

*A Discourse of the Rule of the Decrease of the Height of the Mercury in the 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 of Weather.*

By EDM. HALLEY.

THE Elastick Property of the *Air* has been long since made out, by Experiments before the *R. Society* and elsewhere; and the Resistence 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 shown 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 ten 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  $\frac{1}{4}$ ; but by reason 'twas Summer Weather, and consequently the *Air* rarified when all these were tried, we may without sensible Error say in 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  $13\frac{1}{2}$  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

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 *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 AB, CE, AKGE, ALDE, &c. (in Fig. 5.) are always equal, and consequently the 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, KG, 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 Sum will give the Spaces of *Air* between the several Heights of the *Barometer*; that is to say, the Sum 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 the *Air* answering to equal Parts of *Mercury* in the *Barometer*, are as the Areas CBKG, GKLD, DLFM, &c. These Areas 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 assigned Height of the *Mercury*, may most easily be found: For the Line *CB* in the *Hyperbola*, where of the *Areas* design the *Tabular Logarithms*, being 0,0144765; 'twill be, as 0,0144765, to the difference of the *Logarithms* of 30, and any other lesser Number, so 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 *Converse* of this Proportion may the Height of the *Mercury* be found, having the *Altitude* of the Place given. From these Rules I derived the following Tables.

*A Table shewing the Altitude to given Heights of the Mercury.*

<i>Inch.</i>	<i>Feet.</i>
30	0
29	915
28	1862
27	2844
26	3863
25	4922
20	10947
15	18715
10	29662
5	48378
1	91831
0,5	110547
0,25	129262
0,1	29 mil. or 154000
0,01	41 mil. 216169
0,001	53 mil. 278338

*A Table shewing the Heights of the Mercury at given Altitudes.*

<i>Feet.</i>	<i>Inch.</i>
0	30, 00
1000	28, 91
2000	27, 86
3000	26, 85
4000	25, 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

Up-

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 'tis probable that the utmost power of its spring cannot exert itself, to so great an extension, and that no part of the *Atmosphere* reaches above 45 miles from the surface of the Earth.

This seems confirmed from the Observations of the *Crepusculum*, which is observed 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. 6.* that the proportion of the height of the whole *Air*, to the Semidiameter of the Earth, is much about as 1 to 90, or as the excess of the *Secant* of about  $8\frac{1}{2}$  degrees to *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  $8\frac{1}{2}$  degrees *circiter*, whose *Secant* being 10 111 it follows that as 10000 to 111, so the Semidiameter 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.

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 the comparing it to Wool, Cotton, and the like Springy Bodies.

Hitherto I have only considered the *Air* and *Atmosphere*, as one unaltered Body, as having constantly at the Earth's Surface the 800th part of the weight of Water, and being capable of Rarefaction and Condensation *in infinitum*; neither of which *Hypotheses* are rigidly true: for here in *England* 'tis notoriously known, that the weight of the whole *Atmosphere* is various, being counterpoised sometimes by 28 $\frac{1}{2}$  Inches of *Mercury*, and at other times by no less than 30 $\frac{1}{2}$ , 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 rising from almost all Bodies, which assimilating into the form of *Air* are kept suspended therein, as Salts dissolved 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 increase the weight of that *Air* they lie incorporated withal, after the same manner as melted Salts do augment the *specifick* gravity of Water. The other consideration is, that the Rarefaction and Condensation of the *Air* is not precisely according to the Proportion here laid down; for tho' Experiment very nearly agrees thereto, as may be seen in the 58th Chapter of Mr. *Hook's Micrographie*, 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

been found by several Experiments tried here, and at *Florence*, by the *Academia del Cimento*. Nor can the Rarefaction proceed *in infinitum* ; for supposing the Spring whereby it dilates it self, occasioned 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 compressible into a very small Space, have yet a determinate Bulk which they cannot exceed, when freed from all manner of Pressure.

These Objections being true do disturb the Geometrical accuracy of these Conclusions, drawn from the specific Gravity of the *Air* observed at any time ; but the Method here shewn will compute by a like Calculation, the Heights of the *Quicksilver*, and the Rarefactions of the *Air* from any assigned Height of the *Barometer* at the Earth's Surface, and any specific Gravity given. As to the Condensation and Rarefaction 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, the Vapours are raised most copiously, so that tho' the *Air*, properly so called, be expanded and consequently lighter, yet the *Interstices* thereof being crowded 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 *Caernarvanshire*, 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 Inch. or 4 Inch. 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 Inch. by my Calculation should be 1288 Yards ; and it agrees as well with the Observations in the Appendix to Mr. *Pascal's* Book, *del Equilibre des*

*Liqueurs*, made on the high Hill in *Auvergne*, call'd *le puy de Domme*. So that the Rarefaction and Vapours seem not to have altered 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 *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 myself, seem to have some appearance of Truth; *first* then, 'tis 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 increased 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 assigned 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 inclined 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, tho' 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-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 we have had from others, and my own Observati-  
on 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 offered; and such an one I am bold 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 enquire into the Cause of its Uncertainty, but the Matter of Fact being most undoubted, the legitimate Consequences thereof must be allowed me; let it proceed from what it will.

