III. *An Account of a Book entitul'd* Vegetable Staticks: *Or an Account of ſome* Statical Experiments *on the* Sap *in* Vegetables; *being an* Eſſay *towards a* natural Hiſtory of Vegetation. *Alſo, a Specimen of an* Attempt *to Analyſe the* Air, *by a great Variety of* Chymico-Statical Experiments; *which were read at ſeveral Meetings before the* Royal Society, *&c. By* Stephen Hales, *B.D.F.R.S. Rector of* Farringdon, Hampſhire, *and Miniſter of* Teddington, Middleſex. *The Account by the Rev.* John Theoph. Deſaguliers, L.L.D. *R.S.S.*

AS the Antients us'd to ſay, that Geometry and Arithmetick are the Wings of a Mathematician; ſo a Mechanical Hand, and a Mathematical Head are the neceſſary Qualifications of an Experimental Philoſopher. The firſt alone may enable a Man to make a great many Experiments, but not to judge of them: For without being able to obſerve, compare, and calculate the exact Quantity of Weight, Force, Velocity, Motion, or any other Change to be taken notice of in making Experiments; Effects may be attributed to Cauſes which are not adequate to them, and ſometimes expected to be produc'd even without a Cauſe; as appears by the Coſt and Trouble of thoſe who have attempted to find

find the Perpetual Motion. Tho' ſuch Perſons may make ſome Diſcoveries, their Philoſophy will be at beſt but conjectural, and their Concluſions only gueſs-work. The mere Mathematician on the other hand, wants *Poſtulata* in Phyſics; or taking things for granted upon the Reports of others, comes often to wrong Concluſions, tho' he reaſons juſtly; becauſe his Premiſes are falſe: Whereas he might have been ſet right in ſeveral caſes, by only obſerving the Operations of Handycraft-Workmen, which he had over look'd or deſpis'd. Men of warm Imaginations, who wanted Mechanicks or Mathematicks, or wou'd not apply them to Phyſicks, have peſter'd the Learned World with Philoſophical Romances, ſuch as the Carteſian Syſtem, contriv'd for the Diverſion of the lazy and talkative; or Modern Theories, which their Authors, blinded by Vanity, and urg'd by Obſtinacy, have defended to the laſt, againſt Reaſon, Mathematicks and Experiments; nay, and have often for the Support of their Hypotheſes, contriv'd complex Experiments; from whoſe Inaccuracy they have drawn Arguments to deceive themſelves and others, as much to the diſadvantage of true Philoſophy, as the Scholaſtick Diſputes of the *Ariſtotelians*; in which, Victory, not Truth, was contended for.

But the incomparable Sir *Iſaac Newton* has not only ſhorten'd the Geometrician's Work, by his wonderful Diſcoveries in abſtract Mathematicks; but has alſo taught us, by his own Practice, how to make, and judge of, Experiments and Obſervations with the utmoſt Accuracy: And as he avoided making Hypotheſes; he was ſo cautious as to deliver only by way of Queries, ſeveral Truths which he was convinc'd of; becauſe he wanted a ſufficient Number of Experiments to make them as evident as thoſe others, whereby he has ſo far

far improv'd and advanc'd Natural Knowledge. Our Author has follow'd his ſteps, aſſerting nothing but what is evidently deduc'd from thoſe Experiments, which he has carefully made, and faithfully related; giving an exact Account of the Weights, Meaſures, Powers and Velocities, and other Circumſtances of the Things he obſerv'd; with ſo plain a Deſcription of his *Apparatus*, and manner of making every Experiment and Obſervation, that as his Conſequences are juſtly and eaſily drawn, ſo his Premiſes or Facts may be judg'd of by any Body that will be at the Pains to make the Experiments, which are moſt of them very eaſy and ſimple.

His Account of every Thing is written in ſuch an intelligible manner, that the inquiſitive Reader is capable of underſtanding it, without being puzzled with perplex'd Calculations and complex Experiments; which Authors have ſometimes contriv'd, in order to be admir'd for thoſe Things, which they themſelves found out either by mere chance, or with very little Labour. He has illuſtrated, and put paſt all Doubt, ſeveral Truths mention'd in Sir *Iſaac Newton's* Queries; which tho' believ'd by ſome of our Eminent Philoſophers, were call'd in queſtion by others of an inferiour Claſs, who were not acquainted with thoſe Facts and Experiments upon which Sir *Iſaac Newton* had built thoſe Queries.

But not to detain my Reader too long in general Remarks, I proceed to give a ſhort Account of each Chapter of our ingenious and indefatigable Philoſopher's Book.

CHAP.

CHAP. I.

Experiments ſhewing the Quantity of Moiſture imbib'd and perſpir'd by Plants and Trees.

OUR Author having cover'd with mill'd Lead a Garden-Pot, in which a Sun-flower was growing, ſo as to leave only one Paſſage for Air to communicate with the Earth, and another to pour in Water to water the Plant, made ſeveral curious Experiments upon it; from the Obſervation of which it appear'd,

1. That the Plant, which weigh'd about 3 lb perſpir'd 30 Ounces in a 12 Hours Day, in the Month of *July*, 1724. But in a warm Night it perſpir'd only three Ounces, and nothing in a cold Night; nay, ſometimes it gain'd Weight by imbibing Dew.

2. That as the Area of the Surface of the Leaves was equal to 5616 ſquare Inches, and the Area of the Roots only to 2286 ſquare Inches; the Moiſture or Water imbib'd by the Roots to ſupply the Perſpiration at the Leaves muſt move faſter in the Roots than thro' Leaves, in the Proportion of 5 to 2; but in the Stem, whoſe tranſverſe Section was one ſquare Inch, faſter than in the Leaves, in the Proportion of 5616 to 1.

3. That by comparing his Experiments made on this and other Sun-flowers and Plants, with Dr. *Keil's* Experiments mention'd in the *Medicina Statica Britannica*, it is evident, that a Man (Surface for Surface) perſpires more than a Plant, in the Proportion of 3 ½ to 1 — That the Quantity of the Food of a Man is to the Food of a Plant nearly as 7 to 2; but, Bulk for Bulk, the Plant imbibes into its Veſſels 17 times

times more Fluid than the Quantity of the Chyle which enters into a Man's Veſſels; and that becauſe, as the Sap to Plants is leſs nutritive than Chyle to Man, it muſt be more in Quantity. To ſuck in the more Sap, a Plant has a very great Surface, and thereby (Perſpiration promoting its imbibing of the Sap) perſpires 17 times more than a Man in proportion to their reſpective Weights.

