

www.e-rara.ch

**Philosophia britannica or a new and comprehensive system of the
newtonian philosophy, astronomy, and geography, in a course of twelve
lectures ...**

Martin, Benjamin

London, 1771

ETH-Bibliothek Zürich

Shelf Mark: Rar 1968

Persistent Link: <https://doi.org/10.3931/e-rara-9757>

Lecture VI.

www.e-rara.ch

Die Plattform e-rara.ch macht die in Schweizer Bibliotheken vorhandenen Drucke online verfügbar. Das Spektrum reicht von Büchern über Karten bis zu illustrierten Materialien – von den Anfängen des Buchdrucks bis ins 20. Jahrhundert.

e-rara.ch provides online access to rare books available in Swiss libraries. The holdings extend from books and maps to illustrated material – from the beginnings of printing to the 20th century.

e-rara.ch met en ligne des reproductions numériques d'imprimés conservés dans les bibliothèques de Suisse. L'éventail va des livres aux documents iconographiques en passant par les cartes – des débuts de l'imprimerie jusqu'au 20e siècle.

e-rara.ch mette a disposizione in rete le edizioni antiche conservate nelle biblioteche svizzere. La collezione comprende libri, carte geografiche e materiale illustrato che risalgono agli inizi della tipografia fino ad arrivare al XX secolo.

Nutzungsbedingungen Dieses Digitalisat kann kostenfrei heruntergeladen werden. Die Lizenzierungsart und die Nutzungsbedingungen sind individuell zu jedem Dokument in den Titelinformationen angegeben. Für weitere Informationen siehe auch [Link]

Terms of Use This digital copy can be downloaded free of charge. The type of licensing and the terms of use are indicated in the title information for each document individually. For further information please refer to the terms of use on [Link]

Conditions d'utilisation Ce document numérique peut être téléchargé gratuitement. Son statut juridique et ses conditions d'utilisation sont précisés dans sa notice détaillée. Pour de plus amples informations, voir [Link]

Condizioni di utilizzo Questo documento può essere scaricato gratuitamente. Il tipo di licenza e le condizioni di utilizzo sono indicate nella notizia bibliografica del singolo documento. Per ulteriori informazioni vedi anche [Link]

LECTURE VI.

Of PNEUMATICS, or Doctrine of the AIR, or ATMOSPHERE in general. Of Artificial or Factitious AIR; the great Quantity thereof in Natural Bodies; various Experiments relating thereto. Of the Weight of the AIR; of the Nature of the BAROMETER for estimating the same; an Account of the several Kinds, viz. the Perpendicular, Diagonal, Horizontal, Perpendent, Wheel, and Water BAROMETERS. The best Way of making the Common Barometer. The Nature and Use of the NONIUS, applied thereto, explain'd. The Use of the Barometer in measuring the Heights of Mountains, &c. The SPRING or ELASTICITY of the Air accounted for, and explain'd. The Nature of the SEAGAGE explain'd. The Altitude of the ATMOSPHERE determin'd. The Art of SAILING in the AIR proved impossible. The ABSOLUTE WEIGHT of the Air determin'd by Experiment. Its variable Pressure on HUMAN BODIES; the Quantity thereof computed. An Account of fifty Experi-

Experiments of the AIR-PUMP relating to the Weight, Spring, and other Properties of the Air. A particular Description of the Air-Pump; an Air-Pump of a new Invention. The DIVING-BELL explain'd. The Nature and Use of THERMOMETERS explain'd. The Newtonian STANDARD THERMOMETER. Farenheit's new Mercurial Thermometer explain'd. HYGROMETERS of several Sorts explain'd. The Common AIR-GUN explain'd. The MAGAZINE AIR-GUN particularly described.

THAT Part of *Natural Philosophy* which treats of the *Nature, Properties and Effects of the ATMOSPHERE, or Body of Air* encompassing the *Earth*, is called PNEUMATICS, from the Greek Word for *Wind* or *Breath*.

THE *Air* is generally esteemed a *Fluid*, but yet differs from the general Nature of Fluids in three Particulars, viz. (1.) In that it is *compressible*, which Property no other Fluid has. (2.) It cannot be *congealed*, or any how *fixed*, as all other Fluids may. (3.) It is of a *different Density* in every Part, decreasing from the *Earth's* Surface upwards; whereas other Fluids are of an uniform Density throughout. The

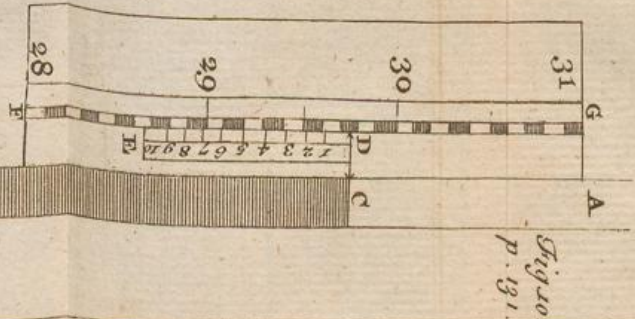
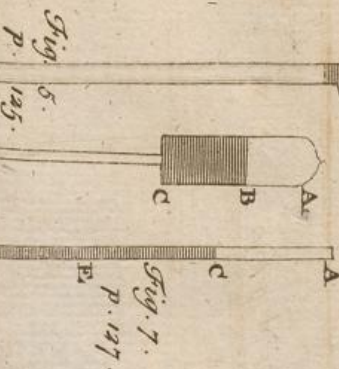
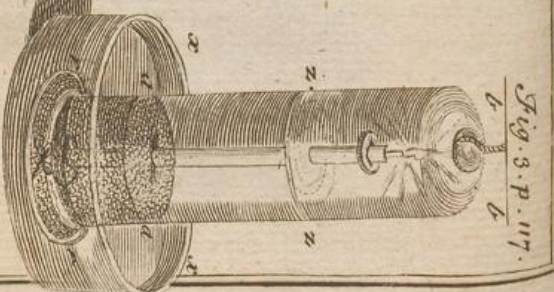
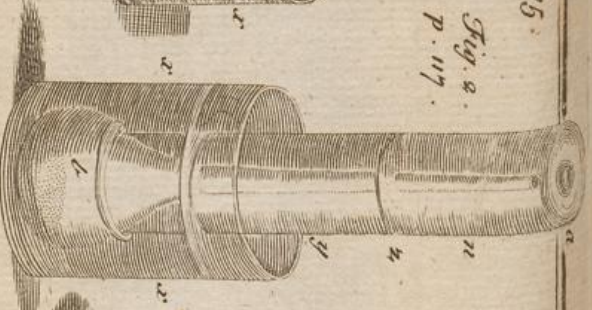
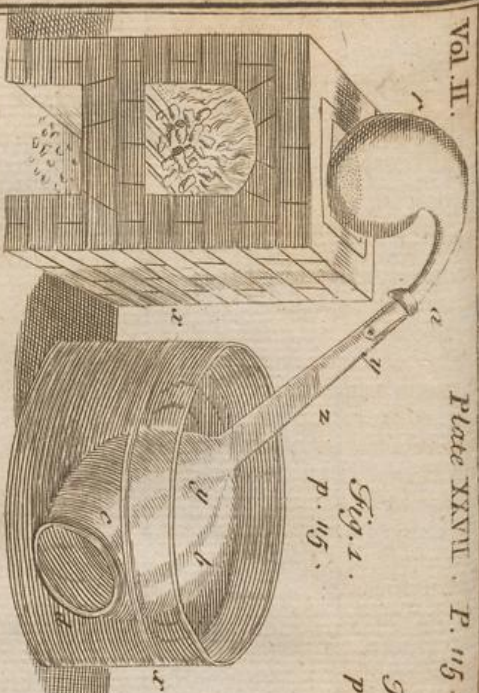
Air is therefore a Fluid *sui generis*, if it be properly any Fluid at all (LXXXV).

THAT the Air was created at first with the Earth itself, is not to be doubted; and that ever since there has been a *constant Generation* of Particles of Air by the mutual Action of Bodies upon each other, as in *Fermentations*, and all Kinds of *natural and artificial Chemistry*, Sir *Isaac Newton* thinks very reasonable to suppose; and Mr. *Boyle* has given numerous Experiments relating to the Production of *artificial or factitious Air* (LXXXVI).

THAT

(LXXXV) What is here said of the incongealable Quality of the Air, relates to the Impossibility of changing it from a *Fluid to a Fixed State* by Cold, as Water is congeal'd or converted into Ice; and melted Metals are brought to their fixed State: And in this particular limited Sense, the Air is *incongealable*, or incapable of Fixation. But yet it is not absolutely so; for we find by various Experiments, that Air has a fixed State in the Composition of natural Bodies, from which, when set at Liberty, it becomes a fluid elastic Air, like the common Air; and this again, from a *Fluid*, may be reduced to a *fixed State* in Composition with other Matter, though not *per se*; for we know, as yet, of no fixed Body consisting entirely of Air.

(LXXXVI) 1. Since Air is absolutely necessary for the Life of Man, and most Animals, yea, and Vegetables too, it was necessary at the first Formation of the Earth to render it a Habitation for Animals, and a proper Matrix for the Production of Plants. Now since there is a constant Generation of Air from all terrestrial Substances (as we shall shew by and by) it follows, that the original Atmosphere must be always increasing in



THAT the Air is a *heavy or ponderous Body*, must follow from the Nature of the Matter

in Quantity and Bulk, unless we suppose all that is generated is again absorb'd or refixed in the Substance of Bodies. And this alternate Transmutation of the State of Air is extremely manifest from numberless Experiments which have been made by Mr. Boyle, and Dr. Hales, of which I shall here give an Account of some of the principal of both Kinds, as follows.

2. The Production of artificial or factitious Air is caused either (1.) by slow Degrees from Putrefactions and Fermentations of all Kinds; or (2.) more expeditiously by some Sorts of chymical Dissolutions of Bodies; or (3.) and lastly, almost instantaneously by the Explosion of Gunpowder, and the Mixture of some Kinds of Bodies. Thus, if Paste or Dough with Leaven be placed in an exhausted Receiver, it will, after some Time, by Fermentation, produce a considerable Quantity of Air, which will appear very plainly by the Sinking the Quicksilver in the Gage. Thus also any Animal or Vegetable Substance, putrifying in *Vacuo*, will produce the same Effect.

3. Gunpowder, fired in *Vacuo*, instantly generates a large Quantity of Air in the Receiver, which causes the Quicksilver to subside. And in the remarkable Experiment of Dr. Stare, half a Drachm of Oil of Caraway-Seed, poured upon a Drachm of the Compound Spirits of Nitre, produced such a prodigious Quantity of Air, as instantly blew up the Receiver, which was six Inches in Diameter, and eight Inches deep. The Pressure, therefore, of the Atmosphere on the exhausted Receiver, which it overcame, was above 400 lb. reckoning 15 lb. to a square Inch.

4. But Dr. Hales, in his *Vegetable Statics*, has greatly excelled in his Experiments of this Kind, and in the Methods of making them: One of which was by *Distillation*, the other by *Fermentation*. That by *Distillation* is as follows: the Matter to be distill'd is put into the Retort *r*, and then at *a* is cemented very fast the

Plate
XXVII.
Fig. 1.

Glass

Matter of which it doth consist; and since those Particles arise from Bodies of every Kind

Glass Vessel *ab*, which was very capacious at *b*, and had an Aperture *cd*, or Hole at the Bottom. The Bolt-Head *ab* being thus immersed in Water, with one Leg of an inverted Syphon put up as far as *z*, the Water would rise in the Bolt-head, and drive out the Air through the Syphon, which being taken out, the Water will remain in the Vessel to the Part *z*; at the same Time, while the Bolt-head is under Water, it is placed in the Vessel *xx*, which with the Bolt-head and Retort is carried to the Chymical Furnace, where the Retort has the Heat and Fire gradually communicated to it, and the Bolt-head *ab* and Vessel *xx* well screen'd from the Heat of the Fire.

5. As the Matter distill'd, all except the Air, would go down into the Water of the Bolt-head and Vessel; the Air that was generated or destroyed by the Process would be shewn by causing the Surface of the Water in the Bolt-Head to stand below or above the Point *z*, as at *y*, when all was set aside till it became quite cold. Thus if the Body distilling generates Air of an elastic Quality, that added to the former will not permit the Water *y* to rise so high as *z*, and the Space between *z* and *y* below will shew how much Air was produced from its fixed State.

6. But if, when all is cold, the Surface of the Water *y* be seen above the Point *z*, it then shews that the distill'd Body did destroy, that is, imbibe or absorb, a Part of the natural Air above *z*; and the Space between *z* and *y*, fill'd with Water, will shew what Quantity was changed from a repellent elastic to a fixed State, by the strong Attraction of the absorbing Particles of the distilled Body. This Quantity of generated or absorbed Air it is easy to measure in Cubic Inches, by stopping the End of the Bolt-head with a Cork, and then from a Quantity of Water of a known Weight to fill it first to *z*, and afterwards to *y*; and the Difference of Weight in the two Bulks of Water gives the Number of Cubic Inches

Kind in or upon the Earth, 'tis evident
the constituent Parts of Air are of a most
hetero-

Inches from a Table of specific Gravities, in the Manner we have formerly shewn.

7. The other Method which the Doctor made use of for estimating the surprising Effects of Fermentation arising from various Mixtures of solid and fluid Substances, in generating and absorbing Air, was as follows: He put the Ingredients into the Bolt-head *b*, and then run the long Neck thereof into a tall cylindric Glass *ay*, and inclining both almost horizontally in a large Vessel of Water, the Water ran into the Vessel *ay*, and driving out Part of the Air would possess its Place upon turning them up and placing both in a Vessel of Water *xx*, as you see in the Figure, where the Surface of the Water stands in the inverted Glass *ay* at the Point *z*.

Plate
XXVII.
Fig. 2.

8. If the Ingredients generated Air, then the Water would fall from *z* to *y*, and the empty Space *z y* was equal to the Quantity of generated Air; but if on Fermentation they absorbed or fixed the active Particles of Air, then the Surface of the Water would ascend from *z* to *n*; and the Cylinder *z n* would be the Bulk of Air absorb'd, which is easily known in Cubic Inches.

9. When the Subjects for trying these Experiments were a burning Candle, burning Brimstone, Nitre, Gunpowder fired, living Animals, &c. the Doctor used to make use of a Pedestal, on the Top of which was a Plate whereon he laid the Matter to be fired; then inverting the tall cylindric Glass over it, and drawing the Water up to *z z* with an inverted Syphon, he set fire to the Matters lying on the Plate by means of a Burning-Glass centering the Sun's Rays in its Focus upon the same. See the Figure.

Fig. 3.

10. But the Way that I make use of, and which is the most easy and expeditious possible, is instead of having the cylindric Glass close upon the Top at *b b*, to have it open by a small Neck, on which a brass Cap is cemented with a Female-Screw to receive a Stop-Cock,

to

heterogeneous Nature, and infinitely various in their specific Gravities; Whence also it will

to take off the Communication of the external Air when Occasion requires. Thus the Use and Trouble of the Syphon is superseded; and in case of noxious Fumes, Vapours, &c. from *Aqua fortis*, burning Brimstone, &c. a Syringe screwed on to the Stop-Cock will draw off the Air, and raise the Water to what Height you please, without the cumbersome Use of a large Pair of Bellows, as the Doctor made use of.

II. I shall here subjoin the Quantity of Air which various Substances produce by Distillation, which I have collected from the Doctor's Experiments, and reduced to Cubic Inches.

A Cubic Inch of Hog's Blood	—	—	33
Tallow	—	—	25
Deer's Horn	—	—	234
Oyster-Shell	—	—	324
Heart-Oak	—	—	216
Pease	—	—	396
Amber	—	—	270
Oil of Aniseed	—	—	22
Oil of Cloves	—	—	88
Honey	—	—	144
Yellow Bees Wax	—	—	54
Coarsest Sugar	—	—	126
Newcastle Coal	—	—	360
Fresh Earth	—	—	43
Antimony	—	—	28
Pyrites	—	—	83
Sea-Salt mixed with Bone-Calx	—	—	64
Nitre, with ditto	—	—	180
Sal Tartar ditto	—	—	224
Rhenish Tartar	—	—	504
Calculus humanus	—	—	645
Stone in the Gall-Bladder	—	—	648

12. These are the principal Experiments by Distillation. Others were made by Fermentation in various Mixtures,

will follow, that as the Matter which composes the Body of Air, or Atmosphere, is
always

Mixtures, some of which generated Air, others absorb'd it, and some did neither generate nor absorb Air. The principal Subjects, which of themselves absorb Air, are the Fumes of burning Brimstone or Matches, the Flame and Fumes of a burning Candle, the Breath of living and expiring Animals, as Rats, Mice, &c.

13. Thus the Doctor found that Linen Matches dipped in melted Brimstone, and fired under a Glass in a Quantity of 594 Cubic Inches, absorb'd $\frac{1}{5}$, which was full one Fourth of the Whole. A Candle burning till it went out, its Fumes afterwards consumed $\frac{1}{11}$ Part of the whole Quantity of Air, which was 594 Cubic Inches. A half-grown Rat expired in the confined Air in ten Hours, and absorb'd 45 Cubic Inches of Air, which was $\frac{1}{13}$ Part of the whole 594.

14. From what has been said we see with how much Reason Sir Isaac Newton philosophized on this Subject in the following Words. " True permanent Air arises
 " by Fermentation or Heat from those Bodies the Chymists call *fixed*, whose Particles adhere by a strong
 " Attraction, and are not therefore separated and rarified without Fermentation; 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 again: " Dense Bodies, by Fermentation, rarify into
 " several Sorts of Air; and this Air by Fermentation, and sometimes without it, returns into dense
 " Bodies." See his *Optics*, Query 30, 31.

15. Now since Air is a heavy Body, a Cubic Inch whereof weighs very near $\frac{1}{2}$ of a Grain, it follows, that Air in its fixed State in Bodies makes a Part of their Substance, and in some of them a very great Part too, as is known from the Quantity and Weight of the Air discharged upon the Analysis of the Bodies. This has escaped the Observation of Chymists, who have hitherto taught that all Bodies were ultimately resolveable into
 I 4 what

always variable, so will its Weight or Gravity be likewise; as we constantly experience

what they call *Four Elements* only, viz. *Water*, *Oil*, *Salt*, and *Earth*. But by the following Table it will appear, that Air is an Element of Natural Bodies in as proper a Sense as any of the other.

16. In the first Column of this Table you have the Bulk of the Body in Cubic Inches and Parts; in the second, the Number of Cubic Inches of generated Air; in the third is the Weight of the Body in Grains; in the fourth is the Weight of the generated Air; and the fifth shews what Part of the Whole the Air makes.

	C. Inch.	C. Inch.	Grs.	Grs.	Prop.
Deer's Horn,	$\frac{1}{2}$ —	117 —	241 —	33 —	$\frac{1}{7}$
Oyster-Shell,	$\frac{1}{2}$ —	162 —	266 —	46 —	$\frac{1}{6}$
Heart of Oak,	$\frac{1}{2}$ —	108 —	135 —	30 —	$\frac{1}{4}$
Indian Wheat,	—	270 —	388 —	77 —	$\frac{1}{5}$
Pease,	1 —	396 —	318 —	113 —	$\frac{1}{3}$
Mustard-Seed,	—	270 —	437 —	77 —	$\frac{1}{6}$
Amber,	$\frac{1}{2}$ —	135 —	135 —	38 —	$\frac{10}{35}$
Dry Tobacco,	—	153 —	142 —	44 —	$\frac{1}{3}$
Honey with Calx of Bones, }	1 —	144 —	359 —	41 —	$\frac{1}{9}$
Yellow Wax,	1 —	54 —	243 —	15 —	$\frac{1}{16}$
Coarse Sugar,	1 —	126 —	373 —	36 —	$\frac{1}{10}$
Newcastle Coal,	$\frac{1}{2}$ —	180 —	158 —	51 —	$\frac{1}{3}$
Nitre with Calx of Bones, }	$\frac{1}{2}$ —	90 —	211 —	26 —	$\frac{1}{8}$
Rhenish Tartar,	1 —	504 —	443 —	144 —	$\frac{1}{3}$
Calculus humanus,	$\frac{1}{4}$ —	516 —	230 —	147 —	$\frac{1}{2}$

17. Thus we see that different Bodies contain different Quantities of fixed Air, from a Sixteenth to a Half of the whole Substance. From hence we may be fully satisfied of the Truth of Sir Isaac Newton's Reasoning in the 31st Query of his *Optics*, in these Words: "The
 " Particles, when they are shaken off from Bodies by
 " Heat or Fermentation, so soon as they are beyond
 " the Reach of the Attraction of the Body, recede from
 " it,

ence by the BAROMETER, of various Kinds and Structure (LXXXVII).

SINCE

“ it, and also from one another, with great Strength,
 “ and keep at a 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 unintelligible by
 “ feigning the Particles of Air to be springy and ram-
 “ mous, or roll’d up like Hoops, or by any other
 “ Means than by a repulsive Power.”

