg™ electronic work under this agreement, disclaim all liability to you for damages, costs and expenses, including legal fees. YOU AGREE THAT YOU HAVE NO REMEDIES FOR NEGLIGENCE, STRICT LIABILITY, BREACH OF WARRANTY OR BREACH OF CONTRACT EXCEPT THOSE PROVIDED IN PARAGRAPH 1.F.3. YOU AGREE THAT THE FOUNDATION, THE TRADEMARK OWNER, AND ANY DISTRIBUTOR UNDER THIS AGREEMENT WILL NOT BE LIABLE TO YOU FOR ACTUAL, DIRECT, INDIRECT, CONSEQUENTIAL, PUNITIVE OR INCIDENTAL DAMAGES EVEN IF YOU GIVE NOTICE OF THE POSSIBILITY OF SUCH DAMAGE.

1.F.3. LIMITED RIGHT OF REPLACEMENT OR REFUND - If you discover a defect in this electronic work within 90 days of receiving it, you can receive a refund of the money (if any) you paid for it by sending a written explanation to the person you received the work from. If you received the work on a physical medium, you must return the medium with your written explanation. The person or entity that provided you with the defective work may elect to provide a replacement copy in lieu of a refund. If you received the work electronically, the person or entity providing it to you may choose to give you a second opportunity to receive the work electronically in lieu of a refund. If the second copy is also defective, you may demand a refund in writing without further opportunities to fix the problem.

1.F.4. Except for the limited right of replacement or refund set forth in paragraph 1.F.3, this work is provided to you ‘AS-IS’, WITH NO OTHER WARRANTIES OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY OR FITNESS FOR ANY PURPOSE.

1.F.5. Some states do not allow disclaimers of certain implied warranties or the exclusion or limitation of certain types of damages. If any disclaimer or limitation set forth in this agreement violates the law of the state applicable to this agreement, the agreement shall be interpreted to make the maximum disclaimer or limitation permitted by the applicable state law. The invalidity or unenforceability of any provision of this agreement shall not void the remaining provisions.

1.F.6. INDEMNITY - You agree to indemnify and hold the Foundation, the trademark owner, any agent or employee of the Foundation, anyone providing copies of Project Gutenberg™ electronic works in accordance with this agreement, and any volunteers associated with the production, promotion and distribution of Project Gutenberg™ electronic works, harmless from all liability, costs and expenses, including legal fees, that arise directly or indirectly from any of the following which you do or cause to occur: (a) distribution of this or any Project Gutenberg™ work, (b) alteration, modification, or additions or deletions to any Project Gutenberg™ work, and (c) any Defect you cause.

Section 2. Information about the Mission of Project Gutenberg™

Project Gutenberg™ is synonymous with the free distribution of electronic works in formats readable by the widest variety of computers including obsolete, old, middle-aged and new computers. It exists because of the efforts of hundreds of volunteers and donations from people in all walks of life.

Volunteers and financial support to provide volunteers with the assistance they need are critical to reaching Project Gutenberg™’s goals and ensuring that the Project Gutenberg™ collection will remain freely available for generations to come. In 2001, the Project

Gutenberg Literary Archive Foundation was created to provide a secure and permanent future for Project Gutenberg™ and future generations. To learn more about the Project Gutenberg Literary Archive Foundation and how your efforts and donations can help, see Sections 3 and 4 and the Foundation information page at www.gutenberg.org.

Section 3. Information about the Project Gutenberg Literary Archive Foundation

The Project Gutenberg Literary Archive Foundation is a non-profit 501(c)(3) educational corporation organized under the laws of the state of Mississippi and granted tax exempt status by the Internal Revenue Service. The Foundation's EIN or federal tax identification number is 64-6221541. Contributions to the Project Gutenberg Literary Archive Foundation are tax deductible to the full extent permitted by U.S. federal laws and your state's laws.

The Foundation's business office is located at 809 North 1500 West, Salt Lake City, UT 84116, (801) 596-1887. Email contact links and up to date contact information can be found at the Foundation's website and official page at www.gutenberg.org/contact

Section 4. Information about Donations to the Project Gutenberg Literary Archive Foundation

Project Gutenberg™ depends upon and cannot survive without widespread public support and donations to carry out its mission of increasing the number of public domain and licensed works that can be freely distributed in machine-readable form accessible by the widest array of equipment including outdated equipment. Many small donations ($1 to $5,000) are particularly important to maintaining tax exempt status with the IRS.

The Foundation is committed to complying with the laws regulating charities and charitable donations in all 50 states of the United States. Compliance requirements are not uniform and it takes a considerable effort, much paperwork and many fees to meet and keep up with these requirements. We do not solicit donations in locations where we have not received written confirmation of compliance. To SEND DONATIONS or determine the status of compliance for any particular state visit www.gutenberg.org/donate.

While we cannot and do not solicit contributions from states where we have not met the solicitation requirements, we know of no prohibition against accepting unsolicited donations from donors in such states who approach us with offers to donate.

International donations are gratefully accepted, but we cannot make any statements concerning tax treatment of donations received from outside the United States. U.S. laws alone swamp our small staff.

Please check the Project Gutenberg web pages for current donation methods and addresses. Donations are accepted in a number of other ways including checks, online payments and credit card donations. To donate, please visit: www.gutenberg.org/donate

Section 5. General Information About Project Gutenberg™ electronic works

Professor Michael S. Hart was the originator of the Project Gutenberg™ concept of a library of electronic works that could be freely shared with anyone. For forty years, he produced and distributed Project Gutenberg™ eBooks with only a loose network of volunteer support.

Project Gutenberg™ eBooks are often created from several printed editions, all of which are confirmed as not protected by copyright in the U.S. unless a copyright notice is included. Thus, we do not necessarily keep eBooks in compliance with any particular paper edition.

Most people start at our website which has the main PG search facility: www.gutenberg.org.

This website includes information about Project Gutenberg™, including how to make donations to the Project Gutenberg Literary Archive Foundation, how to help produce our new eBooks, and how to subscribe to our email newsletter to hear about new eBooks.