4. That a Man or a Plant may perſpire different Quantities, and yet continue in a healthy ſtate. A Man may perſpire in 24 Hours from 1½ ℔ to 3 ℔; and a Plant, which at one time perſpir'd but 16 Ounces, may without being leſs healthy, perſpire 28 Ounces in the ſame time.

Mr. *Hales* obſerv'd, that in order to ſupply the Evaporation in the Leaves of a Vine, the Sap roſe 152 Inches in 12 Hours, ſuppoſing the Sap to riſe as denſe as Water; but if it riſes in a Steam, which muſt at leaſt be 10 times rarer than Water, then the Velocity of the Sap will be 10 times greater, and conſequently riſe at the rate of 125 Inches in an Hour.

N.B. *That the Heat of the Sun ſhould rariſie the Moiſture of the Earth to that Degree, or a great deal more, to drive it into the Roots of Plants, is very probable from ſome Obſervations that Mr.* H. Beighton F. R. S. *and my ſelf have made upon the Engine to raiſe Water by Fire; whereby it appears that the Steam or Vapour of boyling Water is rarer than the Water from which it was produc'd, above* 13000 *times, when its Elaſticity is equal to that of common Air.*

Our Curious Experimenter, by his Obſervations upon 12 Evergreens, found, that they perſpire much leſs than other Plants, and compares them to the exanguious Tribe of Animals; which, as they perſpire little,

little, ſo they live the whole Winter without Food. He likewiſe obſerv'd, what part of an Inch in Thickneſs is perſpir'd by a Man and by ſeveral Plants: By a Man in 24 Hours $\frac{1}{50}$ part of an Inch; and by the following Plants, *viz.* the Vine, the Sun-flower, the Cabbage, the Apple-Tree, the Lemon-Tree, $\frac{1}{191}$, $\frac{1}{165}$, $\frac{1}{86}$, $\frac{1}{104}$, $\frac{1}{242}$ part of an Inch in 12 Hours.

That when the perſpiring Surface is diminiſh'd by taking away the Leaves, the power of imbibing is likewiſe diminiſh'd; for the ſame Bough, which with the Leaves on imbib'd 30 Ounces in 12 Hours, without the Leaves imbib'd only 1 Ounce.

That Fruit will imbibe thro' the Stem in proportion to its Surface, tried in an Apple, which imbib'd as much as two Leaves equal to it in Surface.

That as the Leaves draw Nouriſhment to the Bloſſoms and Fruit, ſo they grow large firſt in thoſe Places where the Bloſſoms are.

That Hops in the middle of an Hop-Ground thrive beſt, becauſe they imbibe and perſpire the leaſt.

That by 9000 Hop-Vines growing on one Acre of Ground, 220 Gallons of Water are imbib'd in a 12 Hours Day, which Quantity of Water is equal to a Depth of $\frac{1}{101}$ part of an Inch ſpread on the ſaid Surface.

That Fire-Blaſts (as the Gardiners call them) may be occaſion'd by Solar Rays reflected from, or condens'd by Clouds, or even collected by means of the denſe Steams, which ariſe moſt plentifully in the middle of the Hop-Ground.

That the perſpiring Matter of Trees is not protruded by the Power of the Veſſels, but exhal'd by Heat, which he proves by ſeveral curious Experiments.

He made Trees imbibe Spirit of Wine, and other Liquors impregnated with Aromaticks, which gave a Smell and Taſte to the Stalk, Leaves and Wood; but could not penetrate to the Fruit, by reaſon of the Fineneſs of the Capillary Sap-Veſſels near the Fruit, which aſſimilated to their own Subſtance the high-taſted and perfum'd Liquors. Spirits kill'd the Trees, as far as they were imbib'd; but ſcented Waters did not.

He receiv'd in proper Veſſels the Matter perſpir'd from Trees which is a taſteleſs Water; but corrupts and ſtinks ſooner than common Water.

He weigh'd three Cubick Feet of the ſame ſort of (Brick-) Earth, taken from the Surface of the Earth downwards, in *July* 1724, the lighteſt of which was about twice the ſpecifick Gravity of Water: Then ſetting them to dry, found by the loſs of Weight, how much Water they contain'd; the greateſt Quantity exhal'd from a Cubick Foot being 10 ℔, and the leaſt, 6 ℔, 11 Ounces. N. B. *The Weights he made uſe of were Avoirdupoids.*

In order to find the Heat of the external Air in Green-Houſes and in Stoves, as alſo the Degrees of Heat at ſeveral Depths in the Earth, and in hot Beds, he provided ſix Thermometers, whoſe Stems were of different lengths, but adjuſted in their mark'd Degrees; ſo that they began at the freezing Point, and ended at 90 Degrees, where the Heat was equal to the Heat of warm Water, that may be born by the Hand, without ſtirring it about, which is the middle Point between freezing, and the Heat of boiling Water.

By theſe Thermometers he obſerv'd the Degrees of Heat in ſeveral Caſes to be as follows: *Of the Blood* =64. *Of the Human Body* =54. *Milk from the Cow, and Heat fit to hatch Eggs* = 55. *Urine* = 58. *Temperate*

perate Air = 18. *Greateſt Heat of Sunſhine in the Year* 1724 = 74. *And now this Year* 1727, *it is at* 76. *The common Heat of the Noon-Sun in* July = 50. *Air in the Shade at the ſame time* = 38. *The Heat in* May *or* June, *the fitteſt for Plants*, = *from* 17 *to* 30 *Deg. Autumnal Heat* = *from* 10 *to* 20 *A hot Bed, too hot for Plants, and about the Heat of Blood in Fevers* = 75. *Due Heat of a hot Bed* = 56. *Heat under a Glaſs at the ſame time* = 34; *and in the open Air* = 17.

Thermometers of this kind are now made by JOHN FOWLER in *Swithin's Alley* near the *Royal Exchange*, which have the Names of the following Plants, oppoſite to their reſpective moſt kindly Degrees of Heat, *viz. Melon-Thiſtle* = 31, *Ananas* = 29, *Piemento* = 26, *Euphorbium* = 24, *Cereus* = 21 $\frac{1}{2}$, *Aloes* = 19, *Indian Fig* = 16 $\frac{1}{2}$, *Ficoides* = 14, *Oranges* = 12, *Myrtles* = 9.