18. That the Particles of Air cannot be thus coil’d up and detain’d in their elastic State in the Substance of Bodies, is easy to be shewn from Calculation. Thus, for Instance, one Cubic Inch of Oak yields 216 Cubic Inches of Air: Now suppose the Pressure of the Atmosphere be on every Square Inch about 15 *lb.* (as we shall shew) then in order to compress 216 Cubic Inches into one Cubic Inch, the Weight of 216 Times 15 *lb.* or 3240 *lb.* which would be the Force to confine it on each Side the Cube, which, as it has six Sides, will require $6 \times 3240 = 19440$ *lb.* or near twenty thousand Weight, to confine this Air in its elastic State in one Cubic Inch, supposing it to be all Air; but, as it is not, the Force will be greater still. This Force therefore of 19440 *lb.* must be exerted in every Cubic Inch of the Oaken Tree, which would rend it in Pieces with a vast Explosion. It is therefore not to be doubted but Air in Bodies does exist in a fixed and unelastic State; and that it is roused, and put into an active repellent State, by means of Fire and Fermentation.

19. They who would see the numberless Uses that may be made of this important Doctrine of artificial Air, and the surprising Scenes of Knowledge which it lays open in the most abstruse and difficult Parts of *Physics*, may consult all the latter Part of the invaluable Book above mentioned, viz. Dr. Hales’s *Vegetable and Chymico-Statistical Experiments*, some of which we shall take notice of also in the Sequel of these Notes.

(LXXXVII) 1. The Weight of the Air is manifest from Reason and various Experiments. The Particles are

SINCE the Particles of Air are such as being separated from Bodies beyond the Sphere

are affected by the Power of the Earth's Attraction, and must therefore all gravitate or tend towards its Centre, which is what constitutes Weight in them, and all other Bodies. The Experiments to shew the Weight of the Air are numerous which we shew on the Air-Pump, among which one is absolute and very exact, by weighing it in a Balance, in the same manner as all other heavy Bodies are weigh'd.

2. The Method I take for this is, I believe, the most exact and nice that can possibly be thought of. For since (as we have shewn) the Friction of the Balance is in Proportion to the Weight with which it is charged, the less the Weight is the less will be the Friction, and consequently the more nice and exquisite will be the Experiment. In order to this I take a very thin large Florence Flask, whose Capacity is exactly known in Cubic Inches: This I exhaust of all the Air as near as can be, and then hang it to the end of a very fine and exact Hydrostatic Balance, which I counter-balance by Grain-Weights in a Scale hanging from the other End. When the Equilibrium is nicely obtain'd, I lift up the Valve, and let the Air rush into the Flask, which is sensibly heard, and seen to gravitate in the Glafs, by causing it gradually to descend till it be fill'd with Air, and will then preponderate greatly. Then to restore the Equilibrium, I find by Experience 'tis necessary to add about 8 Grains for every Pint the Flask contains; which shews that a Gallon of Air weighs about a Dram, and a Bushel an Ounce Troy; and because one Pint = 28 Cubic Inches nearly, therefore one Cubic Inch of Air weighs $\frac{8}{28} = \frac{2}{7}$ of a Grain, at a Mean.

3. As the Air is a heterogeneous Fluid, it will vary in its Weight according to its different component Parts, and also according to its different Altitudes, which it must have as an elastic and fluctuating Fluid. Since few Bodies are lighter than Water, and that Water is most easily rarified into Vapour, it follows, that the Atmosphere fill'd with aqueous Particles will be lightest, as

Sphere of corpuscular Attraction, are strongly repell'd from those Bodies; this Repellency

as we generally find it is in moist rainy Weather; and also that it must oftner be in this light than in a heavier State: And that Instrument which shews the Variation of the Air's Gravity, or its different Weight at different Times, is call'd a BAROMETER, of which there are various Kinds, which are here described; but I shall first give an Account of the most simple Structure or Form of those Instruments, which is as follows.

A Glass Tube, hermetically seal'd at one End, is to be fill'd with Quicksilver, well defecated and purged of its Air: The Finger being then placed on the open End in immediate Contact with the Mercury, so as not the least Particle of Air is admitted, the Tube is inverted, and carefully immersed with the Finger on the open End in a Basen of the same prepared Mercury; then upon removing the Finger, the Mercury in the Basen will join that in the Tube; and the said Column of Mercury in the Tube will be seen immediately to subside, or sink down to a certain Pitch or Altitude, if the Tube be above 31 Inches long, as it ought to be.

4. Let AB be such a Tube of 34 Inches Length, and $\frac{1}{2}$ of an Inch in Diameter, (as it ought to be for this Purpose) hermetically seal'd at A, and open at B; let CD be the Basen of Mercury, in which the Tube is immersed inverted, the Surface of the Mercury in the Basen EF, and in the Tube GH. Now, 'tis easy to understand, that if all this could be perform'd in *Vacuo*, as soon as the Tube was inverted, all the Mercury would descend into the Basen, because as a heavy Body it must tend towards the Centre of the Earth, till it meets with some Obstacle, as the Basen, to obstruct its Motion, and support it. I say, all this would happen in *Vacuo*, unless we can suppose any Power in the Tube sufficient to sustain the Column of Mercury; now there can be no such Power but that of *Cohesion*, which indeed, in Tubes of a small Bore, has been found able to sustain it; but in so large a Bore, as we suppose

Plate
XXVII.
Fig. 4.

pellency being mutual between the Particles, they do by this means constantly
repel

suppose this Tube to have, that Power is by far too small to support so heavy a Column, which must therefore of Course sink into the Bason; and so stand upon the same Level in the Bason, and in the Tube.

5. But since the Mercury does not totally subside when this Experiment is made in the Air, the Column which remains in the Tube must owe its Suspension to the Air as its Cause, since nothing within or without the Tube can be supposed (with any Shew of Reason) to produce such an Effect, besides itself. Now allowing the Air to be a gravitating Fluid, it must necessarily cause such an Effect, as the Suspension of Mercury in the Tube; for by its Gravity a Force of Pressure must be produced on all the Surface of Mercury in the Bason, which is contiguous to it, and on every Part equally. Now since the Mercury in the Bason is *in Equilibrium* with that in the Tube, it is plain the Weight of the Mercury in the Tube, and the Weight of the Air upon every circular Area of the Surface of the Mercury in the Bason, equal to the Orifice of the Tube, must be equal, for else they could not balance each other, as we find they do; the Column of Mercury therefore is sustain'd by the Counter-Pressure of a Column of Air of the same Base, and whose Altitude is equal to that of the Atmosphere.

6. That the Weight of the Columns of Air and Mercury, we have now been speaking of, are precisely equal to each other, will be farther evident, if we consider, that upon Supposition the Quicksilver were thoroughly purg'd from Air, when it subsides in the Tube, it must leave a *Vacuum* in all that Part of the Tube above it, and so there is nothing to act upon its upper Surface to depress it; it will therefore always sink or rise to such an Altitude, as the various Gravity of the Air requires, and of which it is therefore an adequate Expression or Measure, as its Nature imports. This Invention was owing to that happy Italian Genius *Toricelli*, a Disciple of

repel each other, and therefore they must observe an equal Distance among themselves.

of the famous *Galileo*. And hence it is very often call'd the *Torricellian Tube*, and the *Torricellian Experiment*, &c.

7. Since, as we have shewn, this suspended Column of Mercury exactly indicates the Gravity of the Air at all Times, it has employ'd the Attention of all Mankind, who very sensibly find themselves affected with the different State of the Air; but more especially has it merited the Consideration of Philosophers, who have taken all Opportunities to explore, by this Means, the two Extremes of the Air's Gravity, *viz.* when it is least and greatest of all, by observing the least and greatest Altitude of this mercurial Column, which by long Experience we find to be very nearly between 28 and 31 Inches, it being very rarely less or more than those Heights; whence $29\frac{1}{2}$ Inches is fixed upon as the Mean-Altitude, expressive of the Mean-Gravity of the Air, which therefore let be represented by *BH*, and let the greatest Altitude be *BI*, and the least *BK*, then is *IK* call'd the *Scale of Variation*.

8. Now as there is a Space of 3 Inches in the perpendicular Tube for the Mercury to rise and fall in, and since Fluids will always have the same Altitude in a Tube of any Form or Inclination; Artists have contrived Methods to increase the Motion of the Mercury, by making it move over a larger Space; and thus have invented several different Forms of Barometers, the principal whereof I shall here describe. That which, next to the upright one, is in most Esteem, is called the *Diagonal Barometer*, and is that in *Fig. V.* where *A B C* is a Tube seal'd at *C*, immersed in Mercury at *A*; this Tube is perpendicular from *A* to *B*, where the Scale of Variation begins; from thence it is bent into *B C*, making an acute Angle *F B C*. This Part *B C* proceeds to the highest Limit in the Scale of Variation, *viz.* *I C*; and consequently while the Mercury rises from *K* to *I* in the common Barometer, it will move in this

Plate
XXVII.
Fig. 5.

selves. When, therefore, those aerial Particles are obliged by any impress'd Force to

this from B to C (See *Annotat. LXIX. 4.*) and so the Scale will by this means be enlarged in the Proportion of B C to F B = I K, *i. e.* of the Diagonal to the least Side of a Parallelogram.

9. The Fault which this Form is subject to is this, that as the Quicksilver is a very heavy Body, and supported on the Part B C, like a Body on an Inclined Plane, it must have a great Degree of Friction, which is the more so as the Part B C is more oblique, and consequently the very small and nice Variation of the Air's Pressure cannot be so well shewn in this Form, where the Motion is not absolutely free; and it very often happens, from the Inclination of the Part B C, that the Quicksilver divides into several Parts, and so requires the Trouble of filling the Tube anew too frequently. This Form is the Invention of Sir Samuel Moreland.

10. Another Form of the Barometer for enlarging the Scale of Variation, was contrived by Mr. Cassini, and afterwards compleated by Mr. John Bernouilli. It consists of a Tube A C D F, seal'd on the upper End A, and bent to a Right Angle at D, whence it has the Name of the *horizontal rectangular Barometer*. The Mercury stands on both Legs from E to B. The Scale of Variation from A to C, is here made of a larger Part, and then it is evident in moving 3 Inches from A to C, it will move through so many Times 3 Inches in the small Leg D F, as the Bore of D F is less than the Bore of A C, whence the Motion of the Mercury at E must be extremely sensible, but the Inconvenience here too is, that the Mercury is very apt to break off in the Leg E, as also to run out at the End F; besides that, here is also a great Degree of Friction, and not only that, but the Part D F being of a very small Bore, the Attraction of Cohesion will a little impede the free Motion of the Mercury therein.

Plate
XXVII.
Fig. 6.

11. The

to approach nearer to each other, the *repulsive Power* will re-act or resist the said Force

11. The next Sort of Barometer that I shall describe, is call'd the PENDENT BAROMETER, because being a single Tube only, it is hung up by a String at the End A. This Tube is a little tapering or conical, the End A being a little less than B; it is seal'd at A, and fill'd with Mercury from A to F = 31 Inches; then when the Tube is inverted, the Mercury, if the Gravity of the Air be not greatest, will sink down in the Tube and abide in that Part C D, which will admit its Length or Altitude C D to be the same with that in the Common Barometer. Thus by reason of the conical Bore of the Tube, as the Air grows lighter the Mercury will descend, till when it is lightest of all, the Mercury will stand from the lower Part of the Tube B to E, so that B E = 28 Inches. Consequently the Mercury will, in such a Tube, move from A to E, 32 Inches, if the Tube be 5 Feet or 60 Inches long, and so the Scale A E is here above 10 Times greater than in the Common Barometer. The Fault of this Barometer is, that the Tube being of a very small Bore, the Attraction of Cohesion will be very considerable, and prove an Impediment to that Freedom of Motion as is necessary to shew a very small Variation of the Air's Weight; for which Reason, when you shake the Tube a little, the Mercury will not settle again where it was, or have the same Altitude as before; besides, that by its Weight it is very apt to break off in the lower Part, and fall out of the Tube. We owe this Invention to Mr. Amontons, who first published it in A. D. 1695.

12. The next Barometer which I shall mention is call'd the WHEEL BAROMETER, from its Structure, which is easily understood from the Figure. Where A B D G represents the Quicksilver in a Glass Tube, having a large round Head or Ball at Top, and turn'd up at Bottom to F; upon the Surface of the Mercury in the recurv'd Leg there is placed an Iron Ball G with a String

Plate
XXVII.
Fig. 7.

Force with an equal *Momentum*; and thus cause what we call the RENITENCY, ELASTICITY,

a String going over a Pulley C D, and is balanced by another Weight H hanging freely in the Air. As the Surface of the Mercury at A B is very large, and that at G very small, the Motion of the Quicksilver, and consequently of the Ball G, will at Bottom be very considerable; but as the Weight G moves up and down, it turns the Pulley C D, and that a Hand or Index K L, by the Divisions of a large graduated Circle M N O P; by which means the minute Variations of the Air are plainly shewn, if the Instrument be so very accurately made that the Friction of the several Parts be inconsiderable. This is one of the many curious Inventions of Dr. Hooke.

13. These are the principal Contrivances hitherto invented for enlarging the Scale of Variation in simple Mercurial Barometers. There are other Inventions of compound Barometers, viz, such as are made of Mercury and Water, or other Liquors for that Purpose; but they are so difficult to make, so faulty when made, and so troublesome to use, that it is not worth while to describe them. However, as the Reader may have an Idea of one of the best Sort, I shall here give him that which owes its Invention to the Reverend Mr. Rowning, together with his Demonstration of its Theory.

Plate
XXVII.
Fig. 9.

14. A B C is a compound Tube seal'd at A, and open at C, empty from A to D, fill'd with Mercury; from thence to B, and from thence to E with Water; let G, B, H, be in an horizontal Line, then it is plain from the Nature of the Syphon, that all the compound Fluid contain'd in the Part between H and G, must ever be in *Equilibrio* with itself be the Weight of the Air what it will, because the Pressure at H and G, must always be equal. Whence 'tis evident, that the Column of Mercury D H is in *Equilibrio* with the Column of Water G E, and a Column of Air of the same Base conjointly, and will therefore vary with the Sum of

Fig. 1.
p. 130.

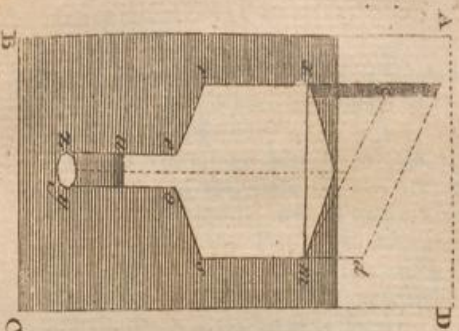


Fig. 4



Fig. 3.
p. 135.

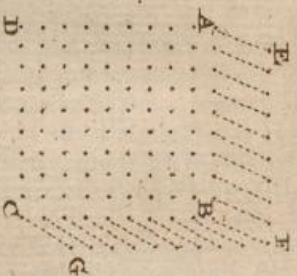


Fig. 7.
p. 146.

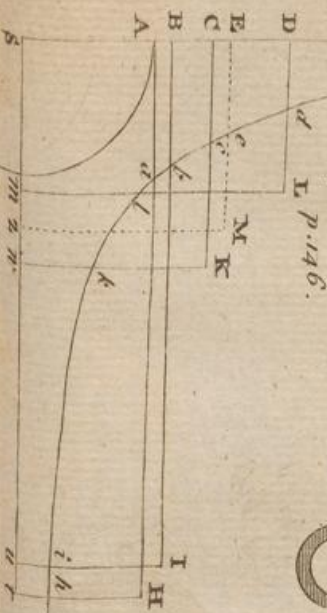


Fig. 5.
p. 139.

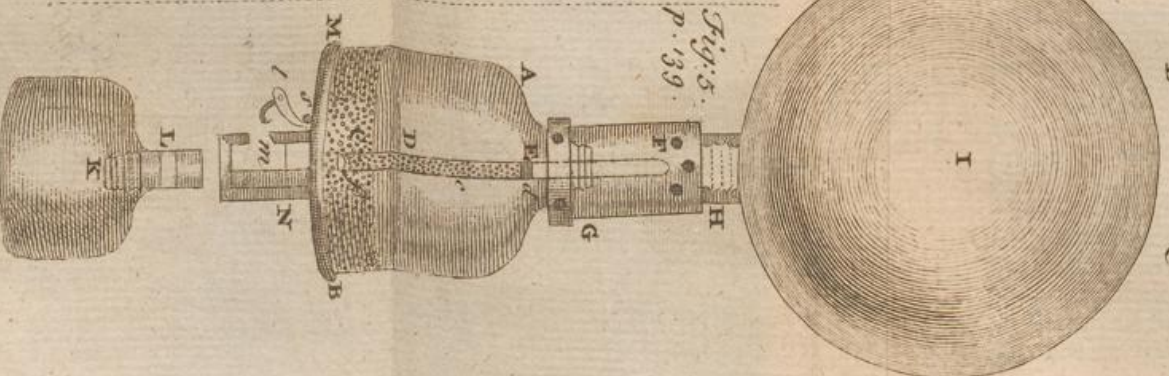
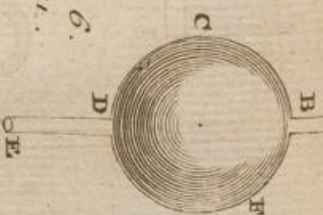


Fig. 6.
p. 141.



TICITY, or SPRING of the Air; which is so sensible by the common Experiment of a blown

of the Variations of each of these; all which must now be computed.

15. The Variation of the Weight of the Air, which we will call V , is measured by the Space which the Mercury moves in the common Barometer in a given Time. Let x be the Space which the Water at E moves through in the same Time, and let the Diameter of the Tube A F be to that of the Tube F C as D to 1,

then will the Space moved through at B be as $\frac{x}{D^2}$, and therefore G E the Difference of the Legs E K and

K B, will vary in its Weight by $x + \frac{x}{D^2}$. Also since the Space moved through by the Mercury at B and D is

as $\frac{x}{D^2}$, the Difference D H will vary its Weight by $\frac{2x}{D^2}$. But this Variation of Weight is equal to both the

former, and since $x + \frac{x}{D^2}$ is an Altitude of Water, if we put m to 1 as the Specific Gravity of Mercury to

Water, we shall have $m : 1 :: x + \frac{x}{D^2} : \frac{x + \frac{x}{D^2}}{m} =$ Altitude of Mercury of the same Weight, consequently,

$\frac{2x}{D^2} = V + \frac{x + \frac{x}{D^2}}{m}$; which Equation, when reduced,

gives $x = \frac{V D^2 m}{2m - D^2 - 1}$, which gives this Analogy; as $x : V :: m D^2 : 2m - D^2 - 1$, so is the Scale of

Variation in this, to that in the common Barometer. 16. Hence if $m = 14$, and $D = 1$; we have $x : V :: 14 : 26 :: 7 : 13$; which shews that when the Tubes A F and F C are of an equal Bore, the Variation in

this is less than that of the common Barometer in the Ratio of 7 to 13. If $2m - D^2 - 1 = 0$, or $2m - 1 = D^2$, then $D = \sqrt{2m - 1} = 5,2$; whence it appears that when the Diameter of A F is to that of F C as 5,2 to 1, the Variation x will be infinite in respect of that in the common Barometer. If $D = 5$, then $x : V :: 175 : 1$; which shews how very large the Scale of Variation in this Barometer may be made in Comparison of the common one. But I believe such a Structure as this will afford more Pleasure in Speculation than in Practice; and when all is done, the Barometer of the *common Form*, as it is most simple, so it will be found the most easy and accurate of all others.

Plate
XXVIII.
Fig. 1.

17. Before I conclude this Article, I shall just mention the Barometer invented by the Rev. Mr. *Caswell* of *Oxford*. Suppose A B C D be a Bucket of Water, in which is placed the Baroscope *x r e z y o s m*, which consists of a hollow Body *x r s m*, and Tube *e z y o*, made of Brass, Tin, Glass, &c. The Bottom of the Tube *z y* has a Lead-Weight to sink it, so that the Top of the Body may just swim even with the Surface of Water, by the Addition of some Grain-Weights. As the Instrument is put into the Water, with the Mouth downwards, the Water ascends into the Tube to the Height of *y u*; there is added on the Top a small concave Cylinder, or Pipe, to sustain the Instrument from sinking to the Bottom when the Air becomes heavier; *m d* is a Wire, and *m s*, *d e*, are two Threads, oblique to the Surface of the Water; of these Threads there may be several; and as the Water just touches the Top or Crown of the Instrument, when the Altitude of the Mercury is least in the Common Barometer, so as the Air increases in Weight, the Instrument sinks in the Water, and a small Bubble is formed on the Thread, which continually ascends and descends through all the Length of the Thread. From a Calculation on the Theory, it appears, that this Barometer is above 1200 Times more exact than the Common Barometer. See the whole Calculation in the Professor's own Words in the *Phil. Transactions*.