A Second Cause is the uncertain Exhalation and Precipitation of the Vapours, lodging in the *Air*, 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.

I. *Why in calm Weather, the Air being inclined 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



ing at one time lower than at another, is the effect of two contrary Winds blowing *from* the place where 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 the greater height of the *Barometer* is occasioned 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 increased both in height and weight, the *Mercury* pressed 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 precipitate and fall down in Drops, which is the reason of the serene and good Weather which attends the greater heights of the *Mercury*.

3. *Why upon very great Winds or Storms, though 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 caused by the very rapid Motion of the *Air* in these Storms; for the Tract or Region of the Earth's 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

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 natural Consequence of the *Air's* Rarefaction.

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 35th degree of North Latitude, the Westerly and South-Westerly Winds, blow almost always *Trade*, 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 29 Inches, upon an Easterly Wind, but then it blew exceeding hard, and so comes to be accounted for by what was observed upon the 3d Remark.

5. *Why in calm and frosty 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 condensed, and in that State is brought hitherwards by those Winds, and being accumulated by the Opposition of the Westerly Wind blowing in the *Ocean*, the *Mercury* must

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 half in less than six hours, after a long continued Storm of South-west Wind. This seems to be occasioned by the sudden accession of new *Air* to supply the great Evacuation which such continued Storms make thereof, in those places where they happen (as in the third Remark) and by the Recoil of the *Air*, after the Force ceases that impell'd it; and the reason why the *Mercury* rises so fast, is because the *Air* being very much rarified beyond its mean Density, the neighbouring *Air* runs in the more swiftly to bring it to an *Æquilibrium*, 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 more Southerly?* The Truth of the Matter of Fact is proved from Observations made at *Clermont* and *Paris*, compared 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 Extream; and then the Northerly Winds bringing the condensed and ponderous *Air* from the Neighbourhood of the *Pole*, and that again being checked 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 Equinoctial, 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

these Variations of the Height of the *Mercury*, for in the Places above-named, there is always an easy Gale of Wind blowing nearly upon the same Point, *viz.* E. N. E. at *Bur-badoes*, 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 observed 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 Winds are Trade for half the Year one way, and half the Year another; only 'tis probable, that there may something worth noting happen, about the Times of the Change or Shifting of the Winds, which might be obtained 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 the *Equilibrium*, and sometimes again *to-wards* those Parts, where it is condensed and crouded above the mean state, which may be thought contradictory to the Laws of *Statics* and the Rules of the *Equilibrium* 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 descend 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*, overagainst 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*. The next *Transaction* shall give an *Historical Relation* of those *Winds* which are found to have any thing of *Constancy*, and shall endeavour to assign the *Causes* thereof.

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An Account of two Books, (1.) *A Free Enquiry into the vulgarly received Notion of Nature*, by the Honourable *R. Boyle, Esq;* Printed by *J. Taylor* at the *Globe* in *St. Paul's Church-Yard*, Anno 1686. 8vo.

**T**IS not without reason, that the renowned Author of this Treatise wonders that none have written concerning *Nature* herself, and yet so many have so largely treated of the Works of *Nature*. But this will seem less strange to him that considers for how many *Ages* the whole learned *World* has been devoted to the *Peripatetick* Principles of *Matter* and *Form*, and with how blind an *Obedience* the *Doctrine* of *Aristotle* hath been universally received and maintained: For the vulgar *Notion* of *Nature* concurring with the *Peripatetick*, having been generally admitted, all *Men* thought it unsafe to oppugn the *Opinion* of the *Multitude*, and at the same time to call in question the *Authority* of those reputed for *Learning*; subjecting their own *Judgments*, by a servile *Resignation* unworthy the *Name* of a *Philosopher*, to the *Dogma's* of others. This seems to be the chief, if not the only *Cause* of the *Propagation*

*Orbita quatuor Interiorum Satellitum Saturni cum Anse omniium maxime diductæ conspiciuntur*