He obſerv'd the Air to be cooler than the Earth out of the Sun, but hotter in Sunſhine; and that as ſoon as the Heat of the Sun is ſo far decreas'd, as no longer to give a brisk Agitation to (or turn into Steam) the Moiſture of the Earth, the Leaves of the Plants fall off.

CHAP. II.

Experiments whereby to find the Force with which Trees imbibe Moiſture.

OUR Author, in order to make a juſt Eſtimate of the Force with which the Moiſture is drawn up by Plants and Trees, contriv'd an *Aquea-mercurial* Gage in the following manner. He took a Glaſs-Tube of an Inch Diameter, and about 8 Inches long, into one End of which he cemented a ſmaller Tube of about ¼ of an Inch Diameter, and 18 Inches long; into the other End he, ſucceſſively, cemented a Root, or Branch, or Stem of a Tree or Plant, whoſe imbibing Force he wanted to find out, which he did in the following manner, *viz.* He turn'd the ſmall End of the Gage upwards; and having pour'd Water into it, down upon the Wood cemented in, he ſtopt the Orifice with his Finger; then turning the little End downward again, he plac'd it into a Veſſel of *Mercury*, before he took off his Finger; which having done, he made his Obſervations. For as the Plant imbib'd the Water, the *Mercury* roſe up in the ſmall Tube, following the Water, and ſhewing by its Height, the Force of imbibing: And for every Inch that the *Mercury* roſe, Water would have riſen 13 ⅓ Inches, as it is ſo much lighter ſpecifically than Water.

With this Gage our Author made Experiments upon Roots, Branches in an erect, Branches in an inverted Situation, large ones, as well as ſmall, even to Sprigs of Plants and Fruits; and found, that all of them imbib'd the Water, ſo as to raiſe the *Mercury* in the ſmall Tube, but to different Heights. The *Mercury* was raiſed the quickeſt, and to the greateſt height (*viz.* 12 Inches,

Inches in 7 Minutes) by a Nonpareil-Branch two Foot high, with 20 Apples, and ſeveral lateral Branches, whoſe tranſverſe Section was ¼ of an Inch diameter. It is to be obſerv'd, that the *Mercury* roſe higheſt in a warm Sun; but the whole force of imbibing was much greater than the *Mercury* could ſhew; becauſe ſeveral Bubbles of Air came out of the Section of the Branch, as the Water went up, which happ'ned moſtly in large Branches, which raiſed the *Mercury* but to a ſmall height: But Branches ſtripp'd of their Leaves, hardly raiſed it all.

He made Peaſe imbibe Water, under the preſſure of great Weights; and found, that Peaſe, when ſwell'd, ſuſtained a Weight equal to 1600 ℔, by their force of imbibing, or growing.

The force of imbibing, he ſhews, to be owing to the attractive power of the Particles of which Plants are made up; all kinds of Wood (even Cork) when their Particles are well ſoak'd, being heavier than Water.

N. B. *It is very difficult to ſoak Cork ſo thoroughly as to make it heavier than Water: But I found it true, in a Tube where a Cork had been ſeal'd up with Water for four Years, ſo as to be moveable in the ſaid Water.*

CHAP.

CHAP. III.

Experiments, ſhewing the Force of the Riſe of the Sap in the Vine, in the Bleeding Seaſon.

MR. *Hales*, by a very curious Contrivance of Glaſs-Tubes, ſcrew'd and cemented at the top of one another, and altogether fixed to the Stem of a Vine, obſerv'd, that in the bleeding Seaſon (*viz.* in *March* and *April*) the Sap will riſe into the Tubes, by the force of the Roots and Stem, to very great heights, even above the Top of the Vine, as it did up to the Top of a Tube 25 Feet high (in two Hours) and ran out at the ſaid Tube, tho' 7 Feet above the Top of the Vine. But the Force was ſuch, that the Mercury, in a Gage (in other Experiments) was puſh'd up 32 $\frac{1}{2}$ Inches high, which was equivalent to above 43 Feet of Water. This is a much greater Force than the Blood is impell'd with in Animals: Which laſt Force he tried in the Crural Artery of an Horſe, of a Dog, and of a Deer: For having tied them down alive upon their Backs, and fixed a Glaſs-Tube to the Crural Artery open'd, he found, that in the Horſe the Blood roſe above 8 Feet, in the Dog about 7 Feet, and in the Deer not quite 6: And theſe Heights are 5, 7, and 8 times leſs than the Height to which the Sap is raiſed by the Vine. The Sap riſes all Night, but moſt in the Morning of a warm Day; but in very hot Weather it ceaſes to riſe about Ten in the Morning, and then begins again to riſe about 3 or 4 in the Afternoon; and during the great Heat, Bubbles of Air drawn in by the Roots, come up the Tube from the Section of the Stem, the Sap in the Tube ſinking and riſing as the Weather is cloudy or clear, like the Liquor in a Thermometer.

That

That the Force was not only in the Root, but in the Stem and Branches, appear'd by ſeveral Experiments, one of which was, that a Vine, at 44 Feet, 4 Inches in diſtance from the Root, puſh'd up Sap with the Force of a Column of 30 Feet, 11 Inches of Water.

By a nice Experiment he ſhews, that the Sap does not come indifferently thro' all the Interſtices of the Wood; but is confined to its proper Veſſels.

The Fibres, or Capillary Tubes, out of the bleeding Seaſon, cannot protrude the Sap beyond their Orifices in the Section of the Stem; but, aſſiſted by the Perſpiration of the Leaves, the Sap will riſe in that very Branch, which would imbibe Water, if it was cut off, and a Tube applied to it with Water, poured in; nay, it wou'd alſo imbibe Water at the ſmall End.

CHAP. IV.

Experiments, ſhewing the ready lateral Motion of the Sap, and conſequently the lateral Communication of the Sap-Veſſels: The free Paſſage of it from the ſmall Branches towards the Stem, as well as from the Stem to the Branches. With an Account of ſome Experiments relating to the Circulation, or Non-Circulation of the Sap.