18. Though I have made and tried the Barometer above described, and find it to answer the Theory very well,

well, yet is it not fit for common Use, because it can only shew the extreme minute Variations of the Air's Gravity for the *present Time*, by reason it is affected by the Heat as well as Weight of the Air. While the Degree of Heat remains the same, nothing can exceed this Instrument as a Barometer; but as the Heat of the Air varies, so will the Elasticity of the included Air, which therefore will cause the Instrument to vary its Gravity, while that of the Air remains the same, and so cannot be of constant Use.

19. I have already hinted that the Common Barometer, after all, is the best Instrument to measure the Air's Gravity; which that it may do to the greatest Perfection, the following Things are necessary. (1.) That the Tube be at least of $\frac{1}{4}$ of an Inch Bore; $\frac{1}{3}$ of an Inch is a good Size. (2.) The Tube ought to be new, clean, and dry within when fill'd; in order to this, the Tube should be hermetically sealed at both Ends at the Glass-House when made; one End of which may be cut off with a File when you intend to use it. (3.) The Diameter of the Cistern that holds the Mercury, in which the Tube is immersed, should be as large as conveniently may be, that the Mercury therein may have nearly at all times the same Altitude; otherwise the Index will not be true. (4.) The Mercury must be very pure, and free from any Mixture of Tin, Lead, or other Metal. (5.) It ought to be purged from Air entirely, as it may be by boiling it, and filling the Tube with it while boiling hot nearly. (6.) The Tube must be heated hot when fill'd, to avoid breaking by the boiling Mercury. (7.) It should be rubb'd very hard, to excite the Electric Virtue, which will expel the Particles of Air from the Surface within. (8.) There ought to be a *Nonius* (as it is call'd) applied to the Index of the graduated Plate, to measure more accurately the Rise and Fall of the Mercury.

20. This Artifice is of singular Use in this and many other Cases. It bears the Inventor *Nonius's* Name, and its Nature and Manner of applying it is as follows. A B is the upper Part of the Barometer, in which the Surface of the Mercury is at C. F G is the usual Plate of 3 Inches Extent, from 28 to 31; and D E is the

Plate
XXVII.
Fig. 10.

the small Plate call'd the *Nonius*, so contrived as to slide by the other in such manner that its Index D may be always set on one Part to the Surface of the Mercury, and on the other End pointing to the Division in the Scale of Inches corresponding thereto. Again, the *Nonius* is divided into 10 equal Parts, which together are equal to 11 of the Divisions of the Scale; that is, $DE = 11$ Tenths of an Inch; and consequently each small Division of the *Nonius* is equal to $1,1$; two of them to $2,2$; three of them to $3,3$; and so on. Whence 'tis easy to observe, that if the Index D points between any two Divisions of the Scale, as here between 29,7 and 29,8, we need only look back to see what Division of the *Nonius* coincides with a Division of the Scale, and that will shew how many Tenths of a Tenth, that is, how many Tenths beyond 29,7 in the present Case: But you observe the *Nonius* coincides with a Division of the Scale at the fifth Division; consequently, the Mercury stands at 29,75 Inches in the Scale; and so you proceed with the greatest Ease to the hundredth Part of an Inch, which is a great Degree of Exactness.

21. From what has been said we may easily see the excellent Use of the Barometer in measuring the Heights of Places, as Mountains, Towers, &c. For since (as we shall shew) the specific Gravity of Air (such as is near the Earth's Surface) is to that of Mercury as 1 to 12040, 'tis plain 12040 Inches of Air in Height will balance one Inch Height of Mercury; consequently, 1204 Inches, or 100 Feet, answers to $\frac{1}{10}$ of an Inch of Mercury. Therefore if a good Barometer be carried to the Top of a Mountain, or other high Place, the Mercury will subside near one Tenth of an Inch for every 100 Feet of perpendicular Ascent, and so will be a proper Index of the whole Height ascended.

22. But since Mercury is not quite 14 times heavier than Water, the Number 12040 is somewhat too large, and therefore a less Height than 100 Feet will answer to $\frac{1}{10}$ of an Inch Descent of Mercury in the Barometer; and what that is will be shewn from the Experiments made by Dr. *Nettleton* very exactly, as in the Table below.

Altitude

Altitude of 8.

	Height.	Bottom.	Top.	Difference.	for $\frac{1}{10}$
Tower of <i>Halifax</i>	102	29,78	29,66	— 0,12	— 85
Coal Mine	140	29,48	29,32	— 0,16	— 87
Another, <i>ditto</i>	236	29,30	29,23	— 0,27	— 87
A small Hill	312	29,81	29,45	— 0,36	— 86
<i>Halifax</i> Hill	507	30,00	29,45	— 0,55	— 91

23. Having the Height, to which the Mercury will stand at any one Elevation, it is easy to find at what Height it will stand at any other proposed. For since the Density of the Air decreases in a Geometrical Ratio, as the Altitudes increase in an Arithmetical one, the latter will be as the Logarithms of the former reciprocally: But the Weight of the Air is as the Density, and the Height of the Mercury in the Barometer is as the Weight, therefore the Elevations are as the Logarithms of the Height of the Mercury reciprocally; and consequently, if we take 30 Inches for the Standard Altitude, and 85 Feet for the Altitude requisite to make it fall $\frac{1}{10}$ of an Inch; then by saying, As the Logarithm of $\frac{1}{29,9}$ is to 85, so is the Logarithm of $\frac{1}{29,5}$ to the Elevation which will make it fall $\frac{1}{2}$ an Inch; and so for any other.

24. After this Manner, the Doctor has computed the following Tables.

A TABLE shewing the Number of Feet ascending, required to make the Mercury fall to any given Height in the Tube, from 30 to 26 Inches. As also the Number of Feet descending, requir'd to make the Mercury rise, from 30 to 31 Inches.

Inch.	Dec.	Feet.	Dec.	Inch.	Dec.	Feet.	Dec.
31	0	834	79	28	4	1395	32
30	9	752	53	28	3	1485	13
30	8	670	01	28	2	1575	26
30	7	587	21	28	1	1665	70
30	6	504	15	28	0	1756	47
30	5	420	82	27	9	1847	55
30	4	337	21	27	8	1938	97
30	3	253	32	27	7	2030	72
30	2	169	10	27	6	2122	80
30	1	84	72	27	5	2215	21
30	0	00	00	27	4	2307	95
29	9	85	00	27	3	2401	02
29	8	170	29	27	2	2494	44
29	7	255	87	27	1	2588	20
29	6	341	73	27	0	2682	33
29	5	427	89	26	9	2776	80
29	4	514	34	26	8	2871	62
29	3	601	08	26	7	2966	79
29	2	688	11	26	6	3062	32
29	1	775	44	26	5	3158	21
29	0	863	08	26	4	3254	46
28	9	951	01	26	3	3351	07
28	8	1039	25	26	2	3448	05
28	7	1127	80	26	1	3545	41
28	6	1216	66	26	0	3643	14
28	5	1305	83				

A TABLE shewing the Number of Feet requir'd to make the Mercury fall one Tenth of an Inch from any given Height in the Tube, from 31 to 26 Inches.

Inch.	Dec.	Feet.	Dec.	Inch.	Dec.	Feet.	Dec.
31	0	82	26	28	4	89	81
30	9	82	53	28	3	90	13
30	8	82	79	28	2	90	45
30	7	83	06	28	1	90	76
30	6	83	33	28	0	91	09
30	5	83	61	27	9	91	42
30	4	83	89	27	8	91	75
30	3	84	16	27	7	92	08
30	2	84	44	27	6	92	41
30	1	84	72	27	5	92	74
30	0	85	00	27	4	93	07
29	9	85	29	27	3	93	41
29	8	85	58	27	2	93	76
29	7	85	86	27	1	94	12
29	6	86	16	27	0	94	47
29	5	86	45	26	9	94	82
29	4	86	74	26	8	95	17
29	3	87	03	26	7	95	53
29	2	87	33	26	6	95	89
29	1	87	63	26	5	96	25
29	0	87	93	26	4	96	61
28	9	88	24	26	3	96	98
28	8	88	55	26	2	97	36
28	7	88	86	26	1	97	73
28	6	89	17	26	0	98	10
28	5	89	49				

a *blown Bladder*, and many others on the *Air-Pump*. (LXXXVIII).

By

(LXXXVIII) 1. That we may here exhibit a plain and clear Idea of the Force with which the Particles of Air repel one another, 'twill be necessary to proceed in the following Manner. If in any Distance A B, there are placed any Number of Particles at equal Intervals from one another; and in any other equal Distance C D, there are placed twice as many Particles at equal Intervals also; 'tis plain the Intervals between the Particles in C D will be but half so great as those between the Particles in the Line A B. Hence the Number of Particles in any equal Parts of A B, C D, will be inversely as their Distances from each other. Or, if we put N = Number of Particles, and I = to the Interval between each; then will N be always as $\frac{1}{I}$, for Lines, or linear Dimensions.

Plate
XXVIII.
Fig. 2.

2. But for *Superficies*, since they are as the Square of their like Sides, we shall have N^2 as $\frac{1}{I^2}$; and in like Manner, since *Solids* are as the Cubes of their like Sides, we shall have N^3 as $\frac{1}{I^3}$. But N^2 is as the Density of the Superficies; and N^3 as the Density of the Solid; consequently the Density D, of a Superficies of this Sort, is as $\frac{1}{I^2}$; and of a Solid as $\frac{1}{I^3}$. And to facilitate the Idea, let A B C be a Superficies of such Particles, equal to a square Inch; and D F a Solid of a cubic Inch.

Fig. 3.

3. Next let it be supposed that each of these Particles repels those, and those only, which are next to it; and let this repulsive Force (F) be inversely as the n Power of the Interval I , between the Centres of two adjacent Particles; that is, let F be as $\frac{1}{I^n}$. Hence 'tis manifest such an Assemblage of Particles must constitute

By reason of the *Spring of the Air*, its DENSITY must be always different in different Altitudes from the Earth's Surface; for the lower Parts of the Air, being pressed by the Weight of the superior Parts, will be made to accede nearer to each other,

tute an *elastic Fluid*, or such an one as, when compressed, or acted upon by any external Agent, will, by Virtue of its innate repellent Power, re-act or make Resistance with an equal Degree of Force.

4. Now the Force of the superficial Parts is as the Density D , and the repellent Force F between two Particles, conjointly, or as $D \times F$; but D is as $\frac{1}{I^2}$, and

F is as $\frac{1}{I^n}$; wherefore $D \times F$ is as $\frac{1}{I^2} \times \frac{1}{I^n} = \frac{1}{I^{n+2}}$, which therefore will express the elastic Force of the Fluid. Now the Density D of the Fluid in the cubic Inch is as $\frac{1}{I^3}$, whence $I^3 D$ is as 1, I^3 as $\frac{1}{D}$, and I as

$\frac{1}{\sqrt[3]{D}}$; which substituted for I in the Expression of the elastic Force $\frac{1}{I^{n+2}}$, gives $D^{\frac{n+2}{3}}$; that is, the elastic or compressive Force is as the Cube Root of that Power of the Density, whose Index is $n+2$.

5. Hence if E the elastic Force be as the Density D , in any Fluid; then the general Expression $D^{\frac{n+2}{3}}$ becomes $E^{\frac{n+2}{2}}$, whence in that Case $\frac{n+2}{3} = 1$, and so $n+2=3$ and $n=1$. Consequently, in such a Fluid F is as $\frac{1}{I}$, or the Particles repel each other with Forces that are reciprocally proportional to the Distance of their Centres. Such then is the Property of the Air, whose

other, and the more so as the Weight of the incumbent Air is greater; and hence we see the *Density* of the Air is greatest at the Earth's Surface, and decreases upwards in *Geometrical Proportion* to the Altitudes taken in *arithmetical Progression*. Now it is found that the Air is four Times more rare at

whose Density is always proportional to the Forces which compresses it, which is also proved by the following Experiment.

6. Let Mercury be poured into an inflected Tube ABCD, open at both Ends, to a small Height as BC. Then stopping the Orifice D very close with a Cork or otherwise, measure the Length of confined Air DC very nicely, and pour Mercury into the other Leg AB, till its Height above the Surface of that in CD be equal to the Height at which it stands in the Barometer. Then it is plain the Air in the shorter Leg will be compressed with a Force twice as great as at first when it possessed the whole Space CD; for then it was compressed only with the Weight of the Atmosphere; but now it is compress'd by that Weight, and the additional equal Weight of a Column of Quicksilver. Let E be now the Surface of the Mercury in the Leg CD, and upon measuring DE, the Space into which the Air is now compress'd, it will be found to be just half the former Space CD, that is, $DE = \frac{1}{2} DC$.

7. Hence it appears that the Spaces $S = DC$, and $s = DE$, which a given Quantity of Air possesses, under different Pressures p and P , are as those Pressures reciprocally; that is, $S : s :: P : p$. And because the Densities d , D , where the Quantity of Matter is given (*An. LVI. 9.*) are reciprocally as the Magnitudes of Bodies, *viz.* $d : D :: s : S$; therefore the Densities of the Air are as the compressing Forces directly, *viz.* $d : D :: p : P$. This Property of the Air is the Principle to which we owe the Invention and Contrivance of several very useful

Plate
XXIX.
Fig. 4.

at the Height of seven Miles than at the Earth's Surface; and therefore at the Altitudes of 7. 14. 21. 28. 35. 42. 49. &c. the Rarity of the Air will be 4. 16. 64. 256. 1204. 4096. 16384. &c.

If the Air were of an equal Density throughout, the Height of the Atmosphere might

ful Instruments and Machines, some of which I will exhibit here, and others in the Sequel of this Work.

8. We have shewn in the last *Annotation* that the Pressure of the Air, in its State of Mean Gravity, will support a Column of Quicksilver to the Altitude of 29½ Inches; and (in *Annot. LXIII.*) it was shewn that the specific Gravity of Mercury was to that of Water, as 14 to 1 nearly; therefore the said Mean Pressure of Air will sustain a Column of Water to the Height of $14 \times 29,5 = 413$ Inches = 34 Feet 5 Inches. But since Mercury is not quite 14 Times as heavy as Water, we may take 400 Inches for the Measure of the Mean Gravity of the Air on Water and 29,5 for Mercury; and then we shall have $DC : DE :: P : 29,5$ in Mercury; or $DC : DE :: P : 400$, in Water; consequently $400 DC = DE \times P$.

9. Again, let the Standard Altitude of Mercury or Water be $H = 29,5$ or 400, and let the Altitude $FG = b$; then will $P = H + b$, and then the above Equation will give this Analogy: As $S : s :: H + b : H$, whence $S : S - s :: H : b$, or $DE : EC :: H : b$; consequently, by having DE or CE given, you know the Altitude $b = FG$. Thus for Example: Let $DC = 10$ Inches, it is required to find what Altitude of Water FG will by its Pressure raise the Surface at C one Inch? Here $CE = 1$, $DE = 9$, and $H = 400$: Then $DE : CE :: H : b$, that is, $9 : 1 :: 400 : 44,4$; or $FG = 44\frac{1}{2}$ Inches nearly, or 3 Feet 8½ Inches. Thus again, Query the Altitude FG that shall raise the Surface C 9 Inches, or ⅓ of the Whole? Say, As $1 : 9 :: 400 : 3600 = FG$, or 300 Feet. Thus the Altitudes are found for every tenth Part of the whole Space DC , as in the following Table.

might be determined; for by Experiment we find the Length of a Column of Air 72 Feet high is equal in Weight to *one Inch* of Water of the same Base: Hence the Density of Air is to that of Water as 1 to 864. It is also found by Experiment, that the Weight of a Column of Air the Height of the Atmosphere will be equal to the Weight of

	Feet.	Inches.		Feet.	Inches.
1	3	8	6	50	0
2	8	4	7	77	9
3	14	2	8	133	4
4	22	1	9	300	0
5	33	4	9½	633	4

Plate
XXIX.
Fig. 5.

10. Hence is deduced the Nature and Structure of the SEA-GAGE, invented by Dr. Hales, and Dr. Desaguliers; whose Description thereof I shall here give. AB is the Gage-Bottle, in which is cemented the Gage-Tube FF in the Brass Cap at G. The upper End of the Tube F is hermetically sealed or closed; the open lower End f is immersed in Mercury C, on which swims a small Thickness or Surface of Treacle. On the Top of the Bottle is screw'd on a Tube of Brass HG, pierc'd with several Holes to admit the Water into the Bottle A B. The Body K is a Weight hanging by its Shank L, in a Socket N, with a Notch on one Side at m, in which is forced the Catch l of the Spring S, and passing thro' the Hole L in the Shank of the Weight K, prevents its falling out when once hung on. On the Top, in the upper Part of the Brass Tube at H, is fix'd a large empty Ball, or full-blown Bladder F, which must not be so large, but that the Weight K may be able to sink the Whole under Water.

11. The Instrument thus constructed, is used in the following Manner. The Weight K being hung on, the

of a Column of Water of the same Base, and 32 Feet, or 384 Inches high: Wherefore 864 multiplied by 384 will produce 331776 Inches, or a little above 5 Miles, for the Height of the Atmosphere, were the Density every where the same as at the Earth.

BUT

the Gage is let fall into deep Water, and sinks to the Bottom; the Socket N is somewhat longer than the Shank L, and therefore, after the Weight K comes to the Bottom, the Gage will continue to descend, till the lower Part of the Socket strikes against the Weight; this gives Liberty to the Catch to fly out of the Hole L, and let go the Weight K; when this is done, the Ball or Bladder I, instantly buoys up the Gage to the Top of the Water.

12. While the Gage is under Water, the Water having free Access to the Treacle and Mercury in the Bottle, will by its Pressure force it up into the Tube Ff, and the Height to which it has been forced by the greatest Pressure, *viz.* that at the Bottom, will be shewn by the Mark in the Tube which the Treacle leaves behind it, and which is the only Use of the Treacle. This shews into what Space the whole Air in the Tube Ff is compress'd; and consequently, by the Rule (in *Art.* 9) the Height or Depth of the Water, which by its Weight produced that Compression, which is the Thing required.

13. If the Gage-Tube Ff be of Glass, a Scale might be drawn on it with a Point of a Diamond, shewing, by Inspection, what Height the Water stands above the Bottom, which Scale is made from the Numbers in the foregoing Table, where the Division may be made for Hundredth Parts, as well as Tenths. But the Length of 10 Inches is not sufficient for fathoming Depths at Sea, since it appears by the Table, that when all the Air in such a Length of Tube is compress'd

BUT since the Density of the Air decreases with the Pressure, it will be more rarefied and expanded the higher we go; and by this means the Altitude of the Atmosphere

fed into half an Inch, the Depth of Water is not more than 634 Feet, which is not half a Quarter of a Mile.

14. If to remedy this we make Use of a Tube 50 Inches long, which for Strength may be a Musket-Barrel, and suppose the Air compressed into an 100th Part, or $\frac{1}{100}$ an Inch; then by saying, As 1 : 99 :: 400 : 39600 Inches, or 3300 Feet; even this is but little more than half a Mile, or 2640 Feet. But since 'tis reasonable to suppose the Cavities of the Sea bear some Proportion to the mountainous Parts of Land, some of which are more than three Miles above the Earth's Surface; therefore to explore such great Depths, the Doctor contrived a new Form for his Sea-Gage, or rather for the Gage-Tube in it, as follows. B C D F is a hollow metalline Globe, communicating on the Top with a long Tube A B, whose Capacity is $\frac{1}{7}$ Part of that of the Globe. On the lower Part, at D, it has also a short Tube D E, to stand in the Mercury and Treacle. The Air contain'd in this compound Gage-Tube is compress'd by the Water, as before; but the Degree of Compression, or Height to which the Treacle has been forced, cannot here be seen through the Tube: Therefore to answer that End, a slender Rod of Metal or Wood, with a Knob on the Top, must be thrust up to the Top of the Tube A B, which will receive the Mark of the Treacle, and shew it when taken out.

15. If the Tube A B be 50 Inches long, and of such a Bore as that every Inch in Length should be a cubic Inch of Air, and the Contents of the Globe and Tube together 500 Cubic Inches; then, when the Air is compress'd within 100th Part of the Whole, it is evident the Treacle will not approach nearer than 5 Inches of the Top of the Tube, which will agree to the Depth of 3300 Feet of Water, as above. Twice this Depth will compress the Air into half that Space nearly,

Plate
XXVIII.
Fig. 6.

mosphere becomes indefinite, and terminates in pure *Æther*. But though we cannot assign the real Altitude of the Atmosphere, it is certain from Observations and Expe-

nearly, viz. $2\frac{1}{2}$ Inches, which corresponds to 6600 Feet, which is a Mile and a Quarter. Again, half that Space, or $1\frac{1}{4}$ Inch, will shew double the former Depth, viz. 13200 Feet, or two Miles and a half; which is probably very nearly the greatest Depth of the Sea.