THE Analogy that there is in many reſpects between Plants and Animals, has made ſeveral ingenious Men imagine, that the Sap muſt circulate in Plants, as the Blood does in Animals; and, fond of the Hypotheſis, they have contented themſelves with a few Experiments that ſeem to confirm the Notion: And inſtead of making a ſufficient Number of Experiments

riments and Obſervations, and comparing them impartially, they have ſupplied the reſt by Conjectures, and endeavour'd to ſupport their Hypotheſis by other new Suppoſitions. It is upon this account that they have ſuppoſed particular Veſſels (like Arteries) to carry up the Sap from the Roots to the Extremities or Leaves, and others (like Veins) to bring down the Sap back again to the Roots; imagining the former to be chiefly in the middle of the Wood, and the latter to come down between the Bark and the Wood: But they did not conſider, that a Plant is very differently nouriſhed from an Animal, and therefore requires a very different Mechaniſm and Structure for its Growth and Support.

Our Author has diſproved the above-mentioned Opinion, by ſeveral Experiments and Obſervations; the chief of which are the following.

1. Having cut a long Notch in a growing Branch, which had Leaves on, he obſerved, that the Notch was moiſt at the Bottom towards the Root, and not at the Top.

2. He made the ſame Experiment with another Branch ſet in Water, which imbib'd the Liquor at a tranſverſe Section below the Notch, and found the Notch as before.

3. He obſerv'd, that in the Spring the Sap riſes plentifully between the Bark and the Wood, and that chiefly in Vines; and that if a Ringlet of Bark be taken off all round in bleeding Trees, the Bleeding abates moſtly in the upper part of the bare place.

4. The Sap will move any way by the Attraction of the ſame Capillary Tubes, and Perſpiration of the Leaves; ſhewn by an Apple Tree-Branch, which drew up Moiſture plentifully at the ſmall End; by a Tree, which throve, tho' its Root was taken out of the Ground,

Ground, receiving its Nouriſhment only from two other Trees, to which it was inarch'd, and from which it was ſuſpended; as alſo by a Bough with two Branches cut off from a Tree, one Branch of which out of the Water preſerv'd its Verdure, and receiv'd its Nouriſhment from the other Branch immers'd in Water, whilſt another Bough of the ſame ſort without that help, immediately wither'd.

That there is a lateral Motion of the Sap thro' Veſſels, whereby the longitudinal Capillary Fibres communicate with one another, he prov'd chiefly by the following Experiment, *viz.* He cut four long Notches, one above another, (but looking towards the ſeveral Cardinal Points) in a pretty large Branch, whoſe Section ſome Inches below the ſaid Notches, was immers'd in Water; and found, that by the Attraction of the Fibres and Perſpiration of the Leaves, the Moiſture roſe plentifully, notwithſtanding that the Continuity of the greateſt part (if not of all) the longitudinal Fibres was deſtroy'd by thoſe deep Notches.

This lateral Motion may alſo be deduc'd, from obſerving, that Branches will grow out of Roots, and thrive very well; and that Elders, Sallows, Willows, Briars and Vines will grow, by putting either End of a Stem or Branch into the Ground.

He obſerves, that there is indeed, an alternate Receding and progreſſive Motion of the Sap, which recedes when cold Weather and Rain ſucceeds hot Sunſhine, the Trees then imbibing the Rains and Dews which fall upon the Leaves; but upon the return of the hot Weather, the Perſpiration is renew'd, and the Sap riſes again. This is ſufficient to account for Jeſſamine and the Paſſion-Tree receiving a gilded Tincture below the gilded inoculated Bud; which has been given as an Inſtance of the Circulation of the Sap: But the *Ilex*

grafted on the Engliſh Oak, as it keeps (whilſt the Oak ſheds) its Leaves in Winter, ſhews that the Sap does not circulate.

CHAP. V.

Experiments, whereby to prove, that a great Quantity of Air is inſpir'd by Plants.

OUR Sagacious Author makes it appear in this Chapter, that Plants imbibe a great deal of Air, not only that which comes up with the Sap from the Earth (the Earth containing Air both in an elaſtick and in a fix'd ſtate,) but alſo take it in thro' the old Eyes and Bark, eſpecially at Night, when the Plants are in an imbibing State.

The Experiments whereby he proves the ſaid Aſſertion, are chiefly theſe, viz.

1. An open, empty, Glaſs-Tube ſet upright, had an Apple-Branch cemented in its upper end, the other End ſet in a Veſſel of Water; upon which the Air went up into the Branch out of the Tube, as appear'd by the riſing of Water into the Tube.

2. A Cylinder of Birch of about ¼ Inch Diameter, with the Bark on, cemented in the middle, to the Top of an Air-Pump Receiver, ſo as to fill up the Hole at the Top of the ſaid Receiver, had its lower End immers'd in a Veſſel of Water under the Receiver, upon the Plate of the Air-Pump. Then in working the Pump, Air came out at the Bottom of the ſaid Cylinder, bubbling

(bubbling up thro' the Water in the Veſſel) whether erect or inverted, cemented cloſe on the Top-Section, or not, and whether the old Eyes in the Sides were cemented up, or left bare, the Bark it ſelf being pervious to Air; but then it took in leſs Air than when the old Eyes and upper Section were open.

3. When Water (pour'd into a Cylindrick Glaſs fix'd over the Receiver) cover'd that part of the Wood which was out of the Receiver, no Air came thro' the Bottom; and when the Water was taken away from covering the upper part of the Wood, the Air did not come in thro' the Bottom, till the Top of the Cylinder of Wood had its Bark well dried.

4. He obſerves with Dr. *Grew*, that the Mouths of the Air-Veſſels are very viſible in the Leaves of Pines, and in the Trunks of ſeveral Plants, with a Microſcope; and in ſome even without a Glaſs.

5. In making Experiments upon young Shoots, as their Veſſels are full of Sap, he did not find that the Air paſs'd into or thro' them; (the Air in them being probably become fix'd) but it came in freely at the Roots applied to the Air-Pump in the ſame manner as in the Piece of Birch.

CHAP. VI.

A Specimen of an Attempt to analyze the Air, by a great Variety of Chymio-Statical Experiments, which ſhew, in how great a proportion Air is wrought into the Compoſition of Animal, Vegetable, and Mineral Subſtances; and withal how readily it reſumes its former elaſtick State, when in the Diſſolution of thoſe Subſtances it is diſingaged from them.

THE excellent Mr. *Boyle*, among his many Diſcoveries, found, that Air was producible from Vegetables, by putting Grapes, Plums, Gooſe-berries, Cherries, Peaſe, and ſeveral other ſorts of Grain into exhauſted and unexhauſted Receivers, where they continued ſeveral Days, emitting great Quantities of Air. But Mr. *Boyle* did not ſhew the way to know exactly how much Air a certain Quantity of Vegetable Subſtance will produce.

The incomparable Sir *Iſaac Newton* (*Query* 31, of his *Opticks*) obſerves, that "true permanent Air "ariſes by Fermentation or Heat, from thoſe Bo- "dies which the Chymiſts call *fixed*, whoſe Par- "ticles adhere by a ſtrong Attraction, and are not "therefore ſeparated and rarified without Fermentati- "on. Thoſe Particles receding from one another "with the greateſt repulſive force, and being moſt "difficultly brought together, which upon Contact "were moſt ſtrongly united. And (*Query* 30.) Denſe "Bodies by Fermentation rarify into ſeveral ſorts of "Air, and this Air by Fermentation, and ſometimes "without it, returns into denſe Bodies.

Mr.

Mr. *Hales*, from the Conſideration of this, and ſome of his own Experiments, concluded, that there muſt be Air not only in an elaſtick, but in a fix'd State, in Vegetables and other Subſtances, and therefore that the Air-Pump wou'd not be ſufficient to get all the Air out of Bodies: For which reaſon he contriv'd ways of getting the Air out of ſeveral Subſtances by Fire (diſtilling them,) and by Fermentation, and made uſe of a very ingenious, but ſimple and certain Method, of meaſuring the Quantity of Air generated from(or abſorb'd by) the ſeveral kinds of Bodies upon which he made Experiments. The Deſcription of his Hydroſtatical Gages, and the Manner of making his Experiments, I cannot give better, or ſhorter, than in his own Words (*See Page* 157.)

" In order to make an Eſtimate of the Quantity of " Air which aroſe from any Body by Diſtillation or " Fuſion, I firſt put the Matter which I intended to " diſtil, into a ſmall Retort *r* (*Figure* 4.) and then at " *a* cemented faſt to it the Glaſs-Veſſel *a b*, which was " very capacious at *b*, with a Hole in the bottom. I " bound a Bladder over the Cement, which was made " of Tobacco-pipe-Clay and Bean-flower, well mixed " with ſome Hair, tying over all four ſmall Sticks, " which ſerv'd as Splinters to ſtrengthen the Joynt; " ſometimes, inſtead of the Glaſs-Veſſel *a b*, I made " uſe of a large Bolt-head, which had a round Hole " cut, with a red-hot Iron-ring, at the bottom of it; " through which Hole was put one Leg of an inverted " Syphon, which reached up as far as *z*. Matters being " thus prepared, holding the Retort uppermoſt, I " immerſed the Bolt-head into a large Veſſel of Water, " to *a*, the top of the Bolt-head; as the Water ruſhed " in at the bottom of the Bolt-head, the Air was " driven out through the Syphon: When the Bolt-head

" head was full of Water to z, then I cloſed the out-
" ward Orifice of the Syphon with the End of my
" Finger, and at the ſame time drew the other Leg
" of it out of the Bolt-head, by which means the
" Water continued up to z, and could not ſubſide.
" Then I placed under the Bolt-head, while it was in
" the Water, the Veſſel *xx*; which done, I lifted the
" Veſſel *xx*, with the Bolt-head in it, out of the Water,
" and tyed a waxed-Thread at z to mark the height
" of the Water: And then approached the Retort
" gradually to the Fire, taking care to skreen the
" whole Bolt-head from the Heat of the Fire. The
" Deſcent of the Water in the Bolt-head ſhewed the
" Sums of the Expanſion of the Air, and of the Matter
" which was diſtilling: The Expanſion of the Air alone,
" when the lower part of the Retort was beginning to
" be red-hot, was at a Medium, nearly equal to the
" Capacity of the Retort, ſo that it then took up a
" double Space; and in a white and almoſt melting
" Heat, the Air took up a triple ſpace or ſomething
" more: For which reaſon the leaſt Retorts are beſt
" for theſe Experiments. The Expanſion of the diſtil-
" ling Bodies was ſometimes very little, and ſome-
" times many times greater than that of the Air in
" the Retort, according to their different natures.

" When the Matter was ſufficiently diſtilled, the
" Retort, *&c.* was gradually remov'd from the Fire,
" and when cool enough, was carried into another
" Room, where there was no Fire. When all was
" throughly cold, either the following Day, or ſome-
" times 3 or 4 Days after, I mark'd the Surface of
" the Water *y*, where it then ſtood; if the Surface
" of the Water was below z, then the empty Space
" between *y* and z, ſhewed how much Air was
" generated, or rais'd from a fix'd to an elaſtick
" State, by the Action of the Fire in Diſtillation: But

" if

" if *y* the Surface of the Water was above *z*, the ſpace
" between *z* and *y*, which was filled with Water, ſhew-
" ed the Quantity of Air which had been abſorbed in
" the Operation, *i. e.* was changed from a repelling
" elaſtick, to a fixed State, by the ſtrong Attraction
" of other Particles, which I therefore call *abſorbing*.
" When I would meaſure the Quantity of this new
" generated Air, I ſeparated the Bolt-head from the
" Retort; and putting a Cork into the ſmall End of
" the Bolt-head, I inverted it, and poured in Water
" to *z*. Then from another Veſſel (in which I had a
" known Quantity of Water by Weight) I poured
" in Water to *y*; ſo the Quantity of Water which was
" wanting, upon weighing this Veſſel again, was equal
" to the Bulk of the new generated Air. I choſe to
" meaſure the Quantities of Air, and the Matter from
" whence it aroſe, by one common Meaſure of cubick
" Inches, eſtimated from the ſpecifick Gravities of the
" ſeveral Subſtances, that thereby the Proportion of
" one to the other might the more readily be ſeen.
" I made uſe of the following means to meaſure the
" great Quantities of Air, which were either raiſed
" and generated, or abſorbed by the Fermentation
" ariſing from the Mixture of Variety of ſolid and
" fluid Subſtances, whereby I could eaſily eſtimate the
" ſurpriſing Effects of Fementation on the Air, *viz.*
" I put into the Bolt-head *b* (Fig. 5.) the Ingredients,
" and then run the long Neck of the Bolt-head into the
" deep cylindrical Glaſs *a y*, and inclined the in-
" verted Glaſs *a y*, and Bolt-head almoſt horizontally
" in a large Veſſel of Water, that the Water might
" run into the Glaſs *a y*; when it was almoſt up to
" *a*, the top of the Bolt head, I then immerſed the
" Bottom of the Bolt-head, and lower part *y* of the
" cylindrical Glaſs under Water, raiſing at the ſame
time