16. A Gage of this Kind may be of very great Use in many other Cases. Thus the prodigious Force of Compression arising from Freezing may be accurately tried: Let a Bomb of cast Iron six or eight Inches Diameter, and about one Inch thick, be fill'd with Water; then if a small Gage of this Sort be made and fix'd to a Stick, which is to be set upright in the Middle of the Bomb, so that the Gage-Bottle may be in the central Part; and if then the Hole of the Bomb be fast screw'd up, the Bomb covered over with a *freezing Mixture* (which is made of equal Quantities of Salt and Snow, or pounded Ice) in a little Time the Water will begin to freeze all round the Inside of the Bomb, and by its Expansion will produce a greater Force upon the Water, and a greater Degree of Compression of the Air of course, than by any other Means yet known: And this may be continued till it shall burst the Bomb, when the Gage taken out of the globular Shell of Ice (for the Water will be frozen only on the Outside) will shew the exact Quantity of this Force of Compression.

17. Doctor *Hales* (the Author of this Contrivance) actually made the Experiment, but not having well secured the Gage, it was broken to Pieces; but from computing the Force necessary to burst an Iron Bomb an Inch thick, it appeared that this Force was about equal to 1340 Atmospheres, or the Pressure of 1340 times the Weight of 33 Feet of Water. But this Computation was made upon Supposition that the Cohesion of cast Iron is the same with that of Iron-Wire; but

Experiment, that 45 or 50 Miles is the utmost Height where the *Density is sufficient to refract a Ray of Light*; and therefore that may be esteemed the Altitude of the Air to the least sensible Degree of Density. (LXXXIX).

SINCE

but as it must be considerably less, so the Number 1340 may be diminished to 1000; and then the Air must be compress'd into 1000 times less Space than it had in its natural State, and must in that Case have been more dense than Water: For its Density then to that of common Air was as 1000 to 1; whereas the Density of Water and Air are but as 860 to 1.

18. After the same Manner may be tried the Force with which dried Peas, Beans, &c. expand with Moisture, when confined in a Bomb; for it must be a very strong Vessel indeed, since it has been found by Experiment they will burst a Gun-Barrel in swelling. In like Manner also the elastic Force of factitious Air generated from Bodies by Fermentation may be estimated in a very nice and entertaining Manner: With many other Things of this Sort, which the ingenious Reader will readily excogitate of himself.

(LXXXIX) 1. The Density of the Air on one Hand, and the Rarity on the other, are both limited: No Condensation can reach so far as to cause a Penetration of Parts; the utmost Limit, therefore, of Density, must be a perfect *Plenum*, or a given Quantity of Air reduced into a Space absolutely full, or without any Pore; which is a Degree of Density that has not been, and probably never will be, in the Power of Art to effect.

2. On the other Hand, the Rarity of the Air cannot proceed *ad infinitum*, but has its Limit from its Gravity: For though the Rarefaction of the Air be still greater as the Distance from the Surface of the Earth increaseth, its Spring at length will be so weaken'd, that the Force by which the Particles tend upwards from those next below

SINCE the Gravity of the Air is so various, that at one time it will sustain a Pillar of Mercury 31 Inches high, when at another it will raise it but to the Height of 28 Inches,

below them, will be less than the Force of Gravity by which they tend downwards. The Rarefaction of the Air must therefore be bounded, where these two opposite Forces come to balance each other.

3. Now though we cannot possibly define the Limits of the Atmosphere, yet we may still investigate how much the Air is rarefied at any proposed Altitude above the Earth's Surface: For doing which, several Methods have been proposed; some of which are very tedious, and difficult to be understood. I shall here illustrate Sir Isaac's Theorem for that Purpose, which is very concise and plain. It requires only two different Densities of the Air, at two given Altitudes above the Earth's Surface, to be known, and which we easily obtain by Experiment as follows.

4. Take a Vial A E F B, fill'd two Thirds full of Water to C D; in which let a long Tube I G (open at both Ends) be immersed, and closely cemented to the Vial at A B, so that none of the included Air may escape. This done, blow a little Air through the Tube into the Vial, which increasing the Spring of the contained Air, will cause it to raise and support a Column of Water in the Tube, to such a Height H, that its Weight, together with that of a Column of Air pressing on its Surface H, is equivalent to the increased Spring of the confined Air.

5. The Vial and Tube thus prepared are to be carried up to the Top of a Tower, Mountain, or some high Place; and in the Ascent, since the Column of Air pressing on the Water at H is constantly shortened, so its Force of Pressure will be diminished. The Spring of the Air in the Vial will therefore keep the Column of Water constantly rising in the Tube; so that when you have ascended the Height of about 72 Feet, the Water in the Tube will have risen from H to L, thro' the

28 Inches, in the *Barometer*; it follows, that we may take $29\frac{1}{2}$ Inches of Mercury for the *mean Altitude*, and consequently its Weight for the *mean Weight* of a Pillar of Air

the Space of one Inch; and so in Proportion for any other Altitude, as I have several Times found by trying the Experiment.

6. From hence it appears, that the Altitude of one Inch of Water is equivalent to the Altitude of 72 Feet, or 864 Inches of Air; and therefore the specific Gravity of Air is to that of Water as 1 to 864, or, as Sir Isaac has stated it, 860. Now since the specific Gravity of Water is to that of Mercury as 1 to 14, therefore the specific Gravity of Air to that of Mercury will be as $1 \text{ to } 860 \times 14 = 12040$; and since the Height of Mercury supported by the Air in the Barometer is 2,5 Feet; if we say, As $1 : 12040 :: 2,5 : 2,5 \times 12040 = 30100$ Feet, which would be the Height of the Air were it every where as dense as at the Earth, or about $5\frac{3}{4}$ Miles.

7. But since the Air is not uniformly dense, we must seek its Height by another Method to be taught by and by. In the mean time, as the Air's Density constantly decreases, we shall shew how to find the Ratio of its Density at any Altitude to that at the Earth's Surface. Thus, since the Densities are as the compressing Force, which is as the Altitude of the incumbent Column of Air, and since the Weight of Mercury is to Water as 1 to 14, it is plain that the Air which supports a Column of Mercury 2,33 Feet, will sustain a Column of Water to the Height of 33 Feet. The Density on the Earth's Surface then is as 33.

8. Again; it is evident, since 860 Feet Altitude of Air is equal in Weight to 1 of Water, therefore at the Height of 860 Feet above the Earth, the Air (continuing in the same State) would sustain only 32 Feet of Water. At the Height therefore of 860 Feet, the Density of the Air is as 32.

9. Hence the Density at any other Altitude is easily found by the Hyperbola $f a i h$, and its Asymptotes SF and St , S being the Centre of the Earth, and A its Surface: Then the Earth's Semidiameter $SA = 4000$ Miles

Air of the same Base. But a Column of Mercury whose Base is *one Square Inch*, and Altitude $29\frac{1}{2}$, weighs about 15 lb. which is equal to the Pressure of Air on every *Square Inch*; and therefore upon every *Square*

Plate
XXVIII.
Fig. 7.

Miles nearly, or 21120000 Feet. Take $AB = 860$ Feet, and let the Density of the Air be required for any other Height, as $AC = 7$ Miles, or 36960 Feet. In the Points, A, B, C, erect the Perpendiculars AH, BI, CK, which let be made proportional to the Densities of the Air in the Points A, B, C; that is, let $AH : BI :: 33 : 32$, and $AH : CK :: 33 : x$; and from the Points H, I, let fall the Perpendiculars Ht, Iu,

10. Then putting $SA = Aa = r$, $SB = a$, $SC = b$, and $SB : SA :: Aa : Bb = \frac{rr}{a}$; thus $Cc = \frac{rr}{b}$; then $Aa = Bb = \frac{ar - rr}{a}$, and $Aa - Cc = \frac{br - rr}{b}$. And put $m :$

$n :: 33 : 32 :: AH : BI$. Then by the Nature of the Hyperbola, we have the Area *thiu* as the Logarithm of $\frac{St}{Su}$, and the Area *thkw* as the Logarithm of $\frac{St}{Sw}$; or

the Area *thiu* : *thkw* :: $L. \frac{m}{n} : L. \frac{m}{x}$. But (by Coroll. to Prop. XXII. Lib. 2. of the Principia) it is,

thiu : *thkw* :: $Aa - Bb : Aa - Cc :: \frac{ar - rr}{a} : \frac{br - rr}{b} :: \frac{a - r}{a} : \frac{b - r}{b}$.

11. Now, because $a - r = AB = 860$, and $b - r = AC = 36960$, we have $\frac{860}{21120000} : \frac{36960}{21156960} ::$

$L. \frac{m}{n} : L. \frac{m}{x}$; whence we have $L. \frac{m}{x} = 0,573190$;

therefore $L.m - L.x = 0,573190$; whence $L.m = 0,573190 + L.x = 0,945324$, the Number answering to which is $8,817 = x = CK$, the Density required. Or, the Density at A is to the Density at C as AH to CK , or as 33 to $8,817$, which is nearly as 4 to 1 .

Square Foot it will be 2160lb.; and allowing $14\frac{1}{2}$ Square Feet for the Surface of the Body of a middle-sized Man, it must sustain a Pressure of 31320 Pounds, or

12. From the Nature of the Hyperbola it is plain, the Densities m, n, x , must be in a *geometric Progression*. But to shew these Things more generally: Let $SC = x$ be a variable Distance, and its Fluxion $CE = \dot{x}$; let the Density $CK = y$, the compressing Force in the Altitude C as v , and the Power of Gravity as g . Then will the specific Gravity of the Air be there as gy ; for it will be as the Density y when the Gravity g is given, and as the Gravity when the Density is given: and when neither is given, it will be conjointly as both.

13. Since the whole Weight or Pressure of a Column of any homogeneous Fluid, of a uniform Density, is as its specific Gravity multiplied by its Magnitude, (by *Art. LVI. 10.*) and if the Base be the same as the said Gravity multiplied by the Altitude, and therefore its Fluxion as the specific Gravity multiplied by the Fluxion of the Altitude; therefore we have $gy\dot{x} = -\dot{v}$, because the Density of the Air thro' the very small Space CE may be look'd upon as uniform; and since the Pressure decreases as the Altitude x increases, therefore it is that we make the Fluxion of it negative, viz. $-\dot{v}$.

14. If the Gravity g be as $\frac{1}{x^m}$, and the Density y as any Power n of the compressing Force v , viz. if $y : v^n$, and therefore $v : \frac{1}{y^n}$, by taking the Fluxions we have

$\frac{1}{n} y^{\frac{1-n}{n}} \dot{y} = \dot{v}$. In the Place of g and $\dot{v}$ in the Equation $gy\dot{x} = -\dot{v}$, let their Values be substituted, and we have $\frac{1}{n} y^{\frac{1-n}{n}} \dot{x} = \frac{-\dot{x}}{x^m}$.

15. If we put $n=1$, that is, if the Density be as the compressing Force, we have $\frac{\dot{y}}{y} = \frac{-\dot{x}}{x^m}$. Now, since

or 14 Tons, when the Air is of a mean Gravity. This prodigious Force would crush

any Quantities $x, x+a, x+2a, x+3a$, in arithmetical Progression, have all their Fluxions equal and the same, viz. $\dot{x}$; therefore if any Quantities $\frac{1}{x^{m-1}}$ be taken in such a Progression, their Fluxions $\frac{-m-1 \times \dot{x}}{x^m}$

or $\frac{-\dot{x}}{x^m}$ will be all the same or constant; therefore

$\frac{\dot{y}}{y} = -\frac{\dot{x}}{x^m} \pm 1$; consequently $\dot{y} : y$, that is, the Fluxions of the Densities are as the Densities themselves; which therefore are in Geometrical Progression, as is manifest from the Doctrine of Fluxions.

16. If in the same Hypothesis you put $m=1$, or suppose the Gravity to be every where uniform, or given; then $\frac{\dot{y}}{y} = \frac{-\dot{x}}{x}$. If now we take $\frac{-\dot{x}}{x}$ constant, or make $\dot{x} : x$, then will the Distances x be in Geometrical Progression; and in that Case also we have $\frac{\dot{y}}{y} = 1$, or $\dot{y} : y$; whence also the Densities y are in Geometrical Progression.

17. The Fluent of the above Equation $\frac{1}{n} y^n \dot{y} =$

$\frac{-\dot{x}}{x^m}$ is $\frac{1}{1-n} y^n = \frac{-1}{m-1} x^{1-m} + Q$, a constant Quantity. Here, 'tis plain, it cannot be $n=0$, for then

$y^0 = \text{Infinite}$; nor can $m=1$, because then it would be $x^{1-m} x^0 = 1$, and so the Density y would be every where the same, or constant; neither can $n=1$, for

then $y^n = y^1 = 0$. To determine the Value of Q , we must first define the Altitude SF , where the Density vanishes, or $y=0$, and call it $a=SF$; then we have $Q =$

$\frac{-1}{m-1} a^{1-m}$; and hence $\frac{1}{1-n} y^n = \frac{a^{1-m} - x^{1-m}}{m-1}$, where

crush us into a very small Compass, were it not that it is equal on every Part, and counterbalanced

where 'tis plain $\frac{1-n}{n}$ ought to be a positive Number, and less than Unity, that while the Distances x increase, the Densities y may decrease.

18. If the Altitude at which the Density y vanishes be supposed infinite, then $Q = 0$, and the Equation is

$$\frac{1}{1-n} y^n = \frac{1}{m-1} x^{1-m}. \text{ For if in the Equation (Art.}$$

$$17.) y = 0, \text{ and } x = \text{Infinite, then } \frac{a^{1-m}}{m-1} - \frac{x^{1-m}}{m-1} = 0;$$

therefore $\frac{a^{1-m}}{m-1} = \frac{x^{1-m}}{m-1}$, and so $a = x = \text{Infinite}$, contrary to Supposition.

19. If now the Gravity be reciprocally as the Squares of the Distance, or $m = 2$, we have the Equation

$$\frac{1}{1-n} y^n = \frac{1}{m-1} x^{1-m} \text{ become } \frac{1}{1-n} y^n = \frac{1}{x};$$

whence y will be reciprocally as $x^{\frac{n}{n-1}}$, which is a general Formula for any Hypothesis of the Ratio of the compressing Power and Density. Thus, if you suppose the compressing Force in the duplicate Ratio of the Density, that is, $y^2 : v$; then $y = v^{\frac{1}{2}}$, and $n = \frac{1}{2}$, and there-

fore $\frac{n}{1-n} = 1$, whence y will be reciprocally as x .

Hence all those Cases of *Scholium* to *Prop. XXII. Lib. I.* of the *Principia* are derived, and any others at Pleasure.

20. The Density of the Air decreasing indefinitely, it is evident there is no certain Limit or Boundary of the Atmosphere, which gradually rarefies into pure *Æther*, or *Aura*, as it is often called. But since one principal Effect of the Air is the Refraction of Light; and since the Particles of Light are the smallest Bodies we know of in Nature, 'tis reasonable there to fix the Boundary of what we may properly call *Air*, in the Altitude where

terbalanced by the equal Re-action of the Spring of the Air within us (XC).

THE

Plate
XXIX.
Fig. 2.

it begins to have the Power of producing this least Effect in Nature, *viz.* the refracting a Ray of Light.

21. To discover this Altitude of the Air, we have the following Method. Let ADF be the Surface of the Earth, S the Sun below the Horizon, SB a Ray of Light touching the Earth; which is reflected by a Particle of Air, in the highest Part at B, in the horizontal Line BA to a Spectator at A. The Angle SBN is the Depression of the Sun below the Horizon in this Case, which, because it is at the Moment Twilight ends, is known from Observation to be about 18 Degrees. But because BA is also a Tangent, the Angle ACD = SBN = 18 Degrees; and the Angle ACB = $\frac{1}{2}$ ACD = 9 Degrees; which would be true, did the Ray SB pass through the Atmosphere without Refraction, but because it does not, but is refracted or bent towards H, the Angle ACB must be diminished by the horizontal Refraction, which is about half a Degree; whence the Angle ACB = $8^{\circ} 30'$.

22. Therefore in the right-angled Triangle ACB we have all the Angles given, and one Side, (*viz.* AC = 4000 Miles, or the Semidiameter of the Earth) to find the Side BC, thus,

$$\begin{array}{lcl} \text{As the Sine ABC} & = & 81^{\circ} 30' = 9.995203 \\ \text{Is to the Side AC} & = & 4000 = 3.602060 \\ \text{So is Radius} & & 90^{\circ} = 10.000000 \end{array}$$

$$\text{To the Side BC} = 4044\frac{1}{2} = 3.606857$$

wherefore BC—HC=HB= $44\frac{1}{2}$ Miles, the Height of the Atmosphere required.

(XC) 1. Since a cubic Inch of Mercury weighs very nicely 8,1 oz. *Averdupois*, a Pillar of Mercury, whose Base is one square Inch, and

$$\text{Altitude } \left\{ \begin{array}{l} 28 \\ 29\frac{1}{2} \\ 31 \end{array} \right\} \text{ Inches, will weigh } \left\{ \begin{array}{l} 14 \text{ } 3 \\ 14 \text{ } 15 \\ 15 \text{ } 11 \end{array} \right\} \text{ } \overset{\text{lb. oz.}}{\text{fere.}}$$

2. So that the Air, at a mean Gravity, is equivalent to the Pressure of 15 *lb.* upon every square Inch; and therefore

THE Weight of the Air is proved by a great Variety of curious Experiments, the principal of which here follow.

(1.) BY

therefore upon every *square Foot* it will be equal to 2160 *lb.* and $2160 \times 14,5 = 31320$ *lb.* or 14 Tons nearly, the Weight or Pressure sustain'd by a middle-siz'd Man. When the Air is lightest, this Pressure is $13\frac{1}{5}$ Tons; and when heaviest, it is $14\frac{3}{5}$ Tons, the Difference is 1,1 Ton, = 2464 *lb.* the Weight with which we are compress'd more at one Time than another.

3. This great Difference of Pressure must greatly affect us in regard to the animal Functions, and consequently in respect to our Health. If a Person, for Instance, be asthmatical, he will find his Disorder increase with the Levity of the Air; for since a pure, dense, elastic Air, which is very heavy, is only capable to distend his Lungs in Respiration, when the Air is less compress'd by its diminish'd Weight, it will have less Elasticity, and so be less capable of expanding the Lungs; the Valetudinarian will therefore find his Difficulty of Breathing increase in Proportion.

4. Again, the Reason why we think the Air lightest in fine Weather, when it is really heaviest, is because the greatest Pressure constricts and braces the Fibres and Nerves, and brings them to a due Tone, by which Means all the Blood-Vessels act with their full Power and natural Vigour; hence a proper Velocity is given to the Fluids, and a greater *Momentum* to overcome Obstructions in the Capillaries; thus by a brisk Circulation of the Fluids, and a due Compression of the Solids, we find ourselves firm and well, alert and light, and therefore fancy the Air is so.

5. Whereas, on the contrary, when this Pressure is lessen'd by near 2500 *lb.* the Fibres are relax'd, the contractile Force of the Vessels diminished, a languid Circulation ensues, Obstructions, Viscidities, &c. happen, and produce Agues, Fevers, Aches, &c. in some; and in all, a Sort of Indolence or gloomy Inactivity, and Heaviness; and therefore we imagine that it results from the Heaviness of the Air, when it is just the contrary.

6. If it be required to find the Weight of the whole Atmosphere

(1.) BY actually weighing it in a nice Balance; where we shall see that *one Gallon of Air* will weigh a Dram very nearly.
 (2.) By filling a Glass Tube with Mercury, and inverting it in a Basin of the same Fluid, where it will appear that a Column will be supported in the Tube by the sole Weight or Pressure of the Air, to upwards the Height of 28 Inches. (3.) By taking the Air off from the Surface of the Quick-silver in the Gage of the Air-Pump, which then immediately rises by the Pressure of the external Air. (4.) By exhausting a Receiver

mosphere on the Earth's Surface, we may proceed thus: Suppose the Earth's Diameter in round Numbers 8000 Miles, the Area of a great Circle will be $8000 \times 8000 \times 0,7854 = 50266400$ square Miles, which multiplied by 4, gives 201065600 square Miles for the Surface of the Earth; but because we took the Diameter a little too large, we may take 200,000,000 for the Number of square Miles in the Earth's Surface; in one square Mile are $(5280 \times 5280 =)$ 27878400 square Feet, therefore on the Earth's Surface we have 5575680000000000 square Feet, which multiplied by 2160 (the Pressure on each square Foot, *Art. 2.*) gives 12043468800000000000 lb. for the whole Pressure. N. B. Since 2240 lb. make a Ton, the Pressure 2160 lb. upon a square Foot, is very near a Ton Weight.

Plate
XXIX.
Fig. 3.