" time the End *a* uppermoſt. Then before I took " them out of the Water, I ſet the Bolt-head and " lower part of the cylindrical Glaſs *a y* into the ear- " then Veſſel *x x* full of Water, and having lifted all " out of the great Veſſel of Water, I marked the " Surface *z* of the Water in the Glaſs *a y*. If the In- " gredients in the Bolt-head, upon fermenting, gene- " rated Air, then the Water would fall from *z* to *y*, " and the empty ſpace *z y*, was equal to the Bulk of " theQuantity of Air generated: But if the Ingredients " upon fermentation, did abſorbe, or fix the active " Particles of Air, then the Surface of the Water " would aſcend from *z* to *n*, and the Space *z n*, which " was filled with Water, was equal to the Bulk of Air, " which was abſorbed by the Ingredients, or by the " Fume ariſing from them: When the Quantities of " Air, either generated or abſorbed, were very great, " then I made uſe of large chymical Receivers, inſtead " of the Glaſs *a y*: But if theſe Quantities were very " ſmall, then inſtead of the Bolt-head, I us'd a deep " cylindrical Glaſs, or a common Beer-Glaſs inverted, " and placed under it a Vial or Jelly-Glaſs, taking " care that the Water did not come at the Ingre- " dients in them: Which was eaſily prevented, by " drawing the Water up under the inverted Glaſs " to what height I pleaſed, by means of a *Syphon*. " I meaſured the Bulk of the Spaces *z y* or *z n*, by " pouring in a known Quantity of Water, as in " the foregoing Experiment, and making an allow- " ance for the Bulk of the Neck of the Bolt-head, " within the Space *z y*.

By our Author's Experiments made upon ſeveral Subſtances, it appear'd, that ſome by Diſtillation, and ſome by Fermentation, wou'd generate Air, others wou'd abſorb it; and ſome again, wou'd abſorb Air

Air at one time, and generate it at another; and oftentimes that more Air was generated by Fermentation than by Fire. I have made a Table, to ſhew at one View what the Effects were.

Bodies which generated Air.	*Bodies which abſorb'd Air.*	*Bodies which ſometimes generated, and ſometimes abſorb'd Air.*
Hog's Blood.	Salt of Sal Armoniac.	Gun-Powder.
Tallow.	*Phoſphorus.*	Apples maſh'd.
Fallow-Deer's Horn.	Acid Spirits.	Filings of Steel and *Aqua fortis.*
Oyſter-ſhells.	Lime.	Scurvygraſs-Leaves
A Piece of Oak.	*Pulvis urens.*	*Sal Armoniac* mix'd with Oil of Vitriol.
Indian-Wheat.	Brimſtone-Matches burning.	Spirit of Turpentine mix'd with Oil of Vitriol.
Peaſe.	A burning Candle.	Vineger pour'd on Oyſter-ſhells.
Muſtard-Seed.	Living Animals. *e.g.* a Rat and a Cat.	Limon-Juice.
Amber.	Humane Lungs in breathing.	Ale.
Tobacco.	Filings of Iron with Sp. of Nitre.	Malaga-Raiſins.
Oil of Anniſeed.	Filings of Iron with Spt. of Hartſhhorn.	N. B. *Moſt of the abovemention'd Subſtances were in an abſorbing State in cold Weather.*
Oil of Olives.	Filings of Iron with Spirit of Sal Armoniac.	
Honey.	N. B. *When a lighted Candle is put into that Air which had been foul'd (by a Candle burning and going out in it) tho' it burn'd but a fifth part of the Time that it had done before, it abſorb'd as much Air; which ſhews that Air loaded with Vapours is more apt to loſe its Elaſticity, than clear Air.*	
New-caſtle-Coal.		
Wax.		
Earth.		
Salt.		
Antimony.		
Pyrites from *Walton*-Heath.		
Sea-Salt.		
Nitre.		
Calculus humanus.		
Vitriol.		
Bones.		
Red Lead.		
Chalk.		
Wheat and Barley.		
Filings of ♂ with Oil of Vitriol and Water.		

As ſeveral Perſons may be willing to try a great many of Mr *Hale's* Experiments, I thought proper to mention here, that the Experiments on Subſtances that generate Air, made with the Glaſs-Retort, are difficult and tedious; but a Musket-Barrel with the Touch-hole welded up, and then turn'd into a Semi-circle, makes a very commodious Iron-Retort, whoſe cloſe End being put into the Fire of a Smith's Forge, will be ſo heated with a little blowing, as to get the Air out of any Subſtance in a very little time; having firſt twiſted on upon the open End of the Barrel one End of a Leaden Syphon (which will be very tight, with only a little Sheep's Leather between) whilſt the other End of the Syphon goes up a little way into an inverted Chymical Receiver fill'd with Water. As the Air gets out of the Subſtances diſtill'd, it comes bubbling up thro' the Water, which it depreſſes by its Bulk. N. B. *Antimony and Sulphur muſt not be made uſe of in this Barrel; becauſe they will demetallize the Iron; nor Lead, becauſe it will ſweat out thro' the Iron.*

It appear'd by ſeveral Experiments, that the Air which was got out of the Subſtances above-mention'd, was true permanent Air; for it had, and, after many days, continu'd to have, both the Weight and Elaſticity of common Air, of which a cubick Inch weighs $\frac{1}{2}$ of a Grain, and after it had been compreſs'd, it wou'd expand again to its former Dimenſions.

Moſt of that Air had a poiſonous Quality, a Sparrow dying as it was put into the Air made of Oak, 11 days after the ſaid Air had been made. So Mr. *Boyle* found the Air drawn by the Air-Pump from Bread and ſome other Subſtances, to have a poiſonous Quality.

Air generated by *Indian* wheat and by Peaſe, and moſt other Subſtances, flaſh'd when the Candle was applied to it.

The

The moſt ſolid Parts of Animals or Vegetables commonly generated moſt Air: Of Vegetables, Oak and Peaſe generated the moſt Air; Oak $\frac{1}{5}$ of its Weight, and 216 times its Bulk, and the Peaſe more than $\frac{1}{3}$ of their Weight and 396 times their Bulk. But of all Subſtances, a Stone taken from the Bladder of a Man generated moſt Air, namely a Quantity of Air 645 times the Bulk, and above half the Weight of the Stone.

Our indefatigable Philoſopher, to judge the better of the reſult of theſe Experiments, contrived a Gage with a Tube ſeal'd at one end, and having the other (open End) immers'd in Mercury cover'd with Honey, which in the riſe of the Mercury in the Glaſs wou'd leave a mark to ſhew how far the Mercury had riſen, (See the Deſcription and Draught of it in his Book, *Page* 205;) by the force of compreſs'd Air or of the Air that is generated from ſeveral Subſtances whilſt confin'd; and propoſes this Gage for meaſuring the Depth of the Sea, which muſt anſwer better than any Contrivance hitherto tried.

From obſerving that it wou'd require a Force 48 times greater than that of the Atmoſphere, to compreſs the Air that comes out of an Apple into the ſame ſpace again (which in an Apple of 16 ſquare Inches Surface, is equal to 11776 Pounds,) he concludes that the greateſt part of the ſaid Air muſt be in a fix'd State, and preſerv'd in that State by the Attraction of the Particles of Air and Apple in their Coheſion; otherwiſe Fruits and all other Subſtances that contain much Air, wou'd be torn to pieces by its repellent Force, with a greater Exploſion than that of Gunpowder; and therefore that the Air when extricated, does not conſiſt of fibrous Particles wound up like little Springs, but of Particles which do not touch

one another, but have a repellent Force, which is reciprocally proportionable to the Diſtances of the Particles: Agreeable to what Sir *Iſaac Newton* ſays in his Opticks, *Quer.* 31. "The Particles, when they "are ſhaken off from Bodies by Heat or Fermen- "tation, ſo ſoon as they are beyond the reach of "the Attraction of the Body, receding from it, "as alſo from one another, with great Strength, "and keeping at diſtance, ſo as ſometimes to take "up above a million of times more ſpace than they "did before in the form of a denſe Body; which "vaſt Contraction and Expanſion ſeems unintel- "ligible, by feigning the Particles of Air to be "ſpringy and ramous, or rolled up like Hoops, or "by any other means than by a repulſive Power.

Our Author made ſome Experiments upon a Calve's Lung's, which help to confirm Dr. *James Keil's* Aſſertion, *viz.* that the inner Surface of a Man's Lungs is equal to about 150 * ſquare Feet, which is about 10 times more than the Surface of the whole Body. Then by ſeveral Experiments and curious Obſervations, found, that of the Air which is inſpir'd by the Lungs in an Hour (*viz.* 48000 cubick Inches) about 353 Inches, or 100 Grains in Weight are deſtroy'd in that Time.

He ſhews, that the reaſon that Sulphureons Air is pernicious, is becauſe Sulphureous Air loſes its Elaſticity ſo faſt, that the Lungs will ſubſide in it, and the Blood conſequently ſtagnate. He concludes, that when the Particles of ſuch Air are united into pretty large *Moleculæ* in a fix'd State, they are too big to enter the Veſicles of the Lungs.

* *Since my making this Abſtract, Mr.* Hales *told me, that the inner Surface of the Lungs is double the Quantity here expreſs'd, which was ſo ſet down in his Book by miſtake.*

He

He ſhews the Miſtake of thoſe that ſuppos'd the Air did not loſe its Elaſticity, but its *Vivifying Spirit* by Vapours, by an Experiment made upon a Dog, into whoſe Lungs he drove by Force that effœte Air which the Dog by his own Action cou'd not draw into his Lungs; and whereas the Dog, then, was juſt expiring by the ſubſiding of his Lungs, he kept him alive by the forcible Impulſion of that very Air, as long as he cou'd blow up the Dog's Lungs with it.

He makes it appear, that a cloſe warm Air without a Communication with the outward Air, to carry off the Vapours, muſt be unfit for breathing long; and therefore condemns the uſe of *German* Stoves.

That when Animals are kill'd by Lightning without any viſible Wound, it is becauſe the Sulphureous, Steams have deſtroy'd the Elaſticity of the Air about them; as appears by diſſecting ſuch Animals, whoſe Lungs are always found compreſs'd together without any Air in them. The ſame alſo appears in Men that have been kill'd by Damps in Mines.

Then he gives the Deſcription of an Inſtrument whereby 4 or 5 Quarts of the ſame Air, (which in the common way can ſerve one Man to breathe very little above a Minute) may ſerve 8 ÷ Minutes to breathe, by drawing in the Air which has been in the Lungs thro' 4 Diaphragms of Flannel dipp'd in a *Lixivium* of highly calcin'd Salt of Tartar, and afterwards dried, and blowing back the ſame Air in ſuch manner that it may at every Inſpiration return thro' the ſaid Diaphragms; which is done by means of two Valves. The Moiſture and Sulphureous Vapours of the Air are by this Contrivance ſtopp'd in paſſing thro' the Flannel, and thereby the Air continues wholeſome much longer than it wou'd

wou'd in the common way of breathing: This he propoſes as uſeful to thoſe who have occaſion to go into Places where the Air is infectious; but where the noxious Vapours are not very denſe, Mufflers only of Cloth or Flannel impregrated with Salt of Tartar may ſerve, as he found by ſeveral Experiments.

He ſhews afterwards the Reaſons why *Pulvis fulminans* has more Force than Gun-Powder, and confirms Sir *Iſaac Newton*'s account of Fire and Flame (*Query* 9. and 10. of his *Opticks*) but ſhews Dr *Nieuwentyt*'s, Dr. *Boerhaave*'s and Monſ *L'Emery*'s Account of Fire to be erroneous; but that it was not the matter of Fire, but Elaſtick Air which that laſt nam'd Gentleman had ſo often obſerv'd to be loſt in the Analyſis of Bodies.

That the artifical Sulphur made by Monſ *Geofroy*, was inflammable chiefly on account of the Air ſupplied to it by the Oil of Tartar.