7. I shall now present the Reader with a Solution of a very curious Problem, viz. *To find the Thickness FH of an hollow Ball or Globe F D M E, made of any given Metal, &c. whose specific Gravity is known, such that it shall swim immersed in Part or wholly in any homogeneous Fluid, whose specific Gravity is also known.* Let AB be the Surface of the Fluid, and let the Globe F D E swim therein, immersed to the Depth LM, and let the specific Gravity of the Metal be to that of the Liquor as 1 to 12.

Receiver placed over the Hole of the Brass Plate on the Pump, which will then be kept fast on by the Pressure of the incumbent Air. Or, (5.) More demonstratively by exhausting a small Receiver under one larger, and letting in the Air at once upon it; which will then be fasten'd to the Plate as before, though not placed over the Hole. (6.) By placing the Hand on the open Receiver, and exhausting, the Weight of the Air on the Hand will be extremely sensible. (7.) By placing a plain Piece of Glass on the said open Receiver, which, when the Air is a little exhausted, will

8. Then putting the Diameter $FM = D$, $HN = d$, $LM = x$; we have the spherical Shell equal to the Sphere FDE — Sphere HIK, that is, $\frac{p D^3}{6} - \frac{p d^3}{6}$: also the

Segment of the Liquor DME, is $\frac{p D x^2}{2 D} - \frac{p x^3}{3 D}$; and, in Case of an Equilibrium between these Quantities, we have

$\frac{p D^3}{6} - \frac{p d^3}{6} : \frac{p D x^2}{2 D} - \frac{p x^3}{3 D} :: n : 1$. Whence we shall get $D^3 - d^3 D = 3 D x^2 n - 2 n x^3$; and thence $D^3 - 3 D x^2 n + 2 n x^3 = d^3 D$; or $D^2 - 3 x^2 n + \frac{2 n x^3}{D} = d^2$; whence

at last $d = \sqrt{D^2 - 3 x^2 n - \frac{2 n x^3}{D}}$. Therefore $\frac{D-d}{2} =$

the Thickness of the Shell required.

9. If we suppose the Body to swim in the Fluid wholly immersed, then $x = D$, and $d = \sqrt{D^2 \times 1 - 2n}$ $= D \sqrt{1 - 2n}$. Now admit FDE be a Sphere of Copper 10 Feet in Diameter, and that the Fluid Medium be Air, whose specific Weight to that of Copper is as 1 to

will be broke into Pieces by the Weight of the Air. (8.) A Bladder tied over the same Glass will be broke in the same Manner. (9.) the Air exhausted from a thin Bottle under a Receiver, and then suddenly let in, will, by its Weight, instantly reduce it to very small Pieces. (10.) A Bottle broke by the same means another Way. (11.) By putting a Piece of Wood under Quicksilver in the Receiver, and then exhausting the Air, and letting it in again, it will by its Weight force the Quicksilver into the Pores of the Wood, and very sensibly increase its Weight. (12.) The exhausted Brass Hemispheres prove not only the prodigious Weight of the Air, but also the Quantity thereof very exactly. (13.) By exhausting Glass Bubbles swimming in Water, and letting the Air in again, it will force the Water into the Bubbles, and make them sink. (14.) The

$860 \times 9 = 7640$; hence $n = \frac{1}{7640}$, and therefore $1 - n$

$= 1 - \frac{1}{7640} = \frac{7639}{7640}$; and because $D = 10$ Feet, or 120

Inches, therefore $120 \sqrt{\frac{7639}{7640}} = d = 119,992$; and so

$\frac{D-d}{2} = 0,004 = FH$, the Thickness of the Metal re-

quisite for the Globe to swim in Air.

10. But in order to this, one Thing more is necessary, viz. that the Concavity of the Globe be a pure Void or Vacuum: for if it be filled with Air only, the Globe will

(14.) The Syringe with its Weight descending in *Vacuo*, and ascending again upon the Admission of Air, does very prettily prove the *Pressure of the Air*, and the *Rationale* of Syringes in general (XCI).

THAT

will sink in the Air, be it ever so thin; because in that Case it must be heavier than an equal Bulk or Globe of Air. Hence we see how impossible a Thing is that *Aerial Navigation*, which *Franciscus de Lanis* and other Miracle-Mongers have amused us with, before true Philosophy appeared to deliver us from those vain Speculations, and fruitless Attempts that may be grounded thereon.

(XCI) 1. I shall here give the *Rationale* of the several *Phænomena* of the Experiments on the Air-Pump, as they are shewn in the Order of my Lectures on this Subject. The first of which is, to shew the *absolute Weight of the Air by weighing it in a Balance*; of which we have already given an Account in *Annotation LXXXVII. 2.*

EXPERIMENT II.

2. The Second is, *fixing a small Receiver on the Plate of the Air-pump, by exhausting the Air out of it.* The Reason of which is, that the Pressure of the Air acts now alone on the Outside of the Glass, and perpendicularly on its Top, and presses it down with a Force equal to so many Times 15 lb. as there are square Inches in the Top of the Glass, or in the largest horizontal Section of it. The Spring of the Air, (which is always equipollent to the Pressure) being now taken away from within the said Receiver, will leave it to sustain the entire Force of Pressure, which will therefore fix it fast down to the Plate.

EXPERIMENT III.

3. The Third Experiment *fixes the Glass firmly on the Plate, not, as before, over the Hole, but on one Side of it.* This is to undeceive People in regard to the common erroneous Notion of a *Suction*, which they suppose is something within-side of the Glass that draws it down as the Air passes out though the Hole. But when they

see

THAT Water rises in *Pumps, Syphons,*
and all kinds of *Water Engines,* by the
Pres-

see the Glass placed on one Side the Hole under a Receiver, and that as the Air is drawn out of the Receiver it will by its Spring all escape from under the Glass at the same time, and then when the Air is let into the Receiver all at once, it falls on the little Glass, and fixes it down in such Manner that it is plainly seen to sink into the Leather upon the Plate; I say, when all this is seen and considered, it entirely eradicates that vulgar Error, and sets the Truth in a clear Light.

EXPERIMENT IV.

4. The *Fourth* Experiment fixes a Person's Hand on the Top of an open Receiver. This is done by the Pressure of the Air on the Top or Back of the Hand, when the Spring of the Air is wanting within the Receiver to counter-act it. This great Pressure is very sensible to the Hand, though not hurtful; and the Skin and Flesh is visibly pressed down between the Metacarpal Bones. The Spring of the Air in the Hand at the same time exerts itself, by extending the Skin and Flesh of the Part of the Hand on the Glass as far down as possible, by which means the Blood flows thither in great Quantity, as in Cupping, and makes the Part look very red. If the Area of the Top of the Receiver be 4 Square Inches, the Hand will be pressed or kept on by a Weight equal to 60 lb.

EXPERIMENT V.

5. The *Fifth* Experiment is fixing the Brass Hemispheres together by the Pressure of the external Air, in such Manner as to require two strong Men to pull them asunder. This is done by exhausting the Air from their Cavity, and thereby taken away the Spring, leaving the Pressure to act alone. If the Diameter of the Hemispheres be 4 Inches, the Area will be 12,556 Square Inches, which multiplied by 15 gives 188,3 lb. by which they are compressed together.

EXPERIMENT VI.

6. The *Sixth* Experiment shews the Spring of the Air throwing the Air out of a Glass-Bubble through the Water in which it is placed, in Form of large round Bubbles of Air. This

Pressure of the Air only, is made evident by taking off the said Pressure (in the exhausted Receiver)

This is done by taking the Pressure of the Air off the Surface of the Water in the Jar under the Receiver; and by that means the Spring of the Air having nothing to counter-act or confine it, will exert itself, and cause the Air to escape out of the Bubble, and from all Parts of the Water, in very small Globules rising up to the Top; whence, by the way, it will appear, that Water is a very porous Body, and all its Interstices possessed by Air, which is now expanded into visible Volumes or Globules, and seen to make its Escape.

EXPERIMENT VII.

7. The *Seventh Experiment* is but a Part of the former, and shews, that upon letting the Air again into the Receiver, it falls on the Surface of the Water, and by that means compresses the whole Body of Water, and drives Part of it into the evacuated Glass-Bubble, which then becomes heavier than Water, and sinks to the Bottom. As there is but very little Air left in the Bubble, its Spring will be very weak, and so will yield to the Force of the external Air compressing the Water, and therefore will give the Water Admittance till it becomes so far compressed as to have a Spring equal to that of the outward Air, or to that which was in the Bubble at first. Its Density will then be the same also; and its Bulk, compared with the whole Bulk of the Bubble, will shew what Part of the whole Quantity of Air remained after Exhaustion.

EXPERIMENT VIII.

8. The *Eighth Experiment* shews, that the same Bubble, placed with its Neck upon a hollow Glass over a small Basin, under the Receiver, upon exhausting the Air the small Quantity of Air in the Bubble will again expand itself, and drive out all the Water. The Pressure of the Air, which before kept the Water in the Bubble, being now taken away, the Spring of the Air in the Crown of the Bubble gradually exerts itself, and at last expels all the Water. From this Experiment it plainly appears, that the Spring of the Air is equal to the Pressure, because the Spring drives out all the Water which the Pressure forced into the Bubble.

Receiver) from a Bason of Mercury, which then will not rise in the Pipe of the Syringe on

EXPERIMENT IX.

9. The Ninth Experiment is the Expulsion of the Contents of an Egg through a small Hole in the little End by the Spring of the Air contained in the great End of the Egg. While the Egg is new and good, there is always a small Quantity of Air contained in the great End between the Shell and the Skin or Putamen, which, upon taking off the Pressure of the Air from the Hole, will expand itself, and drive out the White and Yolk through the said Hole in the little End.

EXPERIMENT X.

10. The Tenth Experiment shews, that when half the Shell of the Egg thus emptied is taken off, the said Bubble of Air will, upon Exhaustion, so expand itself by its Spring as to raise up the Skin of the Egg, and throw it so far out as to make the Resemblance of the entire Egg. This will happen only when the Egg is quite new; for as the Egg grows stale, the Air will lose its Spring by degrees, and the Egg will become putrid or addle. It is observed by Naturalists, that this included Bubble of Air is absolutely necessary for the Production and Maturation of the Chick, which is effected by the Warmth and Fermentation occasioned by the constant Incubation of the Hen.

EXPERIMENT XI.

11. The Eleventh Experiment is to shew the great Quantity of Air contained in all solid Bodies. For when a Piece of Brass, Iron, Stone, &c. is put into the Water of a Jar under the Receiver, and the Air drawn out, the Spring of the Air contained in the Pores of those solid Bodies, will, by expanding the Particles, cause them to appear on the Surface in numberless Globules, and exhibit a curious Spectacle to the Eye, like the pearly Drops of Dew on the Piles of Grass; all which suddenly disappear by letting the Air in again.

EXPERIMENT XII.

12. The Twelfth Experiment shews, that a Piece of Cork with a Weight added to it, to make it just sink in the Water, will be raised to the Top, or made to swim, by exhausting the Air. For the Bubbles of Air which are expanded from its

on drawing up the Piston, as it will in the open Air.

THE

its Pores, and adhering to its Surface, render it lighter than Water, in which Case it must necessarily rise to the Top, or swim.

EXPERIMENT XIII.

13. The *Thirteenth* Experiment shews, that *Glass-Images and Bubbles, which sink in Water, will, on exhausting the Receiver, rise to the Top and swim.* For the Bodies of these Images, &c. being hollow, are filled so far with Water as to make them just sink; and the rest of the Cavity being possessed of Air, this Air will, upon taking off the Pressure of the external Air, exert its Spring, and drive out the Water from the Images and Bubbles; they then become lighter than the Water, and rise to the Top. When the Air is let in again, the Water re-enters their Bodies, and they sink down again.

EXPERIMENT XIV.

14. The *Fourteenth* Experiment shews, that a *Bladder nearly emptied of Air, and sunk with a Weight to the Bottom of a Jar of Water, will, upon Exhaustion, rise to the Top and swim.* The Reason of which is, that when the Pressure of the external Air is taken off, the Spring of the little inclosed Air will dilate and expand the Bladder to its full Bulk; and then the Quantity of Water equal to its Bulk will be heavier than the Weight and Bladder, and so will buoy them up to the Top, according to the Laws of *Hydrostatics*, which see.

EXPERIMENT XV.

15. The *Fifteenth* Experiment raises *Beer or Ale into a large white Head or Froth to the Top of the Jar.* This happens on account of the great Tenacity of the Fluid; for when the Pressure of the Air is taken off, the Air in the Beer expands itself into large Globules, to which the Particles of Beer adhering on every Side render them too heavy to rise from the Surface, and fly away in the Air. The Bubbles of Air being thus raised are, as it were, conglutinated or stuck together by the adhesive Quality of the Liquor; and thus rise in great Quantities, the upper Part being raised and sustained by the Expansion of that below. When the Air is let in, the

THE SPRING of the Air is demonstrable by various Experiments: As, (1.) By the great

the Air-Bubbles contract, subside, and retire within the Pores of the Fluid. In the same Manner Soap-Water, Yeast, &c. will rise in a Head.

EXPERIMENT XVI.

16. The Sixteenth Experiment is exhibiting the Phenomenon of Boiling Water in the exhausted Receiver. To this End the Water must be as hot as the Finger can well bear when put under the Receiver. Upon exhausting, the Air-Bubbles will be seen to rise very soon, and at first very small; they soon appear bigger, and at last are so large, and rise with such Rapidity, as greatly to agitate the Water, and cause it to appear in all the Circumstances of Boiling; which Agitation of the Water will continue till the Air be let in again, and then it will cease, and all will be quiet and still as at first. Some People imagine the Water grows hotter by boiling under the Receiver, as it does over the Fire; not considering that Water boils only by the great Expansion and Rarefaction of the Air it contains, from whatever Cause it proceeds, as from the Heat of Fire, from taking off the Pressure of the Atmosphere by the Air-Pump, &c.

EXPERIMENT XVII.

17. The Seventeenth Experiment shews, that a shrivel'd Apple will be plump'd out, and made to look fair, under the exhausted Receiver. The Reason of which is the Expansion of the Air in the Substance of the Apple, when the Pressure is taken off from its Surface; for though some Parts of the Skin be pervious to the included Air, (as appears by the little Streams rising from the Pores of the Apple placed in Water) yet the greatest Part of the Surface is not, and will not therefore suffer the Air to pass out, but will yield and expand to its utmost Dimensions, (and sometimes burst) on which all the Wrinkles disappear, and the Apple puts on a youthful Face, till the Air be again let in, when it instantly returns to its former State of Decay and shrivel'd Countenance.

EXPERIMENT XVIII.

18. The Eighteenth Experiment exhibits the beautiful Appearance

great Expansion of a small Quantity of Air in an emptied Bladder, when the Air is

Appearance of Air rising from all Parts of a vegetable Substance very copiously through the Water in Vacuo. For when the Pressure of the incumbent Air is taken off, the Spring of the Air contain'd in the Air-Vessels of Plants, will, by expanding the Particles, cause them to rise from the Orifices of all the Vessels, and that for a long Time together, by which is shewn what a great Quantity of Air is contained in all vegetable Substances; and since it is seen to come out of the Sides or all over the Surface of a Piece of Stick, as well as from its transverse Sections, it is a convincing Proof that the Texture of the Stems of Plants and Trees consist of Vessels in a longitudinal and also in an horizontal Position.

EXPERIMENT XIX.

19. *The Nineteenth Experiment shews the Method of injecting a vegetable Substance with Quicksilver.* Thus if a Piece of Stick be cut even at each End with a Penknife, and immerfed in Mercury, upon pumping out the Air from the Receiver it will at the same Time come out of the Pores of the Wood through the Mercury, as will be visible at each End. When the Air is let in again, it falls on the Surface of the Mercury, and forces it into the Pores of the Wood to possess the Place of Air. When the Wood is taken out and weighed, it will be found several times heavier than before; it will have changed its Colour, being now of a blueish Hue all over; and if split or cut transversely, the Quicksilver will be seen glittering in all its Pores, and through every Part.

EXPERIMENT XX.

20. *The Twentieth Experiment is the breaking of a Bladder by the Weight of the Air.* For if the Bladder be tied over one End of an open Receiver, as the Air is exhausting the Spring will be weakened, and give way to the Pressure of the Air on the Bladder, in which Case the Bladder will put on a concave Figure, which will be nicely spherical; and this will continue increasing, till

is taken off from the external Parts in the Receiver. (2.) By the Extrusion of a Fluid out

till the Strength of the Bladder be overcome by the Pressure, when it will break with a very great Report.

EXPERIMENT XXI.

21. The *Twenty-first* Experiment is the breaking a *Glass-Bottle* by the Pressure of the Air. For this Purpose the Bottle ought to be of a square Form, and not cylindrical or globular; it should also not be very thick, if small. Then the Bottle is screw'd on to the Hole in the Plate of the Pump, and the Air drawn out; by this means the Bottle sustains the Pressure from without, so long as its Strength will permit; then the Parts yield, and the Bottle is instantly reduced into very small Pieces.

EXPERIMENT XXII.

22. The *Twenty-second* Experiment breaks a Bottle by the Spring of the Air. For the Mouth of the Bottle being securely sealed up, so that no Air from within can escape, it is put under the Receiver; and as the Air is drawn off from its Surface, the Spring of the Air included will take place, and act more and more forcibly against the Sides of the Glass, which having now nothing but its own Strength to defend it, as soon as that is overcome the Parts give way, and the Glass is burst in Pieces.

EXPERIMENT XXIII.

23. The *Twenty-third* Experiment is to shew, that a Bladder being emptied of its Air, all to a very little, and then suspended in the Receiver, the little Portion of Air will expand itself in such manner upon Exhaustion, that at last it will distend and fill out the Bladder to its utmost Bulk, and make it appear as one full-blown. The Reason of which is apparent from what has been so often repeated above; as also, of its contracting again when the Air is let in.

EXPERIMENT XXIV.

24. The *Twenty-fourth* Experiment shews, that the Syringe will descend from the suspended Piston in Vacuo, when the Hole at Bottom is stopped, and a small Weight added to overcome the Friction. If the Hole be stopped in

out of a Glass Bubble, by the Expansion of the Bubble of Air contained therein.

(3.) By

in the open Air, and the Piston drawn up, it will be resisted by the Pressure of the incumbent Column of Air; but in *Vacuo*, where this Air is taken away, the Piston may freely rise; or, which is all one, the Syringe may descend; as it will, if a small Weight be added to overcome the Friction of the Piston. When the Air is let in again, it will be seen to push up the Syringe upon the Piston again.

EXPERIMENT XXV.

25. The *Twenty-fifth* Experiment shews, that *Water rises in Pumps, and Quicksilver in the Barometer, by the Pressure of the Air only*. For a Glass Tube being screwed on to the above-mentioned Syringe, and immersed in the Mercury in the open Air, if the Piston be then lifted up, it will attenuate the Air contained in the Glass Tube, by giving it a greater Space to expand in, and by this means lessen its Spring. The Pressure then of the external Air will raise so much Mercury into the Tube, as its Weight added to that of the Spring of the included Air is an equipollent Force, and then an Equilibrium will ensue: But if the Mercury be placed under the exhausted Receiver, and the Piston lifted up, no Mercury will then be seen to rise; which plainly shews the Cause, viz. the Air's Pressure is in that Case taken away.

EXPERIMENT XXVI.

26. The *Twenty-sixth* Experiment shews, that the *Spring of the Air has a Force equal to the Pressure of the Air, by raising the Quicksilver to the same Height*. For if a Tube open at both Ends be cemented into a Glass Vial, nearly filled with Quicksilver, and placed under the exhausted Receiver, as the Air is gradually exhausted, you will see the Mercury rise from the Vial into the Tube above the Pump, by the Spring of the included Air, to the same Height as it is in the Gage-Tube below by the Pressure, and that during the whole Time of the Exhaustion. And this will always happen, let the Quantity of Air in the Vial be ever so small, or

(3.) By the Expulsion of the White and Yolk of an Egg through a small Hole in the

what it will; the Phænomenon depending not upon the Quantity, but the Strength of the Spring.

EXPERIMENT XXVII.

27. The *Twenty-seventh* Experiment *shews the Method of making an artificial Fountain in Vacuo, by the Air's Pressure.* For this Purpose a very tall Glass Tube is hermetically closed on the Top, and at Bottom by means of a Brass Cap screwed on to a Stop-Cock, and that to the Plate of the Pump; then, when all the Air is exhausted, the Cock is turned, and taken off the Plate, and immersed in Mercury or Water: Then, upon turning the Cock again, the Fluid by the Pressure of the Air will be seen very beautifully to play up in the Tube in the Form of a Fountain.

EXPERIMENT XXVIII.

28. The *Twenty-eighth* Experiment *shews, that the Magnetic Virtue from the Stone, or a touched Piece of Iron, affects the Needle in Vacuo, in the same manner as in open Air.*

EXPERIMENT XXIX.

29. The *Twenty-ninth* Experiment *shews, that the Attraction of Cohesion is the same in Vacuo as in the open Air.* For this Purpose a large Glass Tube, drawn out into a very fine Capillary at Top, when filled with Water will sustain it to a certain Height in the Air: If the same be placed under the Receiver, and the Air drawn out, the Water will remain suspended as before; which shews it to be wholly owing to the Force of Attraction.