That if Fire was a peculiar Matter in Sulphur, it ought to dilate, not to condenſe, the Air; as it appears to do by Experiment. That Fire conſiſts in the Action and Reaction between repellent Air and attracting Sulphur; and that Heat is communicated by the Æthereal Medium mention'd by Sir *Iſaac Newton* in the laſt Edition of his *Opticks*.

That Fermentation will diſſolve Bodies without the Help of included Fire, acting according to its ſeveral Degrees; a lower Degree of it (ſuch as attends every inteſtine Motion) not being inconſiſtent with the healthy State of Plants and Animals.

That acid Particles by their great attractive Force diſſolve Bodies, ruſhing towards their Particles, ſo as to excite Heat, and ſhake aſunder ſome of them, and turn them into Air.

That

That Air, in a fix'd State, is the Bond of Union, which makes Salts durable, and which keeps together the Solid Parts of Vegetables, of Animals, and even Globules of the Blood.

That the Air in a moiſt State is ſooner abſorb'd by Sulphureous Steams, than in a dry State; for a Candle which in a dry Receiver burn'd 70′′, burn'd but 64′′ in the ſame Receiver when it was fill'd with the Fumes of hot Water; but yet abſorb'd one fifth part more of Air. But the abſorbing Subſtances loſe their Force of acting, when united in a large Body, Brimſtone in a Roll abſorbing no Air, tho' it does it ſo plentifully when reduc'd into Minute Particles.

That ſome of the Food of Animals generates, and ſome abſorbs Air, and the Digeſtion in a healthy State is beſt perform'd when there is but a little Air more generated than is abſorb'd.

From the Conſideration of the ſeveral Experiments made by our Author, in his Analyſis of Air, he makes it appear that our Atmoſphere is a Chaos of different Particles, ſome of which are elaſtick, and ſome unelaſtick; and that the elaſtick Parts are endued with very different Degrees of Elaſticity, according as they are bigger or leſs, more or leſs ſolid, more or leſs watry; and therefore that ſome are eaſily and ſome more difficultly reducible to a fix'd State.

That it is chiefly by the Change of Air from a fix'd to an elaſtick, and from an elaſtick to a fix'd State, that this beautiful *Frame of Things* is maintain'd in a continual round of the Production and Diſſolution of animal and vegetable Bodies; and therefore, that there is as much reaſon to adopt Air among the Chymical Principles, as acid Sulphur; tho' it has hitherto been rejected by the Chymiſts.

This will be continu'd in the next.

F I N I S.

Fig. 2.

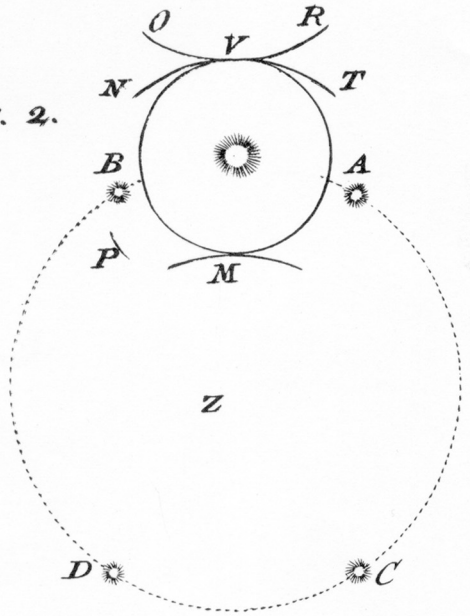

Fig. 1.

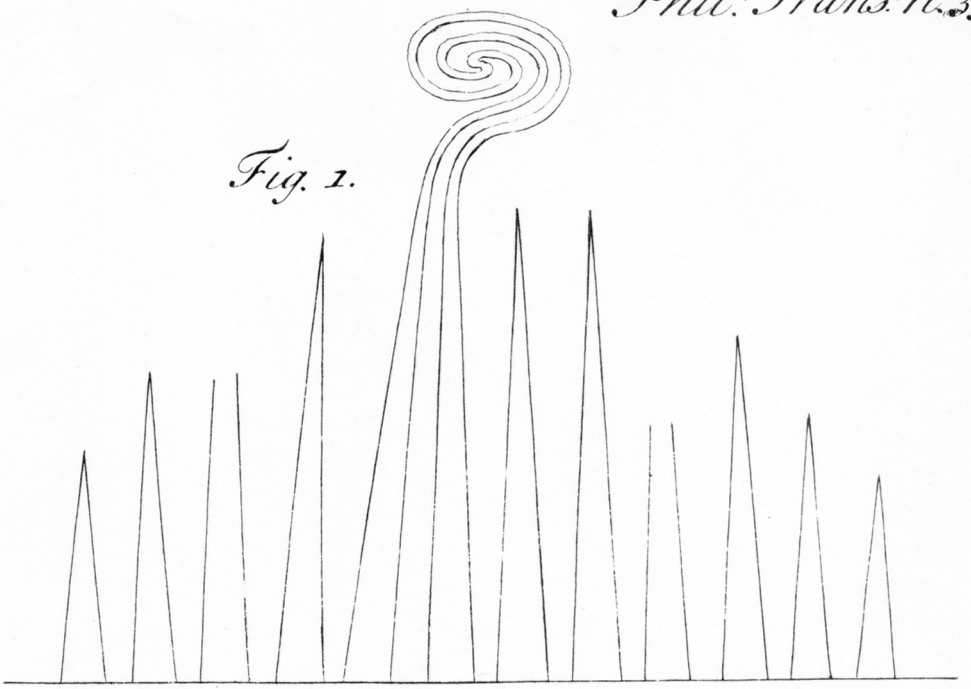

Fig. 3.

Fig. 5.

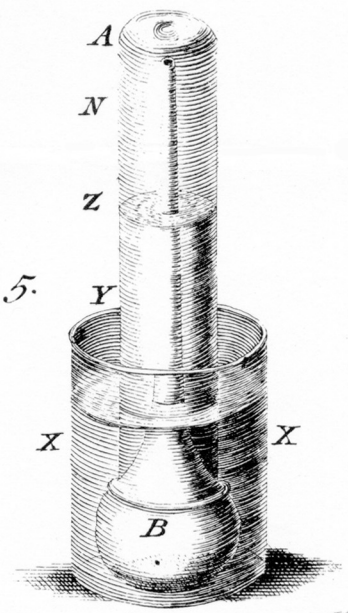

Fig. 4