EXPERIMENT XXX.

30. The *Thirtieth* Experiment *shews, that Bodies which equilibrate each other in the Air, lose their Equilibrium in Vacuo.* Thus if a Piece of Lead at one End of a fine Balance, and a Piece of Cork at the other, are in *Equilibrio* in the Air, and thus placed under the Receiver, as soon as the Air begins to be exhausted, so soon the Equilibrium will begin to be destroyed, till at last, when all the Air is taken away, the Cork will descend, and shew itself really heavier than the Lead. The

the little End, by the Expansion of the Air contained in the great End; and also,

(4.) By

The Reason of which is evident from Hydrostatic Laws; for both Bodies being weighed in Air, each would lose the Weight of an equal Bulk of Air, consequently the Cork will lose a greater Weight than the Lead in the Air; and therefore when the Air is taken away, the Weight that is restored to it being greater than what the Lead has retrieved, will cause it to preponderate, or weigh down the Lead in *Vacuo*. And hence we see that a *Pound of Feathers is really heavier than a Pound of Lead*, if weighed in the Air.

EXPERIMENT XXXI.

31. The *Thirty-first* Experiment *shews the Air to be the Medium of Sounds*. For if a Bell be screwed on to the Air-Pump, it will ring in the Air, and be heard under a thin Receiver: But when the Air is exhausted, the Sound is not heard, which plainly proves it to be propagated by means of the Air; and this is farther evinced by letting the Air gradually into the Receiver, because if, in the mean time, you keep shaking the Bell, the Sound will increase in Proportion as the Glass is filled with Air.

EXPERIMENT XXXII.

32. The *Thirty-second* Experiment *shews, that the Air is necessary for the Existence of Fire and Flame*. Thus if Charcoal thoroughly lighted, and a Candle burning, be placed under the Receiver, as the Air is exhausted the Coals will begin to decline and die away, and the Candle will go out by Degrees.

EXPERIMENT XXXIII.

33. The *Thirty-third* Experiment *shews the Rise of Vapours and Smoke to be owing to the Air*; because when the Air is taken away, the Vapours, which at first rise very plentifully from the wet Leathers of the Plate so as to obscure the Receiver, begin to fall when the Air becomes greatly attenuated; and the Smoke, which at first rose from the Candle extinct, now begins to descend; and when the Air is all exhausted, the Receiver becomes quite clear, and free from all Appearance of Smoke.

- (4.) By raising up the Skin of the Egg (after the Yolk is taken away, and one half of

Smoke or Vapour. Hence, by the way, we see the Reason why, when the Air grows lighter, it lets fall the Vapours, and the Weather becomes misty, hazy, and wet or rainy.

EXPERIMENT XXXIV.

34. The *Thirty-fourth* Experiment *shews the Explosion of Gunpowder is owing to the Air*. For if it be kindled in *Vacuo*, the Air, that so suddenly expands itself from the Powder, and gives such a Shock to the common Air, now finds none to encounter, and so makes no sensible Appearance, otherwise than by the sinking of the Mercury a little in the Gage by its Spring.

EXPERIMENT XXXV.

35. The *Thirty-fifth* Experiment *shews how Halo's are produced by refracted Light*. Thus if a Candle be held on one Side of the Receiver, and the Eye placed at some Distance on the other, as soon as the Air begins to be exhausted, and becomes attenuated and repleted with Vapours to a proper Degree, the Light of the Candle will be refracted through that Medium in Circles of various Colours, very much resembling those seen about the Moon in a hazy Air at Night.

EXPERIMENT XXXVI.

36. The *Thirty-sixth* Experiment *shews how the Lungs of an Animal are affected in Vacuo; in what Manner it dies, and is revived again*. For this Purpose a small Bladder is tied to a Pipe, and screwed into a Bottle, which then represents the Lungs in the Thorax. This Pipe is perforated quite through to the Bladder, and is the more analogous to the *Trachea* or Wind-pipe. The Air confined in the Bottle about the Bladder is in the same Circumstances with that in the Breast about the Lungs. When this *Apparatus* is placed under the Receiver, one or two Exsuctions will attenuate the Air in the Receiver and Bladder, upon which the Spring of included Air in the Bottle will compress the Bladder, as that in the Thorax does the Lungs; and a few more Turns,

of the Shell) by the Expansion of the said included Bubble of Air, so as almost to fill the

Turns will cause the Bladder to be compressed together. The Lungs being thus compressed, the Animal is sensible of a prodigious Weight, the Circulation of the Blood through the Lungs is stopped, the Creature is all over convulsed, and at last expires in the greatest Agonies of a most cruel Death. When the Air is let in again, the Bladder gradually expands, as do the Lungs of the Animal; and if it has not lain too long, the Blood will again pass through them, and the Animal will recover its suspended Life.

EXPERIMENT XXXVII.

37. The *Thirty-seventh* Experiment *shews Air to be absolutely necessary to most Sorts of Animals*. This we do by exhausting the Air from a Cat, a Rat, a Mouse, a Bird, &c. which soon die in the Manner above described. It is not always, indeed, that Gentlemen can thus suffer their Curiosity to get the Ascendant so far over their Humanity, as to desire so shocking a Spectacle. The Ladies (greatly to their Honour) shew more Consideration, in generally voting against it.

EXPERIMENT XXXVIII.

38. The *Thirty-eighth* Experiment *shews Air is not absolutely necessary to the Life of some Animals*: For it is well known that pumping the Air from a Toad, an Eel, a Viper, and all Sorts of Insects, seems not immediately to affect them. Indeed, the winged Insects cannot fly, but they will crawl and run about very briskly. Some say Fish will die for want of Air; I confess I never could kill any. They appear greatly disturbed, swollen, and sickish at first; but Mr. *Hawke* says he has kept them a Week in *Vacuo*, and they recovered their first Illness, and were at the Week's End as lively and alert as those which had been kept as long in the Air.

EXPERIMENT XXXIX.

39. The *Thirty-ninth* Experiment *shews no Winged Animal can fly without Air*. For this Purpose a large Butter-fly is a proper Subject, for as soon as it is put under

the Half-Shell. (5.) Glass Bubbles and Images fill'd with Water, so as to make them

under the Glass it will fly and flutter about, but when the Air is taken away, nothing more of that kind is seen. If a fine Silk be tied about one of the Horns of this Animal, and it be thus suspended in the Middle of the Receiver, it will at first fly towards every Side of the Glass, but when the Air is exhausted, it cannot get out of the perpendicular Position into which it is brought by its Gravity, though it will be constantly endeavouring to do it.

EXPERIMENT XL.

40. The *Fortieth* Experiment is that of *Aduſt* or *Burnt* Air; this Air is brought into the Receiver through the Fire; and if a Candle be put down into it, it instantly goes out, and will do so for many times together; but every time the Candle burns longer than before; which seems to shew, that this Air is somewhat of the same Nature with that in Mines, commonly called *Damps*, and is, like that, purified again by Fire.

EXPERIMENT XLI.

41. The *Forty-first* Experiment shews that *Aduſt* Air is *instant Death* to most Sorts of Animals. Thus a Sparrow put into this Air tumbles down with a kind of Vertigo, is convulsed, and dies directly; much after the same Manner as Men fall down dead in the contaminated Air of Mines, deep Wells, &c.

EXPERIMENT XLII.

42. The *Forty-second* Experiment shews that all Bodies descend equally swift in Vacuo. Thus a Guinea and Feather let fall from the Top of a tall exhausted Receiver, come down to the Bottom in the same time, or both together. But when let fall from thence in the Air, the Feather will descend much slower than the Guinea, and with an oblique or indirect Motion.

EXPERIMENT XLIII.

43. The *Forty-third* Experiment shews all Fermentation and Putrefaction depend on Air. Thus Apples, Pears, Plums, Cherries, &c. which in the Air soon grow

them just sink in Water, will, upon exhausting the Air from the Surface, rise to the

grow mellow, putrid, and rotten, will, if kept in an exhausted Receiver, placed under Water, be preserved a long Time untainted, appear fresh and in their native Bloom. Thus Eggs also, which in the Air soon grow stale, putrid, and addle, will in *Vacuo* retain their Goodness, and be fit for use after a great while. Which is the Reason why many People keep them in Pots of Butter, Lard, &c. to preserve them from the Air.

EXPERIMENT XLIV.

44. The *Forty-fourth* Experiment shews how necessary Air is for the Germination and Growth of Plants and Vegetables. For if the same Seed be planted in two different Pots of Earth at the same Time, and one of them be kept in an exhausted Receiver, the Difference between the Appearance and Growth of each will be sufficiently sensible to any that shall try the Experiment.

EXPERIMENT XLV.

45. The *Forty-fifth* Experiment shews, that the Writing made with Phosphorus upon Paper, laid on the Plate of the Pump, will in *Vacuo* appear luminous, and not be extinguished like common Fire. It will also send up lucid Fumes or Clouds to the Top of the Receiver,

EXPERIMENT XLVI.

46. If the Paper be wetted by Patches, on which the Lines have been drawn with Phosphorus, instead of a Cloud it will give Flashes in *Vacuo*. For these Experiments with Phosphorus the Room should be made very dark.

EXPERIMENT XLVII.

47. The *Forty-seventh* Experiment shews, that upon some Chemical Mixtures a strong Effervescency, Ebullition, and Accension will happen in *Vacuo*. Thus, if to an equal (but small) Quantity of Vitriol, Oil of Tartar per Deliquium, and Oil of Cloves, you put two or three small Pieces of Phosphorus, the Mixture will take Fire in the open Air, and is put out by the Addition of a little Water. It will not only shine, but boil up into a Flame in *Vacuo*.

the Top of the Vessel. (6.) Also a Bladder filled with Air, and just made to sink

EXPERIMENT XLVIII.

48. *Melted Lead, and other Metals, set to cool in Vacuo, have their Surfaces concave; whereas they are convex in the open Air.* The Reason of which is the same as of the Expansion of Water when it congeals into Ice. Thus Ice becomes specifically lighter than Water, and swims in it; as any solid Metal is specifically lighter than when melted: Thus a leaden Bullet swims in melted Lead. What Agent Nature employs in the Affair of Congelation, is perhaps as yet unknown to Mortals; but whatever it be, 'tis certain that one Part of its Operation is to sever the Particles, and fix them at a greater Distance from each other in the fixed, than they are in the fluid State.

EXPERIMENT XLIX.

49. *The Chemical Process of Crystallization will not succeed in Vacuo.* If Salts be mixed with Water and evaporated to a Pellicle, and then placed under an exhausted Receiver, and set in a cool Place as usual, it will not shoot into Crystals, as in the open Air it readily will.

EXPERIMENT L.

50. The *Fiftieth* Experiment shews, that if a Piece of Wood be cemented in the lower Part of the Neck of the open Receiver, and Mercury be poured upon it, after two or three Exhaustions the Pressure of the Air will be so great on the Mercury, as to cause it to descend through the Pores of the Wood in Form of a beautiful Shower; which will shine (if it be well cleansed and the Weather dry) in a dark Room. The Air also will follow the Quicksilver through the Pores of the Wood, and cause the Gage to sink.

51. To these Experiments of a *Vacuum*, I shall add the following Particulars relating to the CONDENSATION of Air: As, (1.) That the Vessel ought to be very strong to bear the Force of the Air's Spring thus increased;

sink with a Weight, will, upon Exhaustion, soon rise by the Expansion of the contained Air.

creased; for which Reason they are generally made of Brass. (2.) If Glass be used for a Condenser, it will not indeed suffer so great a Degree of Condensation, but the Experiment will be pleasanter, by viewing the Subject placed in the condensed Air. (3.) The Spring of the Air will be greater in Proportion to its Condensation, and therefore (4.) The Sound of the Bell will be twice or thrice as loud as in the common Air, if the Air be made twice or thrice as dense by Injection.

(5.) A round Vial will be broke by condensed Air, that could not be broke by the Pressure of the common Air.

(6.) Though Animals soon die by not having the natural requisite Quantity of Air, yet they will not be easily killed by having that Quantity increased by Condensation.

(7.) If Air be condensed upon Water in a Bottle, it will cause it to spout through the Tube of Communication to a very great Height, viz. to 30 Feet, if only one Atmosphere be injected; to 60 Feet, if two; and so on.

(8.) A Bladder, that will sustain the Spring of common Air, will be broke by the Spring of condensed Air. In short, the Force of condensed Air may be so far increased, as to countervail or antagonise the greatest Power of Nature that we can apply.

(9.) Water with Air condensed upon it will conceive a much greater Degree of Heat than in the common Air, where it will boil much sooner than in condensed Air.

(10.) So great may the Degree of Heat acquired in Water this Way be, as to melt soft Solder; and therefore Vessels should have their Parts put together with hard Solder, that are used about these Experiments.

52. From this vast Power of confined and elastic Air and Steam it is that we account for the prodigious Effects of *Papin's DIGESTER* in dissolving Bones and reducing them to a Jelly, so as to become a wholesome and savoury Diet; for which Purpose they are put into a metalline Vessel, with a Cover, which is fast and strongly

Air. (7.) The Spring of the Air will shew itself also by raising heavy Weights laid on a Bladder, half filled with Air, in a proper Vessel under the Receiver. (8.) Beer, Cyder, Water, and porous Bodies, do emit great Quantities of Air under the exhausted Receiver. (9.) Fishes are made so light or buoyant by increasing the Spring of the Air in their Bladders, upon Exhaustion, that they rise to the Top of the Water, and cannot again descend to the Bottom. (10.) Shriveled Apples are made to look fair and smooth by the Spring of the contained Air filling out the Wrinkles. (11.) The Spring of the Air in a square Bottle, cemented close, will immediately burst it in Pieces, upon exhausting the incumbent Air. (12.) But that curious Experiment which shews the Force of the Spring of the Air to be equal to its Weight or

strongly screwed down, and Air-tight. The Digger nearly filled with Water and Bones is set over a gentle Fire, which by Degrees rarefies the Water into Steam, which with the included Air in a short Space of Time acts upon the Bones with so great an Energy, as to effect their utter Dissolution, and cause them to mix and incorporate so intimately with the Water, or Broth, as to make a perfect *Coagulum* or Jelly when all is cold, which may be then sliced out with a Knife. They who would see more of the wonderful Effects of this Instrument may consult the Author's own Book upon the Subject.

or Pressure, is by raising the Mercury, by the Expansion of a small Quantity of confined Air, to the same Height in an exhausted Tube above the Pump, as that which it is raised to in the Mercurial Gage by the Pressure of the Atmosphere below it.

THE great Action of animal Life, *viz.* *Breathing* by *Inspiration* and *Expiration* of Air, is owing to the *Pressure* and *Spring* of the Air conjointly, as is evident by the *Contraction* and *Expansion* of a Bladder in a small Receiver, with a Bladder tied on at Bottom to represent the Diaphragm.

HENCE the Necessity of Air for *Respiration* and *animal Life* in most Sorts of Creatures, which die very soon in the *exhausted Receiver*: Though some Animals will not be killed in this manner; as *Flies*, *Frogs*, *Toads*, some sort of *Fishes*, &c.

THAT Air passing through the Fire, and heated Brass Tube, is unfit for animal Respiration, is shewn by the sudden Death of any Animal put into a Receiver filled therewith. Also Candles and living Coals, put into this adust Air, immediately go out. Hence the noxious and pestilential Qualities of *Damps* and *suffocating Exhalations*, so frequent and fatally experienced in Mines, and other subterranean Places.

THAT

THAT Air in its natural State is necessary for *Fire* and *Flame*, is obvious from the *sudden Extinction of a Candle, a live Coal, &c.* in the *exhausted Receiver*. Also Gunpowder fired therein will not take Flame, or be *explosive*, but *melt and die away*.

THAT the different Velocities with which heavy and light Bodies descend in the Air, is owing to the Air's Resistance only, is manifest from the equal Velocity or Swiftneſs with which all Bodies descend in the *exhausted Receiver*, as is shewn in the Experiment with a *Guinea* and a *Feather*.

AIR is likewise necessary for the Existence and Propagation of Sounds; for a Bell placed under the Receiver, and rung, will not be heard when the Air is drawn out; but in condensed Air, the Sound will be augmented in Proportion to the Condensation.

THAT *Fermentation, Putrefaction, &c.* depend on the Air, and are promoted by it, is shewn by preserving the Fruit in their natural Bloom and Perfection through the Winter in an *exhausted Glass*.

THE Use of the *Diving-Bell* depends on the *Pressure* and *Spring* of the Air: For since the Space which Air takes up is reciprocally as the Power compressing it, 'tis evident

evident that at the Depth of 33 Feet of Water, where the Pressure of the Atmosphere is doubled, the Bell will be half filled with Water; at the Depth of 66 Feet it will be two Thirds filled; at the Depth of 99 Feet it will be three Fourths filled; and so on. Whence appears the Necessity of having the Vessel in the Form of a Bell, that the perpendicular Height of the Water may be as little as possible. Hence also we see how necessary it is to have a very gentle Descent of the Bell, that the Divers may have Time to admit the Air, so greatly condensed, by proper Degrees, lest it should burst the fine Vessels of their Bodies, and kill them: Together with several other Particulars relating to the Nature and Manner of using this Machine, which will be more fully explained in the Note below (XCII).

THE

(XCII.) 1. That the Reader may have a just Idea of the *Campana Urinatoria* or DIVING-BELL, according to the latest Improvements by Dr. Halley and Mr. Triewald of Stockholm, I have here exhibited two Figures of the same. The first is that of Dr. Halley's Form, which was 3 Feet wide at Top, 5 Feet at Bottom, and 8 Feet high; and contained about 63 Cubic Feet, or near 8 Hogheads, in its Concavity.

2. This was coated with Lead, so heavy that it would sink empty; and the Weight was distributed about the Bottom I K, that it would go down in a perpendicular Position

Plate
XXIX.
Fig. 4.

THE *Spring* of the Air is most evidently concerned in that Chirurgical Operation we

Position and no other. In the Top was fixed a strong but clear Glass D, to let in the Light from above; and likewise a Cock, as at B, to let out the hot Air that had been breathed; and below, at L M, was fixed a circular Seat for the Divers to sit on; and lastly, from the Bottom was hung, by three Ropes, a Stage for the Divers to stand upon to do their Business. This Machine was suspended from the Mast of a Ship by a *Sprit*, which was sufficiently secured by *Stays* to the Mast-head, and was directed by *Braces* to carry it over-board clear of the Side of the Ship, and to bring it in again.

3. To supply the Bell with Air under Water, two Barrels, such as C, of about 63 Gallons each, were made and cased with Lead, so that they might sink empty, each having a Hole in its lowest Part to let in the Water, as the Air in them is condensed in their Descent, and to let it out again when they were drawn up full from below. And to a Hole, in the Top of the Barrels, was fixed a Hose or hollow Pipe, well prepared with Bees-Wax and Oil, which was long enough to fall below the Hole at the Bottom, being sunk with a Weight appended, so that the Air in the upper Part of the Barrels could not escape, unless the lower Ends of these Pipes were first lifted up.

4. These Air-Barrels were fitted with Tackle, proper to make them rise and fall alternately, like two Buckets in a Well; in their Descent, they were directed by Lines fastened to the under Edge of the Bell to the Man standing on the Stage to receive them, who by taking up the Ends of the Pipes above the Surface of the Water in the Bell, gave Occasion for the Water in the Barrels to force all the Air in the upper Parts into the Bell, while it entered below, and filled the Barrels. And as soon as one was discharged, by a Signal given, it was drawn up, and the other descended, to be ready for Use.

we call *Cupping*; for when a *Vacuum* is made by a Syringe in the Cupping-Glass applied

5. As the cold Air rush'd into the Bell from the Barrel below, it expell'd the hot Air (which was lighter) through the Cock B, at the Top of the Bell, which was then open'd for that Purpose. By this Method, Air is communicated so quick and in such Plenty, that the Doctor tells us, he himself was one of five who were together at the Bottom, in nine or ten Fathoms Water, for above an Hour and an half at a Time, without any Sort of ill Consequence; and he might have continued there, as long as he pleas'd, for any thing that appeared to the contrary.

6. In going down, 'tis necessary it should be very gently at first, that the dense Air may be inspired to keep up, by its Spring, a Balance to the Pressure of the Air in the Bell. Upon each 12 Feet Descent, the Bell is stopp'd, and the Water that enters is driven out by letting in three or four Barrels of fresh Air. By this Means, the Doctor says, he could (by taking off the Stage) lay the Bottom of the Sea, just within the Compass of the Bell, so far dry, as not to be over Shoes thereon.

7. By the Glass above so much Light was transmitted when the Sun shone, and the Sea was clear and even, that he could see perfectly well to write and read, and much more to take up any Thing under the Bell; and by the Return of the Air-Barrels, he could send up Orders, written with an Iron Pen, on small Pieces of Lead, directing they were to be moved from Place to Place.

8. But in dark Weather, when the Sea was rough and troubled, it would be as dark as Night in the Bell; but then the Doctor found he could keep a Candle burning in the Bell, as long as he pleas'd; it being found by Experiment, that one Candle consumes much about the same Quantity of confined Air as one Man does, viz. about a Gallon per Minute.

applied to any Part, the *Spring* of the Air in the Flesh under the Glass does strongly act,

9. The only Inconvenience the Doctor complain'd of was, that upon first going down they felt a small Pain in their Ears, as if the End of a Quill were forcibly thrust into the Hole of the Ear. This may proceed from its being some Time before the Air can get from the Mouth, through the small Canal of the *Eustachian Tube*, which leads to the inner Cavity of the Ear; where, when it comes, it makes an *Equilibrium* with the outward Air, pressing on the *Tympanum*, and thus the Pain, for a short Time, ceases; then descending lower, the Pain of the Ears returns, and is again abated; and so on till you come down to the Bottom, where the Air is of the same Density continually.

10. One of those Divers (who thought to out-wit Dame Nature for once) put a Piece of chew'd Paper in his Ears, which as the Bell descended, was so forcibly pressed into his Ears, that it was with great Difficulty the Surgeon could extract it. Thus a Bottle with only common Air in it, and cork'd down tight, if it be let down to a considerable Depth of Water, will be found, upon drawing it up again, to have had the Cork forced in by the Pressure of the Water at that Depth.

11. This Bell was so far improved by the Doctor, that he could detach one of his Divers to the Distance of 80 or 100 Yards from it, by a Contrivance of a Cap or Head-piece, somewhat like an inverted Hand-Basket, as at F, with a Glass in the fore Part, for him to see his Way through. This Cap was of Lead, and made to fit quite close about his Shoulders; in the Top of it was fix'd a flexible Pipe communicating with the Bell, and by which he had Air when he wanted, by turning the Stop-Cock near his Head-piece. There was also another Cock at the End in the Bell to prevent any Accident happening from the Person without.

12. This Person was always well clothed with thick Flannels, which were warm'd upon him before he left the

act, and by that Means causes the Flesh to distend and swell into the Glass, while the Pressure

the Bell, and would not suffer the cold Water to penetrate to hurt him. His Cap contain'd Air enough to serve him a Minute or two; then by raising himself above the Bell, and turning the Cock F, he could replenish it with fresh Air. This Pipe he coil'd round his Arm, which served him as a Clue to find his Way to the Bell again.

13. This Diving-Bell receiv'd its last Improvement from Mr. *Martin Triewald*, F. R. S. Captain of *Mechanics* and *Military Architecture*, to his *Swedish Majesty*; the Manner and Form whereof is shewn in a Figure of his own drawing. A, B, is the Bell, which, as appears by the Scale of Feet under it, is much less than Dr. *Halley's*, and therefore will come cheaper. It is sunk with leaden Weights, D, D, appended at the Bottom; the Substance of the Bell is Copper, and tinn'd within all over; and as in the Rivers and Coasts of the *Baltic Sea*, the Water is very clear, so he has illuminated the Bell with three strong convex Lenses G, G, G, with Copper Lids H, H, H, to defend them.

14. The Iron Ring, or Plate E, serves the Diver to stand upon when he is at Work; and it is suspended at such a Distance from the Bottom of the Bell, that when the Diver stands upright, his Head is just above the Water in the Bell, and it is much better there than higher up in the Bell, because the Air is colder, and consequently more fresh and fit for Respiration near the Surface of the Water, than towards the Top of the Bell.

15. But when there is Occasion for the Diver to be wholly in the Bell, and his Head of Course in the upper Part, Mr. *Triewald* has contrived, that even there, when he has breathed the hot Air as long as he well can, by means of a spiral Copper Tube *b, c*, placed close to the Inside of the Bell, he may then draw the cooler and fresher Air from the lowermost Parts; to which End a flexible Leather Tube, about two Feet

Plate
XXIX,
Fig. 5.

Pressure of the Air on the Parts without the Glass accelerates the Motion of the Blood and Fluids, towards the Part where it is diminished or taken off by the Glass.

SINCE we know that *Heat* augments the repellent Power in the Particles of a Fluid, and by that means increases its Elasticity, and thereby causes it to expand itself into a large Space; and that *Cold* has a quite contrary Effect; we learn the Use of the THERMOMETER in indicating the *various Degrees of Heat and Cold in the Air*, by the different Altitudes of the Spirit of Wine in that Instrument (XCIII).

THE

long, is fixed to the upper End of the Tube at *b*, to the other End of which is a turned Ivory Mouth-piece, for the Diver to hold in his Mouth, to respire the Air from below by; and this he may do in any Posture of standing, sitting, bowing his Body, &c.

16. I must not omit in this Place to mention the Invention of a Gentleman at *Newton-Bushe* in *Devonshire*, who contrived a large Case of strong Leather, to hold about half a Hoghead of Air, and made it perfectly Water-tight, adapting to it proper Parts for his Legs and Arms, with a Glass before; so that when he put himself into this Case, he could walk very easily about at the Bottom of the Sea, and go into the Cabin, and other Parts of a Ship in a Wreck, and deliver out the Goods; and this Method he practised forty Years, and thereby acquired a large Fortune, and equal Fame.

(XCIII) 1. A THERMOMETER being design'd to indicate the *various Degrees of Heat and Cold* by the elastic or expansive Power of Bodies of the Fluid Sort, so many Ways, Methods, and Forms of constructing such an useful Instrument have been thought of, and invented

N

Vol. II.

Fig. 4.
P. 150.

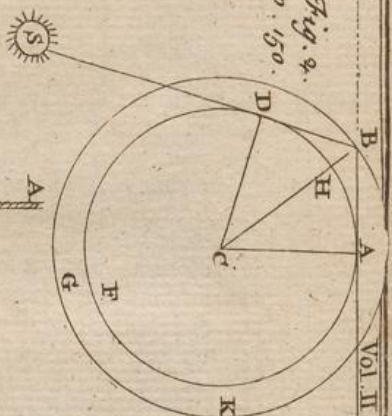


Fig. 4.
P. 147.

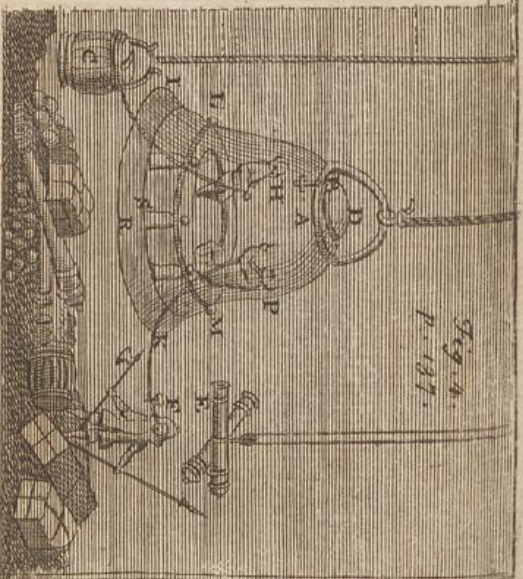


Fig. 5.
P. 179.

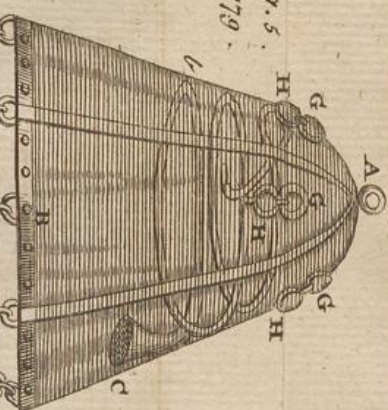


Fig. 1.
P. 181.

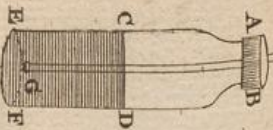


Fig. 6.

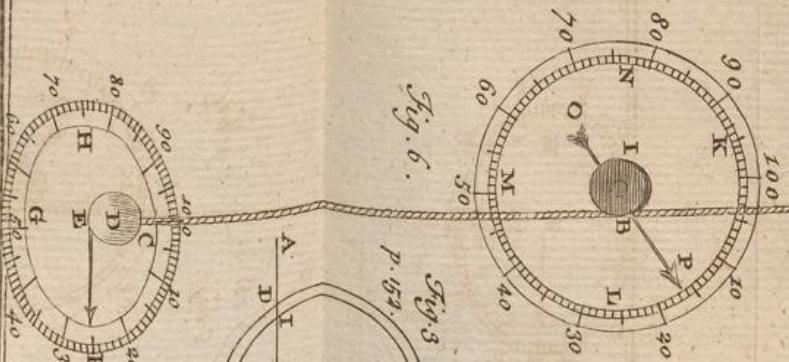
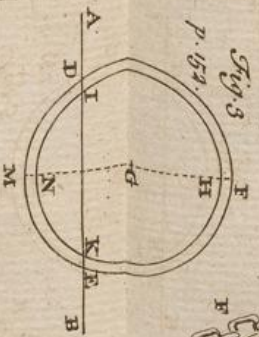


Fig. 3.
P. 152.



A Scale of English Feet.
1 2 3 4

invented at several Times for this Purpose ; at first *Air*, then *Oil*, then *Spirits of Wine*, and lastly, *Quicksilver* have been every Way attempted and tortur'd in this Experiment.

2. The Spring of Air being sooner affected by *Heat* and *Cold* than that of any other Fluid, was first thought upon as the best Expedient to answer this End ; and so it really would be, were it not that the Weight or Pressure of the Atmosphere affects it also at the same time ; and by acting sometimes with, sometimes against it, renders the Effect by Heat or Cold very uncertain, and therefore the Instrument useless. For Example : The Air in the Bottle A F will, by its Expansion, when the Air grows warmer, raise the Water higher in the Tube than the Point H, and if the Air be lighter at this time it will press less on the Surface of the Water at H, and so will suffer it to rise still higher. But if the Air be heavier it will act against the Spring, and not permit it to raise the Water so high. The same may be observed with respect to its Contraction by Cold ; wherefore such an Instrument for common or constant Use, will not do at all, though perhaps none is better calculated for some extemporaneous Uses, as measuring the Degree of Coldness in different Cellars, or of Warmth in divers Rooms upon the same Floor.

3. It was upon this Account found necessary to have Recourse to some other Fluid, which, secured from the Pressure of the Air in a Tube hermetically seal'd, might expand and contract solely by the Heat and Coldness of the Air about it. And because most Fluids are subject to freeze or thicken in great Degrees of Cold, it was soon consider'd that *Spirits of Wine*, a little tinged with *Cochineal*, would best answer the Purpose, and accordingly Thermometers were generally made therewith, and became of common Use.

4. Though the Spirit of Wine Thermometers would do very well to shew the comparative Heat of the Air, yet this was far short of the Virtuoso's Views, who wanted to explore the various and vastly different Degrees of Heat in other Bodies, as *boiling Water*, *boiling Oils*, *melted Metals*, and even *Fire* itself, and Degrees of Cold too, beyond what the Spirit Thermometer can

Plate
XXIX.
Fig. 1.

shew,

shew. For Spirit in a moderate Degree of Heat will burst the Tube; and in an intense Degree of Cold will freeze, as the *French* Philosophers found, who went to measure a Degree upon the Surface of the Earth under the North Polar Circle.

5. It having been found by Experiment, that Linseed Oil required four times the Degree of Heat to make it boil as Water did, it was quickly substituted instead of Spirits for Philosophic Uses. This Sir *Isaac Newton* always used, and by it discovered the comparative Degree of Heat which makes Water boil, which melts Wax, which makes Spirit of Wine boil, and melts Tin and Lead; beyond which we do not find the Oil Thermometer has been apply'd; for which Reason (as also for its sully'ing the Tube) it has been less used of late, and given way to

6. The MERCURIAL THERMOMETER, which will sustain any Degree of Heat or Cold, as far as any Instrument of this Kind can be expected to do. Mr. *Fahrenheit* of *Amsterdam*, was the Contriver of this Thermometer, and though several Artificers made them as well as he, yet they still go by his Name. Dr. *Boerhaave* used only this Thermometer. As the Mercury very freely and uniformly expands itself from hard Frost to the Heat of Summer, so one Sort of those Thermometers are contrived with a Scale, to include those Extremes only, and the Beginning of the Divisions, or 0, is fixed to that Altitude of the Quicksilver, as is observed when Water just begins to freeze, or Snow to thaw; for which reason that is call'd the *Freezing Point* in the Scale. This Thermometer is small, short, put in a neat Frame, and carried in the Pocket any where.

7. But the *Grand Thermometer* of *FARENHEIT* is graduated after a different Manner, as destin'd to a more critical and extensive Use. In this the Bulb, or large Part at the Bottom, is not *spherical* (as in common ones) but *cylindrical*, to the End, that the Heat may penetrate and reach the inmost Parts as soon as possible, so that the whole may expand uniformly together. Hence it is, that in the cylindric Bulb, the Fluid will expand and rise immediately, whereas in the spherical Bulb, it is seen first to fall (by the sudden Expansion

Expansion of the Ball, before the Fluid is heated) and then to rise, by the Expansion of the Fluid when heated. I have here given a Figure, both of *Farenheit's Mercurial Thermometer*, and also of *Sir Isaac Newton's* made with Linseed Oil.

Plate
XXX.
Fig. 3.

8. I take this of *Sir Isaac's* to be the best fitted of any for a *Standard Weather Thermometer*; and even for any Degree of Heat which the various States of the human Body exhibit; and also for those different Degrees which Vegetation requires in the Green-House, Hot-Bed, &c. In all which Cases, 'tis necessary there should be one common, unerring, and universal Measure, or Standard, which at all Times, and in every Place, will shew the same Degree of Heat, by the same Expansion of the Fluid, according to which the Scale should be made in every Standard Thermometer.

9. In order to this, the Tube proposed should be very nicely weigh'd when empty, and then the Bulb, and about a tenth Part of the Length of the Tube above it, is to be fill'd with Quicksilver; then it is to be weigh'd again, and the Excess of this, above the former Weight, will give the Weight of 100th Part. pour'd in; this will give the Weight of 100th Part. Let a Mark be made with a File upon the Tube at the Surface of the inclosed Quicksilver.

10. Then weigh out 9 or 10 Parcels of Quicksilver, each equal to 100th Part of that first put in the Tube, and having pour'd the several Parcels in one after another upon the inclosed Quicksilver, and marked the Tube successively at the Surface of each Parcel, you'll have the Tube divided into proper Intervals, which, if the Bore of the Tube be every where the same, will be equal to each other; if not, they will be unequal; and each of these Intervals is to be divided into 10 others, increasing or decreasing as the Intervals do.

11. When this is done, the Capacity of the Tube is divided into *Thousandth Parts* of that of the Ball, and the contiguous Part of the Tube reaching up to the first Mark. The Tube is now to be put into a Frame, and by the Side of it is to be placed a Scale, divided into *Thousandth Parts*, exactly corresponding to those on

on the Tube; and writing 1000 over-against the first Mark, you write 1010 over-against the second, 1020 against the third, and so on, as you see in the Figure.

12. The Standard Thermometer-Tube, and its Scale, being thus constructed, is then to be fill'd with some proper Fluid, as *Linseed Oil*, where great Degrees of Heat are not propos'd; and Mercury is to be used, when they are. When the Fluid is pour'd in, it is to be adjusted in such a Quantity, that it may stand just at the principal Point, marked 1000, in *Water just freezing*. And here great Precaution is to be used; for many Trials must determine this Point to which the Fluid must always rise by slow Degrees, and with an uniform Motion.

13. When this Point is well secured, all the Trouble is over, the Ball being then immersed in *boiling Water, Spirits, Oils, melted Metals, &c. in Snow, Freezing Mixtures, &c.* the Expansions, by all the various Degrees of Heat and Cold, will be shewn by the Numbers against the Heights to which the Fluid rises in the Tube in each Case, these are to be wrote on the Side of the Scale; and since the same Degree of Heat will cause the same Expansion of the same Fluid at all Times, 'tis evident, if Thermometers were every where constructed in this Manner, the Observations made by them in any Part of the World, may be compared together, which cannot otherwise be done; whence this Part of Philosophy would receive its final Perfection.

14. By one of those Standard Thermometers well made, many more might soon be constructed with any expanding Fluid, without the Trouble of graduating their Tubes by equal Quantities of Quicksilver. For having fill'd the Balls, and a convenient Part of the Tube, with the propos'd Fluid, place them all together in a Vessel of cold Water; and while it is warming as gently as possible, when the Oil in the Standard Thermometer shall arrive successively at the several Divisions of its Scale, at the same Instant of Time mark the new Tubes at the several Heights of their Fluids, and form a Scale for every Tube, that shall correspond to those Marks. Then, while the Liquors subside by cooling gently,

gently, examine whether they nicely agree at the several Marks. To determine the *Freezing Point* in all, they are to stand together in the Water till it just begins to freeze: Or, having all the other Points duly, that may be deduced very exactly by the Rule of *Proportion*.

15. A Thermometer that shall vary very sensibly by every small Variation of Heat and Cold, as those of the Atmosphere, must have a large Ball in Proportion to the Bore of the Tube; and that the Heat or Cold may sooner penetrate the innermost Parts of the Liquor, the Ball should not be spherical, but oblong and flatted like a *French Flask*; and the Lengths of the Tubes should be proportioned to the Degrees of Heat they are intended to discover.

16. Sir *Isaac Newton* graduated his Standard Thermometer on both Sides, as shewn in the Figure. Those on the Right Hand measured the *Heat of the Oil*; as those on the Left measured the Bulk thereof: But since the latter, as well as the former, begins from a Cypher at the Freezing Point, and is regularly continued upwards by the common Divisions 10, 20, 30, 40, &c. it will equally serve both Purposes; since the Degree of Heat will always be proportioned to the Expansion of the Bulk of the Fluid above or below the Freezing Point.

17. By this Division therefore on the Left Hand, I shall express some of the principal Articles of Sir *Isaac Newton's* Scale of the various Degrees of Heat, as in the Tablet below,

D. of Heat,

0	Water just freezing, and Snow just thawing.
1	} The Heats of the Air in Winter.
to 4	
4	
to 8	} The Heats of the Air in Spring and Autumn.
8	
to 12	
13	} The Heats of the Air in Summer.
26	
31	The greatest Summer-Heat.
	The greatest Heat of the external Parts of the Human Body.
	Water just tolerable to the Hand at Rest.
	36½ Water

D. of Heat.

- 36 $\frac{1}{2}$ Water hardly tolerable to the Hand in Motion.
 43 Melted Wax just growing stiff and opake.
 51 $\frac{1}{2}$ Melted Wax just before it bubbles or boils.
 54 Spirit of Wine just begins to boil.
 72 Water begins to boil.
 75 Water boils vehemently.
 86 A Mixture of $\frac{1}{10}$ of Lead, $\frac{2}{3}$ of Tin, and $\frac{1}{2}$ Bismuth, melts.
 103 A Mixture of equal Parts of Tin and Bismuth melts.
 122 A Mixture of $\frac{3}{5}$ of Tin and $\frac{2}{5}$ of Lead melts.
 154 The Heat which melts Tin.
 174 The Heat which melts Bismuth.
 206 The least Heat which melts Lead.
 290 The Heat with which burning Bodies shine in a dark Night.
 410 The Heat of a small Coal-Fire.
 450 The Heat of a small Wood-Fire.

18. Dr. *Hales* considers the Freezing Point as one Boundary to Vegetation, *viz.* on the Side of Cold; and the other Boundary he fixes to that Degree of Heat with which Wax will begin to melt, because a greater Degree of Heat will, instead of collecting and assimilating the nutritive Particles, dissipate them, even those which are most viscid and glutinous; and therefore the Plant will rather fade than vegetate in such Degrees of Heat.

19. This Space the Doctor divided into 100 equal Parts in his Thermometers: But his Numbers express'd in those of the Standard Thermometer, are for several Particulars mentioned by the Doctor as follows. For *Myrtle*, 4 $\frac{1}{2}$; *Oranges*, 6 $\frac{1}{2}$; *Ficoides*, 7 $\frac{1}{2}$; *Indian Fig*, 8 $\frac{1}{2}$; *Aloe*, 10; *Cereus*, 11; *Euphorbium*, 12; *Piament*, 13; *Ananas*, 14 $\frac{1}{2}$; *Melon-Thistle*, 15 $\frac{1}{2}$; *Air under the Glass of a Hot-Bed*, 17; *the Hot-Bed itself*, 28. If the Hot-Bed exceed the Heat of 40 or thereabouts, it will scorch the Plants and kill them. The Heat of Milk from the Cow is 28, that of Urine 29, and of Blood in a Fever nearly 40.

20. As *Fahrenheit's* Thermometer is come into such general Use, I have here placed it by the Standard Thermometer,

THE *Moisture* and *Dryness* of the Air are shewn by the *HYGROMETER*, which is made several Ways, but that with a Cord is most common and useful; for that by shrinking with Moisture will turn an Index one way, and extending with Dryness will turn it the contrary way, over the graduated Limb of a Circle (XCIV) (XCV).

I SHALL

nometer, that the Divisions on each may be reduced to the other's respectively by bare Inspection, and the Use of both be still preserved. If the Reader would see all the different Sorts of Thermometers, or rather all the different Methods of graduating them, he may be fully satisfied by consulting Dr. *George Martine's* Treatise on this Subject.

21. To conclude this Head, it must be observed that the Right Hon. the Earl of *Cavendish* has very lately invented a curious Construction of *Thermometers*, of two different Forms; one contrived to shew the greatest Degree of Heat, and the other the greatest Cold, that may happen in a Person's Absence at any Time. But this Improvement cannot be understood so well by Description as by viewing the Instruments themselves.

(XCIV) 1. An *HYGROMETER*, sometimes call'd a *NOTIOMETER*, is an Instrument or Contrivance, by which we can estimate the Quantity of Moisture or Vapours in the Air; or by which we can compare the various Degrees of its Humidity and Siccity at different Times. For this Purpose different Subjects have been at times essay'd, but none as yet have been found satisfactory or lasting.

2. Thus Cotton, Sponge, &c. hung at the End of a nice Balance, in an exact Equilibre, will by contracting Moisture from the Air become heavier, which will therefore be shewn by its descending; and when the Air becomes drier, it ought to part with the Moisture and become

I SHALL finish this Lecture with giving you an Account of the Structure and

become lighter; but this it will not readily do, and is therefore of little Use. Salts have been likewise used this Way, but to no Purpose.

3. It would be endless to take notice of all the Methods that have been attempted by Philosophers, and most of them without Success. However, as some are better than others, and will endure for a considerable Time very well, I shall here give an Account of one which is the best of any I have hitherto thought of. It is made of a String either of Hemp or Cat's-Gut (as all the best Sort are) and shews the increasing *Moisture* of the Air by its *Twisting* and *Shortening*, and the *Dryness* by *Untwisting* and *Lengthening*.

Plate
XXX.
Fig. 6.

4. Thus let ABC be the lower Part of a twisted Line or Cord, hanging from the Height of the Room against one Side thereof on the Wall or Wainscot; let there be described a large Circle, graduated into 100 equal Parts, such as KLMN; in the Centre of which is a Pin, with a small Pulley IB, carrying an Index OP. If now a Cord be put round the Pulley, and a small Weight or Ball D be suspended at the lower End to keep it strait, then as the Cord gathers *Moisture* from the Air, it will twist and become shorter; the Consequence of which will be, that in contracting it will turn the Pulley IB, and this by its Index will point to the Numbers on the graduated Circle, which will shew the Degree of *Moisture* or *Dryness* by the Contraction or Relaxation of the Cord.

5. Again: If the Ball D hang over the Centre E of another graduated Circle CFGH placed horizontally, carrying an Index EF upon its Divisions, it will shew the same Thing by the twisting and untwisting of the Cord BC, as in the Circle above; so that this may be looked upon as a *Double Hygrometer*, and so simple in its Structure, that any Person may make it; and that it will answer very well for a considerable Time, I am fully

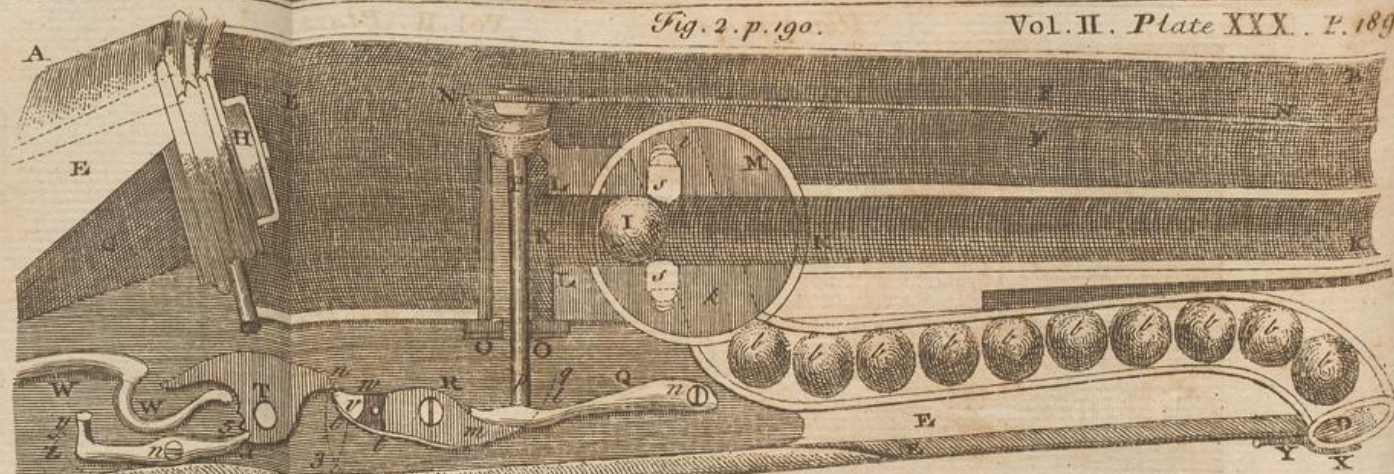


Fig. 1. p. 189.



Fig. 3.
p. 191.

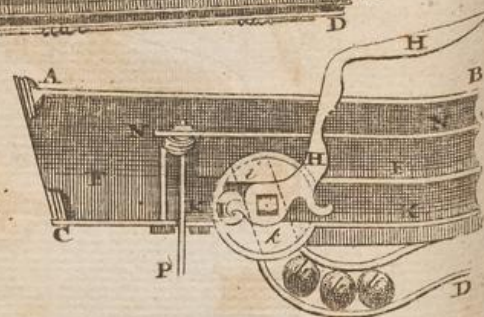
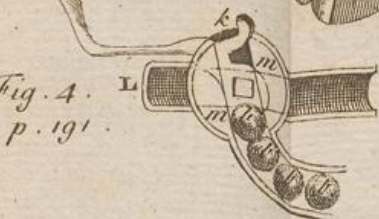


Fig. 4.
p. 191.



FARHENHEIT'S Thermometer

NEWTON'S
Standard
Thermometer

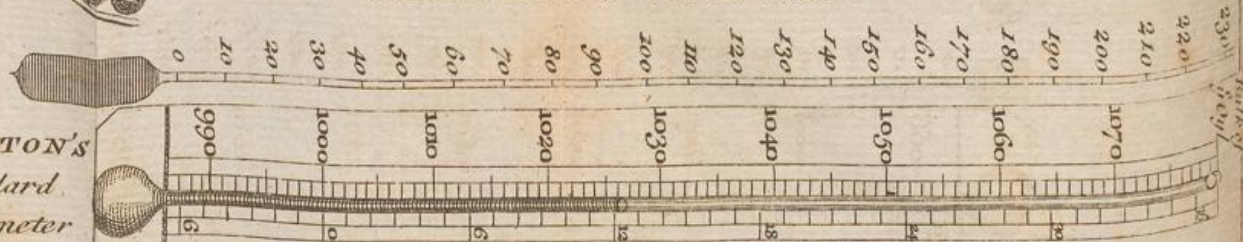


Fig. 5.

and Use of the common AIR-PUMP, and of one of a *new Invention* of my own. The

fully satisfied by Experience: And I believe a better than this was never made.

Note, In the Construction of my *Aerometrum Magnum* or Tripple Weather-Glass, I have a *Barometer*, *Thermometer*, and *Hygrometer* all in one Frame; all of the best Sort; which makes a Piece of Furniture equally useful and elegant.

(XCV) 1. There remains yet one more Pneumatic Machine to be described, which has made considerable Noise in the Philosophic World, but has never been of any Use in Civil Life; I mean, the famous Invention of the AIR-GUN, of which there are two Sorts; one the *Common Air-Gun*, the other the *Magazine Air-gun*: Of both which I shall give the following short Account.

2. The *Common AIR-GUN* is made of Brass, and has two Barrels; the Inside Barrel KA of a small Bore, from which the Bullets are shot; and a larger Barrel ECDR on the Outside of it. There is a Syringe SMNP fixed in the Stock of the Gun, by which the Air is injected into the Cavity between the two Barrels through the Valve EP. The Ball K is put down into its Place in the small Barrel with the Rammer, as in another Gun. At SL is another Valve, which being drawn open by the Trigger O, permits the Air to come behind the Bullet, so as to drive it out with great Force.

3. If this Valve be open'd and shut suddenly, one Charge of condensed Air may make several Discharges of Bullets; but if the whole Air be discharged on one single Bullet, it will drive it out more forcibly. This Discharge is effected by means of a Lock *k* placed here, as usual in other Guns; for the Trigger being pull'd, the Cock *k* will go down, and drive a Lever *a*, that will open the Valve, and let in the Air upon the Bullet K.

4. The

Plate
XXX.
Fig. 1.

Plate
XXII.
Fig. 4.

The common or large Air-Pump is represented where *aa, aa*, are the two Brasses Barrels,

Plate
XXX.
Fig. 2.

4. The Magazine AIR-GUN is the Invention of an ingenious Artist, whose Name is *L. Colbe*. By his Contrivance ten Bullets are so lodged in a Cavity near the Place of Discharge, that they may be drawn into the shooting Barrel, and successively shot so fast as to be nearly of the same Use as so many several Guns. In the Figure you have a Section of the Gun as big in every Part as the Gun itself; and so much of the Length as is necessary to form a compleat Idea of the Whole.

5. A E E is Part of the Stock; G is the End of the Injection Syringe, with its Valve H opening into the Cavity between the Barrels, as before. K K is the small shooting Barrel, which receives the Bullets from the Magazine E D, which is of a serpentine Form, and closed on the End D when the Bullets *b, b, b, b*, are lodged in it. The circular Part *s I s k M i* is the Key of a Cock, having a cylindric Hole through it I K, which is equal to the Bore of the small Barrel, and makes a Part of it in the present Situation.

6. When the Lock is taken off, the several Parts Q, R, T, S, W, &c. come into View, by which means the Discharge is made by pushing up the Pin P p, which raises and opens a Valve V, to let in the Air against the Bullet I from the Cavity F, F, F; which Valve is immediately shut down again by means of a long Spring N N of Brass. This Valve V being a conical Piece of Brass, ground very true in the Part which receives it, will of itself be sufficient to confine the Air.

7. To make a Discharge you pull the Trigger *z z*, which throws up the Seer *y x*, and disengages it from the Notch *x*, upon which the strong Spring W W moves the Tumbler T, to which the Cock is fix'd. This by its End *u* bears down the End *v* of the tumbling Lever R, which by its other End *m* raises at the same time the flat End *l* of the horizontal Lever Q; and by

Barrels, in which the Pistons *cc*, *cc*, move by Chains fasten'd to each of them, and to

by this Means, of Course, the Pin *Pp* is push'd up, which stands upon it, and thus opens the Valve *V*, and discharges the Bullet. This is all evident from a bare View of the Cut.

8. To bring in another Bullet to succeed I instantaneously, there is a Part called the Hammer *H*, which by a square Hole goes on upon the same square End of the Key of the Cock, and turns it about so as to place the cylindric Bore of the Key *IK* in any Situation required. Thus when the Bullet is in the Gun, the Hammer stands as in the Figure, where the Bore of the Key coincides with that of the Barrel *KK*; but when the Ball is discharged, the Hammer *H* is instantly brought down to shut the Pan of the Gun, by which Motion the Bore of the Key is turned into the Situation *ik*, so as to coincide now with the Orifice of the Magazine; and upon lifting the Gun upright, the Ball next the Key tumbles into its Cavity, and falls behind two small Ends *ss*, of two tender Springs, which like Fingers Ends detain it. The Key in this Position is seen in the Figure. Then opening the Hammer again the Bullet is brought into its proper Place near the discharging Valve, and the Bore of the Key makes again a Part of that of the Shooting Barrel.

9. It evidently appears how expeditious a Method this is of charging and discharging a Gun; and were the Force of condensed Air as great as that of Gunpowder, such an Air-Gun would actually answer the End of many Guns, and prove the best Defence against Highwaymen or Robbers that People are aware of; because when they have Reason to suspect them, they might then make five or six Discharges before the Thief can come within Pistol-shot.

10. In the Air-Gun, and in all other Cases where the Air is required to be condensed to a very great Degree, it will be requisite to have the Syringe of a small Bore, viz. not exceeding $\frac{1}{2}$ an Inch in Diameter; because,

Plate
XXX.
Fig. 3, 4.

to a Wheel moving on the Axle *f*, when the Engine is put into Motion by the Winch *bb*. *gg, gg*, are two Pillars or Pieces of Wood supporting the Frame of the Pump-Wheel, which is screw'd upon them by Nuts under the little Pieces of Wood *e, ee*. The Tube or Pipe marked *bb* is called the *Swan-Neck*, made of Brass: By this the Air passes from under the Receiver *oo*, through a small Hole *k* in the Middle of the Brass Plate *iii* on the Top of the Pump, to a Brass Piece in the Box *dd*, which being perforated length-ways, to the Middle Point under each Barrel, does there, through a small Hole, by a Bladder-Valve, transmit the Air from the Receiver into each Barrel to be pump'd out by passing through the Hole in the descending Piston.

cause, as has been shewn, the Pressure against every square Inch is about 15 lb. and against every circular Inch it is therefore about 12 lb. If therefore the Syringe be one Inch in Diameter, when one Atmosphere is injected, there will be a Resistance of 12 lb. against the Piston; when 2, of 24 lb.; and when 10 are injected, there will be a Force of 120 lb. to overcome; whereas 10 Atmospheres act against the circular Half Inch Piston (whose Area is but $\frac{1}{4}$ Part so big) with a Force but a $\frac{1}{4}$ Part so great, viz. 30 lb.; or 40 Atmospheres may be injected with such a Syringe, as well as 10 with the other. In a Word, the Facility of working will be (*cæteris paribus*) inversely as the Squares of the Diameters of the Syringe.

Piston. These Holes in the Pistons and Bottoms of the Barrels are cover'd with Valves, to prevent the Return of the Air into the Receiver. *l l l* is the Mercurial Gage, or common Barometer, immerfed in a Bason of Mercury *m m* fix'd in the Bottom of the Frame, and at Top communicates with the Receiver, which therefore fhews how much the Receiver is exhausted by the Riling of the Mercury in the Tube, by a graduated Scale affixed thereto. The Stopcock *n n*, alfo, communicates with the Receiver, and consequently with the Swan-Neck and Mercurial Tube: Its Use is, by turning the Cock, to re-admit the Air, when there is Occafion. The Receiver is ground true on the Bottom, and is fixed on the Pump at firft by means of wetted Leathers to exclude the Air, inftead of Cement formerly ufed for that Purpofe.

BUT with how much more Conveniency, and lefs Expence, Pneumatical Experiments of all Kinds may be perform'd, by a *New, Elegant, and Portable Air-Pump*, which I have lately contrived and made, will be eafy to apprehend from a bare View of the Figure thereof: In which *AB* is the Head or Part containing the Wheel, which alternately raifes and deprefles the

Plate
XXII.
Fig. 5.

Pistons CD in the Barrels EF, which are strongly prefs'd down by the said Part AB, supported on the two Pillars GH, fix'd into the Bed or Bottom of the Machine IKL. On this Bottom stands the Receiver MN on a large smooth Brass Plate, in the Middle whereof is a Hole, by which the Air passes out of the Receiver into a small Tube on the under Part of the Frame, and goes to the Piece O, which communicates with the perforated Brass Piece on which the Barrel stands, and from which they receive the Air to be exhausted. On the middle Part of this Brass Piece is a Perforation, over which is placed a small Receiver PQ, and under it a Bason of Mercury R, in which a small Tube RS (hermetically sealed at one End, and fill'd with Quicksilver) is inverted; and therefore as the small Receiver PQ is exhausted, (at the same time with the large one MN) the Approach of the *Vacuum* will be shewn by the *Descent of the Quicksilver* in the Tube RS. By the Stop-cock T the Air is again let into the Receiver. I take this to be the *last Improvement* this Machine is capable of, as to its Form; for it consists of only such Parts as are essential. And thus constructed, it may, together with its Receivers,

that is, if the Capacity of the Receiver be equal to that of the Barrel, we shall have $N = \frac{L.R}{L.2}$. Consequently, if R express any Degree of Rarity proposed, as 1, 2, 3, 4, 5, 6, &c. we have N the Number of Turns or Exsuctions to effect it.

4. And from hence the following Table is constructed; in which the first Column expresses the Rarity of the Air in the Receiver, and the second the Number of Turns to produce it.

Rarity.	Number of Turns.	Rarity.	Number of Turns.	Rarity.	Number of Turns.
1	0.	60	5,907	900	9,814
2	1.	64	6.	1000	9,966
3	1,585	70	6,129	1024	10.
4	2.	80	6,322	2000	10,966
5	2,322	90	6,492	2048	11.
6	2,585	100	6,644	3000	11,551
7	2,807	128	7.	4000	11,966
8	3.	200	7,644	4096	12.
9	3,170	256	8.	5000	12,288
10	3,322	300	8,229	6000	12,551
16	4.	400	8,644	7000	12,773
20	4,322	500	8,966	8000	12,966
30	4,907	512	9.	8192	13.
32	5.	600	9,229	9000	13,136
40	5,322	700	9,451	10000	13,288
50	5,644	800	9,644	16384	14.

5. From this Table we may observe, that if any Numbers in the first Column be taken in Geometrical Progression, the corresponding Numbers of the second will be in Arithmetical Progression. Thus against 2, 4, 8, 16 in the first, you see 1, 2, 3, 4 in the second Column.

6. When the Capacity of the Receiver exceeds that of the Barrel, then the Number of Turns N to produce a given Rarefaction R will be greater than before. Therefore if the Number of Turns in this particular Case,

Case, which let us call n , be multiplied by some Number m , it will produce a Number of Turns N that shall affect the Rarefaction R in any Receiver proposed. Now

$$\text{since } n = \frac{L.R}{L.2}, \text{ we shall have } n \times m = \frac{m \times L.R}{L.2} =$$

$$N = \frac{L.R}{L.C + 1 - L.C}; \text{ whence we have } m =$$

$$\frac{L.C + 1 - L.C}{L.2}$$

7. From hence a Table of Multipliers expressing the Value of m , when the Receiver is in any given Proportion larger than the Barrel, is easy to be constructed. Of which the following is a Specimen.

Capacity of Re- ceiver.	Multiplier.	Capacity of Re- ceiver.	Multiplier.	Capacity of Re- ceiver.	Multiplier.
1	1.	20	14,207	300	208,291
2	1,710	30	21,139	400	277,605
3	2,409	40	28,071	500	346,920
4	3,106	50	35,003	600	416,235
5	3,802	60	41,934	700	485,549
6	4,497	70	48,866	800	554,864
7	5,191	80	55,798	900	624,179
8	5,885	90	62,729	1000	693,494
9	6,579	100	69,661		
10	7,273	200	138,976		

8. By means of these two Tables, those who know nothing of *Algebra* may find how many Turns are necessary to rarify the Air in the Receiver to any given Degree, when the Ratio of the Receiver's Capacity to that of the Barrel, is known. For Example: Let the Receiver be 10 times as big as the Barrel, and let it be required to find how many Turns of the Winch will rarify the Air 100 times. First seek the Number that will do it when the Receiver is equal to the Barrel; which I find by the first Table is 6 Turns, and 644 Parts of 1000 of another. Then, against 10 in the second

second Table, I find the Multiplier 7,273, by which if I multiply 6,644, I shall have a Product 48,322, which will express the Number of Turns required.

9. The Ascent of the Quicksilver in the Gage of the Common Pump is proportional to the Quantity of Air drawn out, either upon the Whole, or upon any single Turn of the Winch: And the Deficiency from the Standard Altitude of $29\frac{1}{2}$ Inches is always proportional to the Quantity of Air remaining in the Receiver; as may be easily deduced from what has been said of the *Density, Spring, and Pressure of the Air.*

10. The Gage of a *Condenser* will have the Spaces unpossess'd of Quicksilver at the End decreasing in *Harmonical Proportion*: For since equal Quantities of Air are injected by the Syringe at each Stroke of the Piston, the Quantity of Air in the Condenser will increase in Arithmetical Progression, and so will its Density, and of course the Density of that in the End of the Gage, because the Quicksilver is pressed on each Side equally; but the Spaces diminish as the Densities increase, as we have elsewhere shewn. Therefore the Spaces are *inversely as a Series of Terms in Arithmetical Progression*, and consequently are in *Musical Proportion*; for that this is a Property of *Musical Terms* will be shewn in *Annotat.*
CIX.

*A View of y^e General & Coasting TRADE-WINDS, Monsoons
or y^e Shifting Trade Winds through the WORLD, Variations &c.
According to y^e Newest and most Exact Observations, By D^r Edmund Halley*

